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Spatial variations of throughfall through secondary succession of evergreen broad-leaved forests in eastern China

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Abstract:

Linking spatial variations of throughfall with shifting patterns during forest succession is important for understanding developmental patterns of ecosystem function. However, no such approach has been previously used for the chronosequence of evergreen broad-leaved forests in subtropical regions. This study was conducted in a chronosequence of secondary forest succession in Tiantong National Forest Park, to determine the optimum number of collectors within certain limits of error. Throughfall was 66, 55 and 77% of gross precipitation in an early-succession (SS), sub-climax (SE) and climax (CE) forest, respectively. The coefficient of variations (*CV*) of throughfall reduced with increasing rainfall amounts. Monte Carlo resampling approach was used to find mean values and 90 and 95% confidence intervals of a variable number of collectors (*n*) ranging from 2 to 24. During the study period, with nine collectors at SS, five at SE and five at CE, the error in the mean individual throughfall did not exceed 10%, respectively. This error was reduced to 5% when using 16, 10 and 10 collectors at SS, SE and CE, respectively. The *CV*s decreased greatly with increasing sample size when the sample size was less than 16 for the three successional stages, regardless of rainfall amounts. Based on the Student's *t*-value analysis of the mean individual throughfall volumes, a sample size of 16 at SS, five at SE and four at CE would be enough for throughfall estimates at an accepted error of 10% of 95% confidence level, respectively. Therefore, we concluded that the 25 of collectors used in the present study were sufficient to estimate the throughfall value at an accepted error of 10% at 90 and 95% confidence levels, even for those small rainfalls in eastern China. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS evergreen broad-leaved forest; Tiantong; throughfall; forest succession; Monte Carlo simulation

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INTRODUCTION

Incident rainfall in forest is partitioned into throughfall, stemflow and interception loss (Wullaert *et al.*, 2009). Throughfall reaches the ground directly through gaps in the canopy cover or as canopy drip, whereas stemflow flows down the tree boles (Staelens *et al.*, 2008). Throughfall makes up from 64 to 97% of incident annual rainfall (Rodrigo and Àvila, 2001; Chuyong *et al.*, 2004; Holwerda *et al.*, 2006; Vernimmen *et al.*, 2007; Oyzrzúm *et al.*, 2011). In general, the contribution of throughfall is large compared to that of stemflow (Shinohara *et al.*, 2010). Therefore, a good estimation of the volume of throughfall is fundamental to understanding forest hydrology (Rodrigo and Àvila, 2001).

Throughfall in forest ecosystems is affected by multiple factors such as canopy structure (Dietz *et al.*, 2006; Owens *et al.*, 2006; Shinohara *et al.*, 2010), species composition (Schroth *et al.*, 1999; Marin *et al.*, 2000), and meteorological conditions (Staelens *et al.*, 2008). Thus, it varies in time and space (Levia and Frost, 2006). In order to obtain a proper estimate of the average throughfall volume, a large number of collectors would normally be required (Rodrigo and Àvila, 2001; Keim *et al.*, 2005; Wullaert *et al.*, 2009; Zimmermann *et al.*, 2010), which can be laborious and expensive (Shinohara *et al.*, 2010). Therefore, researchers have attempted to estimate the suitable number of collectors for stand-scale throughfall estimates using different gauge arrangements (Holwerda *et al.*, 2006), Student's *t*-value analysis (Kimmins, 1973; Rodrigo and Àvila, 2001; Price and Carlyle-Moses, 2003), and Monte Carlo sampling (Rodrigo andÀvila, 2001; Shinohara *et al.*, 2010). However, no such approach has been applied to evergreen broad-leaved forests (EBLF, hereafter) in the subtropical area. This paper presents an effort to understand the spatial variations of throughfall in order incorporate a sufficient number of sampling points in particular plant community.

The sites chosen for the present study are representative of the EBLF types covering a large area of China. Despite their formerly widespread geographical distribution, the majority of the monsoon EBLFs now exists as secondary forests (Yan *et al.*, 2007; Wang *et al.*, 2007). Due to different human disturbances, the forests have become a diverse mosaic of different successional stages (Yan *et al.*, 2009). The pioneer vegetation species are often a mixture of re-sprouting evergreen broadleaved species and conifers (Wang *et al.*, 2007). When

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secondary succession proceeds, these mixed species are gradually replaced by evergreen broad-leaved trees such as *Schima superba* Gardn. et Champ in sub-climax forests, and *Castanopsis fargesii* Franch. in climax forests (Yan *et al*., 2006).

In order to study the spatial variations of throughfall in subtropical chronosequence, we conducted a study in Tiantong National Forest Park (TNFP), Eastern China. We hypothesized that, through the succession, a forest with a multi-layered, particularly dense canopy is homogeneous and therefore would cause a relatively low spatial variability (Wullaert *et al*., 2009). This paper aims to find out the minimum number of collectors of throughfall and the associated error of the estimate in three successional EBLFs. Our specific objectives are to determine 1 the relationship between spatial variation of throughfall and forest succession 2 and the most appropriate numbers of sampling collectors to estimate event-based average throughfall in chronosequence of EBLFs.

MATERIALS AND METHODS

Study Area

This study was conducted in the TNFP(29°52'N, 121°39'E, 200 m a.s.l) located in Zhejiang province, Eastern China. This area has a typical subtropical monsoon climate, with a hot, humid summer and a dry, cold winter. Mean annual precipitation (calculated for the period of 1953–1980) is about 1374 mm concentrated from March to October (Song and Wang, 1995). The annual mean air temperature for this period is 16.2 °C. The warmest month is July with a mean temperature of 28.1 °C, and the coldest is January with a mean temperature of 4.2 °C (Song and Wang, 1995). The soil of this area is mainly Acrisols with a pH range of 4.4–5.1. The substrates' parent materials are Mesozoic sediments and acidic intrusive rocks, including quartzite and granite (Song and Wang, 1995).

The mature forests around a Buddhist temple in the center of the park are considered as climax monsoon EBLFs because this area has been protected from clear cutting (Yan *et al*., 2007). Outside of this area, virtually all vegetation is secondary EBLF, and secondary shrubs occur widely (Yan *et al*., 2009). Due to the differences of abandoned ages following repeated cutting, these forests are representative of different successional stages and form a successional chronosequence (Li *et al*., 1999; Ishida *et al*., 2005). Generally, the secondary shrubs are derived from the cessation of repeat cutting, and thus, represent early successional stages. Thereafter, succession proceeds to the sub-climax of EBLF, and finally to the mature climax of EBLF (Yan *et al*., 2009) (See details in Table 1). In Tiantong area, the EBLFs continually drop and flush leaves throughout the year (Yan *et al*., 2008).

Plot delimitation

We chose secondary shrubs to represent early succession (SS, hereafter), *S. superba*- dominated forests to represent sub-climax EBLFs (SE, hereafter) and *C. fargesii*-dominated forests to represent climax EBLFs (CE, hereafter) as study stands representing the three successional stages (Song and Wang 1995; Yan *et al*., 2006). The three vegetation types used for the present study had the same historical vegetation and similar soils, which were developed from the same quartzitic parent material (Yan *et al*., 2006). Overstorey leaf area index (LAI) was measured using an LAI-2000 Plant Canopy Analyzer (LI-COR, Inc. Lincoln, Nebraska).

An experimental plot of 25 m × 25 m was established for each forest type to sample throughfall. Unreplicated forest sampling was used because it was very difficult to delimit duplicate plots for each forest type presenting exactly the same characteristics (Dezzeo and Chacón, 2006). Unreplicated plots may be a limitation of the present study, as in many other publications related to rainfall partitioning into throughfall and stemflow (Chuyong *et al*., 2004; Staelens *et al*., 2006; Staelens *et al*., 2008). However, lack of replication should have little influence here, as the purpose of this study is to understand rainfall partitioning of major vegetation types in EBLFs of eastern China, and, furthermore, spatial replications within each plot (see below) were used for analysis of spatial variations of throughfall.

Measurements of gross precipitation, throughfall and stemflow

Rainfall, throughfall and stemflow samples were continuously collected on a rainfall event basis between 1 March and 31 October, 2009. The rainfall events were classified as separate events if the time between events exceeded 12 h, i.e. there was at least a 12-h interval between the measured events (Iida *et al*., 2005).

Gross precipitation was collected with two collectors (10 l) in a nearby clearing (no trees were within a 20 m radius of the two collectors) approximately 0.3–1.5 km from the three study plots. The collector had an open area of 415 cm^2, and the collector's funnel had a vertical rim 2 cm deep. A polyethylene net with 0.5 mm mesh was installed on the bottom of the funnel to prevent contamination from particulate organic matter and insects (Zimmermann *et al*., 2007).

Throughfall was measured with the same type of gauge used to measure gross precipitation. Twenty-five grids of 5 m × 5 m surface area were established per plot, and throughfall collectors were set at the center of each grid (Figure 1). The funnel openings were 30–50 cm above the forest floor. Low shrubs, ferns and herbs were removed to a radius of at least 0.5 m around each collector.

For practical reasons, stemflow can only be measured on a limited number of trees at a given time (Holwerda *et al*., 2006). In the present study, two trees from each of the four diameters at breast height (DBH) classes were selected in each plot for measuring stemflow. Stemflow was collected by attaching spiral plastic cords (DBH ≥ 20 cm) or collars (5 cm ≤ DBH < 20 cm) around tree trunks to drain into closed containers of plastic on the forest floor. The stemflow depth (mm) per forest type was estimated by the formula used by Shi *et al*. (2010):

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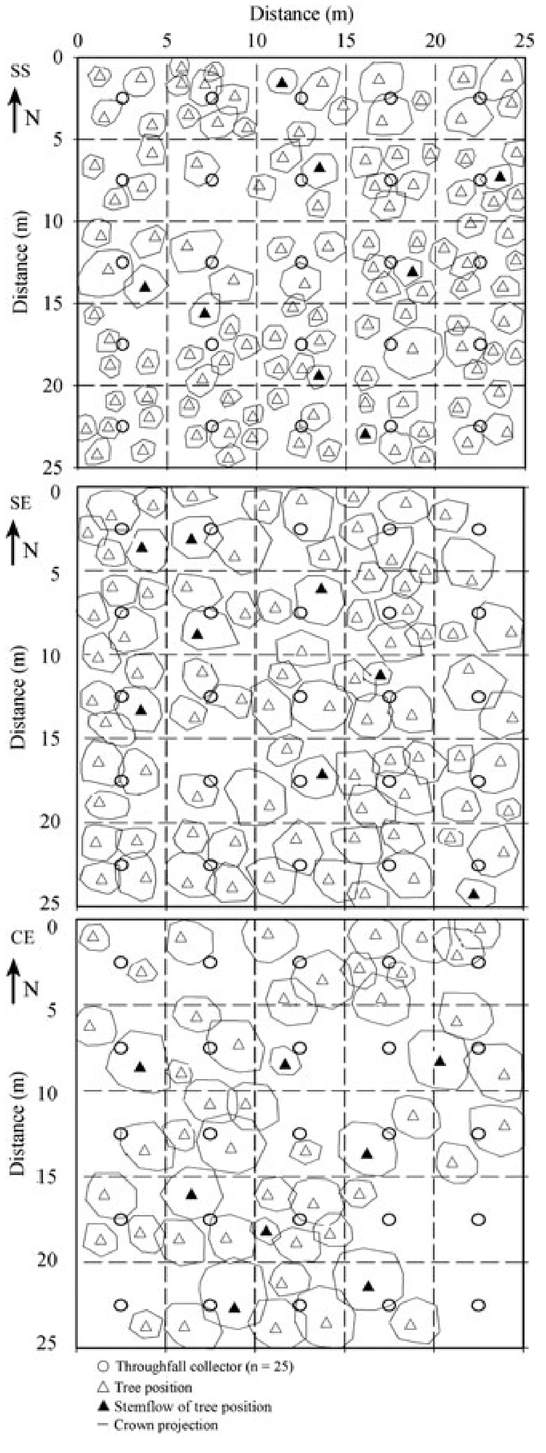

Figure 1. Experimental set-up of the throughfall collectors in the three chronosequence forest plots. (a) SS; (b) SE; (c) CE

$$SF = \sum_{i=1}^{n} \frac{S_n \cdot m}{A \cdot 10^4} \quad (1)$$

where SF is the estimated stemflow depth in millimeters for the plot with an area of A (m^2); n is the number of DBH classes in each plot; S_n is the average stemflow volume (ml) from sampled trees in a certain DBH class and m is the number of trees which belong to a certain DBH class in the plot.

Statistical analysis

In the present study, mean individual throughfall was calculated from March to October, 2009 from 25 collectors and considered as the true throughfall amount. Here, we defined the mean individual throughfall as the whole throughfall amount (mm) divided by the total rainfall events of each collector during the study period. The distribution of the volume (mm) of mean individual throughfall collected throughout the study period with 25 collectors followed a normal distribution (Shapiro-Wilk test, $P = 0.722$, 0.275 and 0.117 for SS, SE and CE, respectively).

In order to simulate the spatial distribution of the average individual throughfall values obtained by sampling a number of collectors (n), a resampling routine was designed as follows. We calculated the mean individual throughfall values varying group sizes of n ($n = 2$–24) collectors. This process was repeated 10,000 times to achieve a sufficiently representative data set of random combinations of collector locations for each grouping (Ritter and Regalado, 2010). The collectors were selected at each step using Monte Carlo resampling without replacement. The Kolmogorov–Smirnov test showed that the distributions of the means generated from the resampling scheme were normally distributed ($P > 0.05$). This procedure allowed us to simulate the distribution of mean individual throughfall values by sampling from 2 to 24 of the 25 available collectors.

For different collector group sizes, a distribution of the mean individual throughfall was obtained. The resampling procedure allowed us not only to determine the mean of the generated distributions, but also the confidence levels of distributions as well (Rodrigo and Àvila, 2001). The distributions of the mean throughfall and the confidence intervals obtained for n collectors can be plotted against the number of collectors to graphically show the variation with the number of collectors. The coefficients of variation (*CV*s) can be used to compare, for the same number of collectors, the variability of the distribution of the means depending on the individual average throughfall data (Rodrigo and Àvila, 2001). Statistical analyses were carried out in R version 2.11.1, SPSS version 18.0, and Sigmaplot version 11.0.

Another procedure for determining the minimum number of collectors required to achieve an acceptable error was based on the results that the distribution of the means of the 25 collectors was normal (Shapiro-Wilk test, $P = 0.722$, 0.275, and 0.117 for SS, SE, and CE, respectively). In order to estimate the required number of collectors to achieve an acceptable error and confidence interval for the three chronosequence stages of EBLFs, Equation 2 derived from the confidence intervals of the means for a normally distributed variable was used (Kimmins, 1973).

$$m = \frac{t^2_{(\alpha, n-1)} CV^2}{E^2} \quad (2)$$

where m is the estimated number of collectors required, t is the Student's t-value with an error probability of α and $n - 1$ degrees of freedom, n is the number of used samplers (here, $n = 25$) and E is the acceptable error expressed as a percentage of the mean (Wullaert *et al.*, 2009).

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RESULTS

Rainfall partitioning

During the study period from March to October 2009, 34 individual rainfall events of a cumulative 1384 mm were measured, with 3 of the 34 events having interception losses of 100% (< 2 mm measured). The monthly rainfall amount from March to October was about 23% higher than the long-term average from 1953 to 1980 (Song and Wang, 1995). The cumulative throughfall amounts (means ± standard error) for SS, SE and CE were 905 ± 55 mm, 764 ± 26 mm and 1060 ± 35 mm, accounting for 65 ± 4%, 55 ± 2% and 77 ± 3% of total rainfall, respectively. The relationships between the amount of throughfall and precipitation were linear for the three communities (Figure 2). Stemflow was 9%, 14% and 6% of rainfall and interception loss was 26%, 31% and 17% of rainfall for SS, SE and CE, respectively. Throughfall clearly dominated the water flux that passed through the forest canopy.

Spatial variations of throughfall

During the study period, the coefficients of variance of throughfall (CV_{Tf}) at the event level were calculated using data for the 25 grids in the three chronosequence stages of EBLFs. The mean CV_{Tf} were 39%, 26% and 25% for SS, SE and CE, respectively. CV_{Tf} decreased with increasing rainfall amount when rainfall depth was less than 35 mm, whereas CV_{Tf} was nearly stable when rainfall depth was ≥ 35 mm for the three forest types (Figure 3). The one-way ANOVA

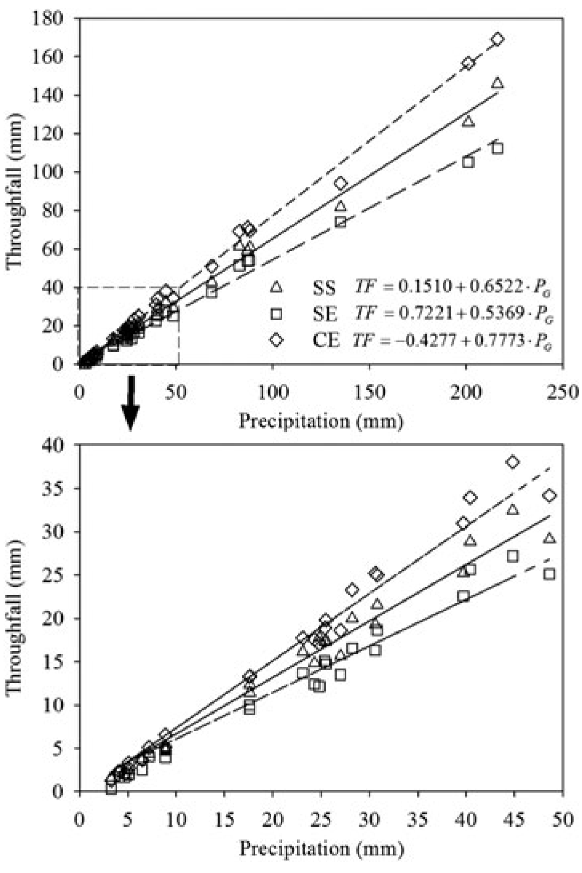

Figure 2. Variation of throughfall depth in the three chronosequence forest stands with rainfall during the study period

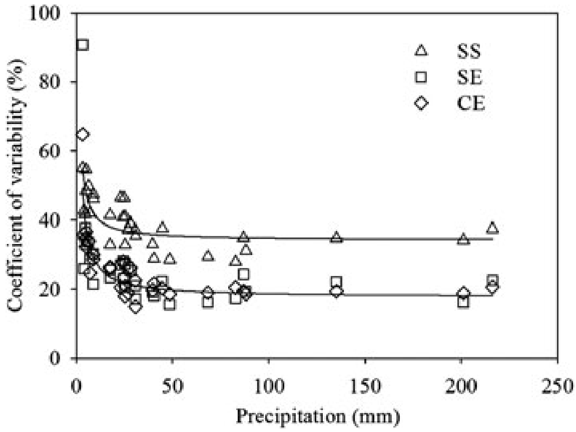

Figure 3. The throughfall coefficient of variation (*CV* %) as a function of gross precipitation amounts (mm) in the three successional stage stands for the study period

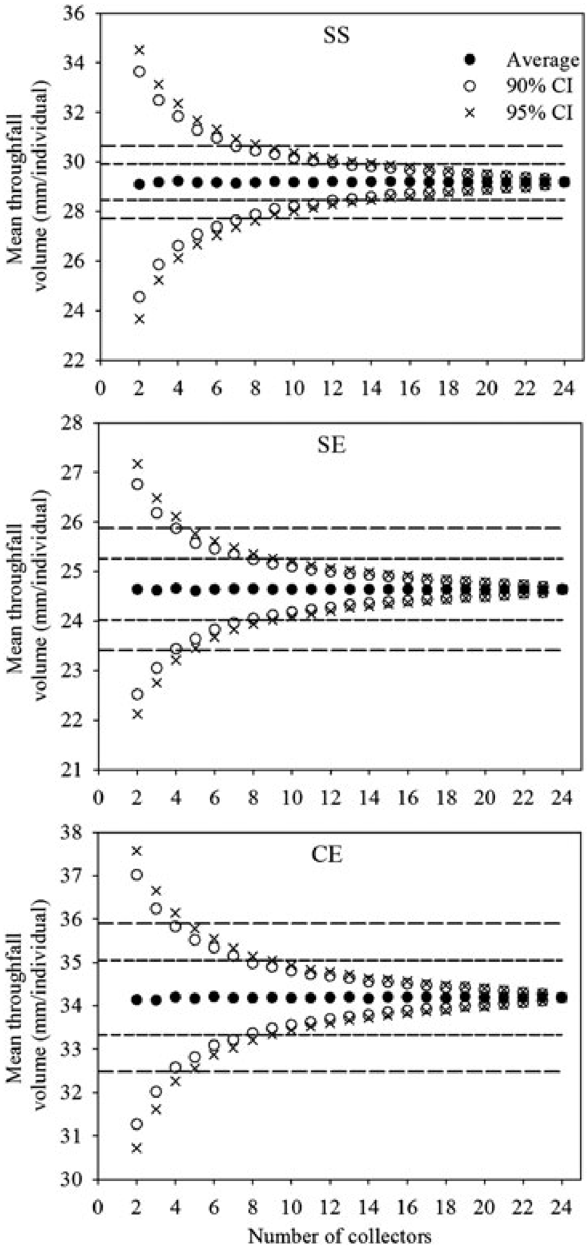

Figure 4. Average and confidence intervals of 90 and 95% of the distribution of the mean individual throughfall obtained by Monte Carlo resampling in relation to the number of collectors. The simulated value corresponding to *n* (*n* = 2–24) collectors and the 5 and 10% error of this value are also showed.

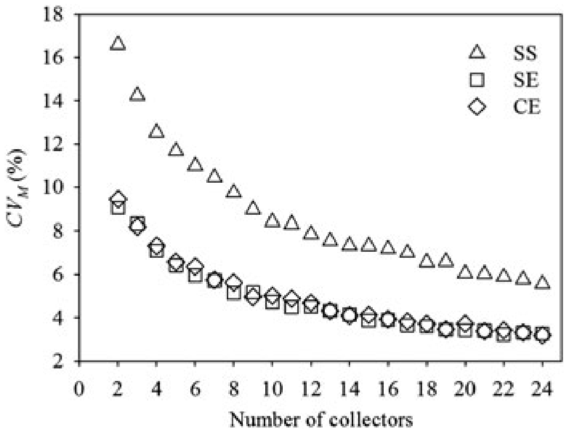

Figure 5. Coefficients of variation (CV_M) for mean individual throughfall values generated by Monte Carlo resampling against the number of collectors in three forest stands

indicated that the CV_{Tf} values for SS were significantly different from the other two forest types ($P < 0.05$), but no difference was found between SE and CE. The *CV* for throughfall at the event level was found to be best represented as an inverse curve function of gross rainfall depth (Figure 3):

$$\text{SS}: CV_{Tf}(\%) = 34.2 + 68.6/P_G(r = 0.749, n = 31) \quad (3)$$

$$\text{SE/CE}: CV_{Tf}(\%) = 17.5 + 113.0/P_G(r = 0.795, n = 31) \quad (4)$$

Number of collectors

Figure 4 showed the averages and the 90 and 95% confidence intervals of mean individual throughfall determined with different number of the 25 collectors ($n = 2$–24). The upper and lower curves of the confidence intervals are rather symmetrical, as expected for a normal distribution (Rodrigo and Àvila, 2001). The confidence interval of the mean individual throughfall spreads out as sample size reduces, such that for a small number of collectors (e.g. $n = 2$), the dispersion around the mean may be as high as 11 mm for SS (Figure 4). The number of collectors within the specified margins of error for mean individual throughfall is higher for SS than for SE and CE. For example, 95% of the distribution of means does not exceed 10% error with more than nine, five and five collectors for SS, SE and CE, respectively. It does not exceed a 5% error with more than 16, 10 and 10 collectors at SS, SE and CE, respectively (Figure 4).

In Figure 5, the CV_{Tf} of the distribution (CV_M) generated by the Monte Carlo sampling technique is plotted against the number of collectors. CV_M greatly decreased with increasing sample size when the sample size was less than 16, and it was nearly stable when the sample size was 16 or more, regardless of rainfall amount. This suggests increasing the sample size greatly improves the accuracy of throughfall estimates on a stand-scale when sample size is less than 16, whereas it does not when the sample size is 16 or more (Figure 5). The variability of the mean

Table I. Description of successional evergreen broad-leaved forests and characteristics of selected plots in Tiantong National Forest Park, Eastern China

Successional stages	Age (yr) [a]	Altitude (m)	Slope	Aspect	Tree density (ha^{-1}) [b]	Height (m)	Leaf area index	Dominant tree species	Forest management and disturbance history [c]
SS	~17	164	25°	SE 20°	2016	5	3.4	*Lithocarpus glaber*, *Loropetalum chinense*, *Symplocos sumuntia*	Derived from natural regeneration after cessation of the repeated cutting. With the supply of natural gas for cooking and heating, the clearance has been significantly reduced in recent decade.
SE	~90	163	20°	SE 70°	1376	19	3.6	*Schima superba*	Snags and down deadwood harvesting. Natural disturbance regimes including typhoon and landslide.
CE	~150	196	26°	SE 45°	752	25	2.8	*Castanopsis fargesii*	Protected from clear cutting. Canopy gap-phase dynamics presented. Typhoon is the major disturbance at regional scale with returning interval of 7–8 years.

SS, Secondary shrub; SE, Sub-climax evergreen broad-leaved forest; CE, Climax evergreen broad-leaved forest.
[a] Years since abandonment, cited from Yan *et al.* (2007),
[b] Trees are considered to have a diameter at breast height (DBH) ≥ 5 cm,
[c] Sources derived from the research of Yan *et al.* (2009).

individual throughfall for SS is higher than for SE and CE stands. On the other hand, the independent sample test shows that there is no difference between SE and CE for the CV_M of throughfall ($P = 0.920$, $n = 23$).

As described in the methodology, we can also use Equation 2 to determine the number of collectors corresponding to a pre-determined accepted error (E) with different levels of significance. Table 2 shows the calculated number of collectors with accepted errors of 5 and 10% at the 90 and 95% confidence level, respectively.

DISCUSSION

Spatial variations of throughfall

To examine the spatial variations of throughfall, the throughfall values were measured in 25 grids in three chronosequence stages of EBLFs. CV_{Tf} was strongly influenced by rainfall amounts when rainfall depth was less than 35 mm and was fairly conservative when rainfall was greater than 50 mm in the three forest types (Figure 3). This result is similar to that obtained by Staelens *et al.* (2006) who found that CV_{TF} values remained constant around 20% in leafed periods and 10% in leafless periods for rainfall greater than 10 mm in deciduous forest. In addition, the averages of CV_{Tf} in this study, 25–39%, were within the range of CV_{Tf} values measured (21–53%) in other lowland rain forests and deciduous conifer types (Table 3). However, CV_{Tf} in this study was higher than that reported for broad-leaved forests in Japan, which were 12% for a mixed white oak forest (Silva and Okumura, 1996), and 17% for a broad-leaved secondary forest (Deguchi *et al.*, 2006) (Table 3).

These differences in the spatial variation of throughfall among stands can be expected due to differences in canopy species, canopy structure, density, spatial homogeneity and meteorological phenomena (Loescher *et al.*, 2002; Raat *et al.*, 2002; Keim *et al.*, 2005; Holwerda *et al.*, 2006; Vernimmen *et al.*, 2007; Zimmermann *et al.*, 2007). Differences in experimental design, such as size of plots, number, size and spatial density of collectors, time scale of sampling throughfall, make it difficult to directly compare our results to previously published articles. Nevertheless, it seems reasonable to expect a relationship between stand characteristics and the spatial variation of throughfall under the same climatic conditions.

Sample size from the simulated method

It is possible to reduce the number of collectors and still maintain a good estimate of the mean throughfall by randomly relocating collectors after each sampling (Kimmins, 1973; Ziegler *et al.*, 2009). This methodology could allow a significant reduction in the number of collectors required or could provide a lower variation in the total throughfall estimates if the same number of gauges are used (Holwerda

Table II. Number of collectors necessary to estimate the mean individual throughfall for the study period at the three chronosequence stages of EBLFs in Tiantong without exceeding a certain error and with different levels of significance

Level of significance	SS: accepted error (%)		SE: accepted error (%)		CE: accepted error (%)	
	5	10	5	10	5	10
0.05	107	27	32	8	31	8
0.10	62	16	19	5	18	4

Table III. Spatial patterns of throughfall amount in this and other studies expressed as the coefficient of variation (*CV*, in %)

Reference	Throughfall gauge: Numbers	Throughfall gauge: Area (cm^2)	Forest type[A]	Duration	*CV* (%)
Loescher *et al.* (2002) [a]	36	95	LRF	2 months	24
Vernimmen *et al.* (2007) [b]	18-20	100	LRF	Annual	27 - 36
Holwerda *et al.* (2006) [c]	30	100	LMRF	Annual	23 - 49
Zimmermann *et al.* (2007) [a]	25	122	LMRF	Annual	53
Keim *et al.* (2005) [d]	94	9	Douglas fir stand	Annual	14 - 26
Raat *et al.* (2002) [a]	24	320	Douglas fir stand	9 months	21
Silva and Okumura (1996)[a]	5	-	Mixed oak forest	11 months	12
Deguchi *et al.*, 2006[a]	9	346	Multi-species forest	Annual	17
This study [a]	25	415	SS	8 months	39
This study [a]	25	415	SE	8 months	26
This study [a]	25	415	CE	8 months	25

[A] Abbreviations are LRF: Lowland rain forest and LMRF: Lowland mountain rain forest.
[a] Mean of *CV* for the rainfall events during the study period.
[b] Ranges of *CV* in three studied evergreen forest types.
[c] Ranges of *CV* in three sampling strategies of LMRF.
[d] Ranges of *CV* in three studied forest types.

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et al., 2006; Vernimmen *et al*., 2007). In summary, simple random sampling appears to be a good choice in the absence of a pronounced spatial structure (Zimmermann *et al*., 2010). However, the throughfall value obtained in a particular week could be highly biased and lead to unreliable results when studying either the temporal variations of the throughfall or its relation with meteorological characteristics which vary over time (Kimmins, 1973; Price and Carlyle-Moses, 2003).

It has been demonstrated in the literature that the sampling strategy and the number of gauges are most important in gaining the true measurement of throughfall input in forest ecosystems (Thimonier, 1998; Price and Carlyle-Moses, 2003). On the other hand, theoretical predictions and limited empirical evidence led others to assume that gauges with larger orifices might collect a more representative sample because they intercept a larger canopy area (Holwerda *et al*., 2006; McJannet *et al*., 2007; Zimmermann *et al*., 2010). Therefore, we evaluated the potential errors resulting from sampling size using Monte Carlo simulations for mean individual throughfall values in three chronosequence stages of EBLFs.

From the curves of Figure 4, we can adjust the following logarithmic functions:

1. for the lower limit of the distribution $y = a + b \ln(x)$
2. for the upper limit of the distribution $y' = a' + b' \ln(x')$.

where y and y' are the lower and upper confidence limits of the distribution of mean individual throughfall, respectively, and x and x' are the number of collectors. From these functions, the number of collectors corresponding to the accepted level of error can be found. Parameter values of a, b, a' and b' of these functions are shown in Table 4.

The variations of the mean individual throughfall calculated for SS were higher than for the other two forest types, as seen by the larger number of collectors needed for the same level of precision (Figure 4). This can be attributed to the differences in the stand structure of the three successional stages, e.g. tree density, tree height, species composition and LAI (Table 1).

Sample size requirements affected by forest type

Equation 2, used to calculate the sample size, which is needed to keep the relative error of the mean below a certain percentage, has been applied in a number of throughfall studies. Large differences exist in the number of required collectors depending on the forest type (Kimmins, 1973). Rodrigo and Àvila (2001) suggested that 9 to 11 fixed gauges suffice to keep the relative error below 10% and 22 to 23 fixed funnels for a 5% error limit in a holm oak forest. In our study, throughfall measurements under SS canopies require much larger numbers of fixed collectors than for measurements under SE and CE canopies at the same accepted error with a 90 and 95% confidence level (Table 2).

The number of collectors determined here from fixed, 23 cm diameter funnel collectors. Obviously, collectors of larger diameter (e.g. Draaijers *et al*., 1996) would integrate the throughfall from a broader canopy area, thus likely decreasing the spatial variability (Rodrigo and Àvila, 2001). A lower number of collectors could be used to achieve a similar level of error in the mean throughfall estimate when using large funnels compared to smaller ones (Rodrigo and Àvila, 2001). Therefore, the numbers of collectors in relation to the area of the collector opening is necessary to optimize the measurement of mean throughfall in long-term observations.

Relationship between sample size and throughfall means

As shown in Figure 3, small rainfalls produce throughfalls with higher *CV*s than larger rainfalls. Accordingly, Rodrigo and Àvila (2001) suggested that the rainfall pattern must be considered when selecting the number of collectors. For instance, Price and Carlyle-Moses (2003) concluded that a much larger number of collectors are necessary to sample precipitation events of < 2 mm than > 4 mm.

In the present study, CV_M for mean individual throughfall was nearly stable when the sample size was 16 or more, regardless of rainfall depth (Figure 5). This result is similar to that obtained by Shinohara *et al*. (2010) who found that CV_M values remained stable when the sample size was eight or more in a bamboo forest. This indicates that increasing the number of sampling throughfall collectors is most effective when the sample size is less than 16 for EBLFs.

CONCLUSION

In order to clarify the spatial variations of throughfall due to succession, space-substitute-time observations were carried out in EBLFs under the same climatic conditions in eastern China. Throughfall in SS, SE and CE were 65%, 55% and 77%, respectively. *CV*s of the mean

Table IV. Logarithmic functions (ln) calculated from the curves in Figure 4. In each case, y is the throughfall volume at the upper and lower limits of confidence (90 and 95 %) of the distribution of mean individual throughfall obtained by resampling and x is the number of collectors

	Interval of confidence (%)	Upper limit	R^2	Lower limit	R^2
SS	90	$y' = 34.0 - 1.58 \ln(x)$	0.955	$y = 24.2 + 1.62 \ln(x)$	0.950
	95	$y' = 35.0 - 1.89 \ln(x)$	0.954	$y = 23.3 + 1.93 \ln(x)$	0.950
SE	90	$y' = 26.9 - 0.75 \ln(x)$	0.951	$y = 22.4 + 0.75 \ln(x)$	0.949
	95	$y' = 27.4 - 0.89 \ln(x)$	0.951	$y = 21.9 + 0.89 \ln(x)$	0.950
CE	90	$y' = 37.3 - 0.99 \ln(x)$	0.955	$y = 31.0 + 1.03 \ln(x)$	0.951
	95	$y' = 37.8 - 1.19 \ln(x)$	0.955	$y = 30.4 + 1.22 \ln(x)$	0.951

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throughfall (measured with 25 fixed gauges per plot) were 39%, 26% and 25% for SS, SE and CE, respectively. Values of *CV* decreased asymptotically with increasing rainfall amounts.

Based on the Monte Carlo resampling method, 5% error was not exceeded when using 16, 10 and 10 collectors for SS, SE and CE, respectively. The CV_M for mean individual throughfall became relatively stable when the number of gauges was 16 or more for each EBLF stand. However, a sample size of 16 for SS, 5 for SE and 4 for CE would be enough for throughfall estimates with an error of 10% and a 90% confidence level based on Student's *t*-value analysis. Spatial throughfall patterns showed high stability in SE and CE during the monitoring period, which might partially explain the differentiation of these ecological niches and the extraordinarily high plant species richness of the SS stand. If the high species richness in SS is also a reason for high throughfall heterogeneity, this could be a positive feedback mechanism.

This study suggested that previous throughfall sampling designs utilized in EBLFs may not have sampled this flux to an acceptable level of precision. Future work in these and other environments should determine the variation in throughfall under the canopy before the establishing long-term sampling.

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