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RESEARCH ARTICLE

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Rainfall redistribution of a virgin *Pinus koraiensis* forest and secondary *Betula platyphylla* forest in Northeast China

Abstract A virgin *Pinus koraiensis* forest in the Xiaoxing'an Mountains was selected to study its rainfall redistribution effect via 97 rainfall occurrences during a growing season. The following results were obtained: 1) The canopy interception of the *P. koraiensis* virgin forest amounted to 98168 mm during a growing season (May to September), which was 19.6 per cent of the total rainfall and 1.3 times that of a secondary *Betula platyphylla* forest. Compared with other forest types in China (11.4%–36.5%), the ratio of the canopy interception in the virgin pine forest was at a medium level. 2) The throughfall of the virgin pine forest was 395.77 mm, which accounted for 78.7% of total precipitation, and the stem-flow was 8.78 mm, accounting for 1.74% of total precipitation. Compared with the secondary birch forest, the virgin pine forest had lower throughfall but higher stem-flow. 3) Cubic regression equations ($p < 0.01$) which describe the relation between throughfall, stem-flow and canopy interception in the virgin pine forest and rainfall in an open field were fitted. A linear regression equation ($p < 0.01$) was found to be a better fit for the relationship between throughfall of the secondary birch forest and rainfall outside the forest. Factors affecting throughfall and stem-flow were analyzed, with results providing a good reference to the study of rainfall redistribution in coniferous and broadleaved mixed forests.

Keywords virgin *Pinus koraiensis* forest, secondary *Betula platyphylla* forest, canopy interception, throughfall, stem-flow

1 Introduction

Canopy plays an important role in rainfall redistribution, especially in the process of intercepting and cushioning rainfall. In this process, precipitation, kinetic energy and potential energy of the rainfall may be abated, helping to decrease the flood peak, protect the soil and restrain water resources (Gong et al., 2004). The canopy interception, one of the most important hydrological parameters, is affected by species, age of the tree, forest density, canopy structure and characteristics of rainfall (Kong and Song, 1990; Wang and Zhang, 1998; Zhao and Wu, 2002; Hall and Calder, 2003; Bao et al., 2004; Dang et al., 2005). The *Pinus koraiensis* virgin forest is a climax community in the Xiaoxing'an Mountains, which, so far, has not been extensively researched. Our study, using an investigative technique of orientation, aims to analyze rainfall redistribution of the *P. koraiensis* forest and a secondary *Betula platyphylla* forest so that the hydrological function of forests can be estimated to an extent sufficient to be useful in understanding and management of the resource (Zhou, 1997; Liu et al., 2001, 2004; Deng et al., 2003; Li, et al., 2004).

2 Study site

The study was conducted at Liangshui National Nature Reserve of the Northeast Forestry University (47°7′15″–14′38″N, 128°48′8″–55′46″E) in Dailing, Yichun City, which lies in the easternmost part of Eurasia. The whole area comprises 12000 hm^2 and the average elevation is 400 m. Weather in this area is classified under the temperate continental climate. The climatic conditions are as follows: the average temperature is −0.3°C, the relative humidity is 78%, the frost-free season usually lasts for 100 to 120 d, the accumulated temperature (> 10°C) is 1702°C, and annual mean precipitation is 676 mm, with the highest rainfall in July.

The main forest types are *P. koraiensis* stands and mixed broadleaved forests. In addition, there are a few secondary virgin forests such as *B. platyphylla* and *Quercus mongolica*, as well as some *Larix gmelini* and *P. koraiensis* plantations. Our study was conducted mainly in virgin pine forests and in a secondary birch forest. Virgin pine, with pine as its dominant species, and *B. costata*,

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Tilia amurensis, *Fraxinus mandshurica* and a few *Juglans mandshurica* trees form an uneven-aged multi-story canopied forest. Because of the low density of the forest, shrubs and herbs grow abundantly. There are many types of shrubs, including *Syringa reticulatavar* var. *mandshurica*, *Corylus mandshurica*, *Acanthopanax senticosus* and *Philadelphus schrenkii*.

The secondary birch forest, with birch as its dominant species, is a secondary community which has regenerated since a 1953 felling. The forest, with a single crown canopy, consists of pine, *Picea koraiensis* and *Abies nephrolepis* trees and other conifer seedlings which regenerate well. There are also a few shrubs, including *Padus asiatica, Spiraea salicifolia*, *Philadelphus schrenkii*, *Aralia mandshurica* and *Corylus mandshurica.*

3 Methods

We chose a typical area to establish a standard 0.2 hm^2 (40 m × 50 m) plot in a virgin pine forest and a similar plot in a secondary birch forest. Table 1 shows the characteristics of the two forest types:

Rainfall (P) was obtained from a nearby weather station, while throughfall (P_t) was measured as follows: we established three long plastic pipelines (length 118 m × width 0.2 m × depth 0.2 m) in each standard plot, drilled holes at the bottom of each pipeline, and joined them using a plastic barrel (with cover) through the holes to collect the throughfall. Based on the distribution of different diameter classes in each standard plot, the stem-flow (P_s) was measured as follows: we sampled five trees in each plot, then laced a plastic pipeline ($d = 6$ cm) which has been cut open on each tree and put a barrel (with cover) under the pipe so that the stem-flow could be collected. We measured the stem-flow immediately after every rainfall, after which the canopy interception (P_i) could be converted based on the number of trees per unit area, number of stems in each diameter class and stem-flow of each diameter class. The formula is $P_i = P - P_s - P_t$.

4 Results

4.1 Rainfall

We observed rainfall 97 times during the growing season (from May to September) in 2005. The total amount of rainfall was 503.23 mm. Most of rainfall ranged in amounts between 4 and 10 mm – a range that accounted for 22.3% of total precipitation frequencies. Rainfall under 10 mm, between 10 and 30 mm and more than 30 mm accounted, respectively, for 84.0%, 11.7% and 4.3% of total precipitation frequencies. Rain occurred mainly in July and September, especially in September (Figs. 1 and 2).

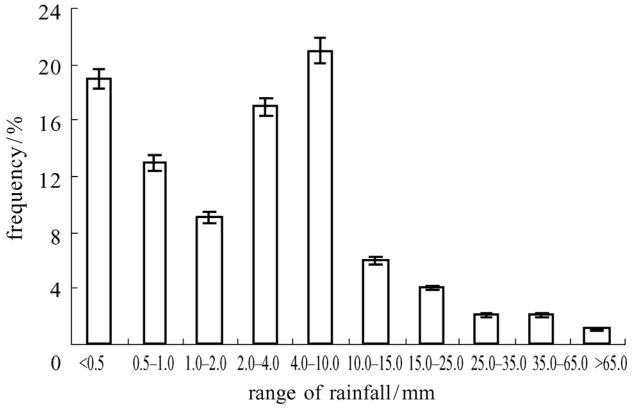

Fig. 1 Grade distribution of atmospheric precipitation

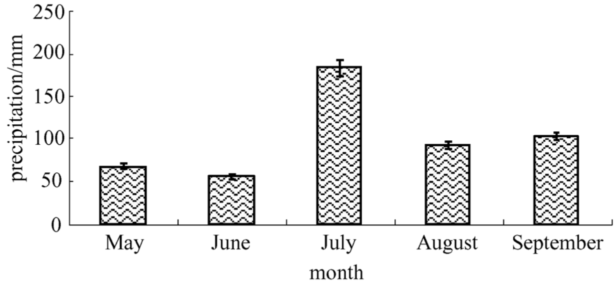

Fig. 2 Monthly distribution of atmospheric precipitation

4.2 Distribution of canopy interception

The result shows that in the growing season, total canopy interception in the pine virgin forest was 98.68 mm, which accounted for 19.6% of total precipitation during the same period. The forest was formed after cutting the virgin pine forest, which had been a closed forest. The secondary birch forest can be easily affected by changing the structure of the forest, composition and biomass. The total canopy interception in the secondary birch forest was 75.4 mm, which accounted for 15.0% of all precipitation in the same period and amounted to 0.77 times the precipitation of the virgin pine forest.

Figure 3 shows that the canopy interception increases along with the outer rainfall. Once the precipitation

Table 1 Comparison on characteristics of the two types of forests

	average diameter/cm	average height/m	density/trees·hm^{-2}	canopy density	shrub coverage/%	herb coverage/%
virgin pine forest	39.0	22.49	265	0.70	65–85	50–85
secondary birch forest	19.1	16.24	490	0.65	15–25	50–80

reaches 60 mm, the growth of canopy interception will slow down and may even decrease. This means that interception reaches a culmination point called maximum canopy interception. In addition, the intensity of rainfall, the prior rainfall, climatic factors, the structure of the forest and other factors affect canopy interception as well (Wang et al., 1998, 2005). The study chose the relationship between rainfall and canopy interception and approximated it with cubic polynomials. The result was significant ($p < 0.01$) (Table 2).

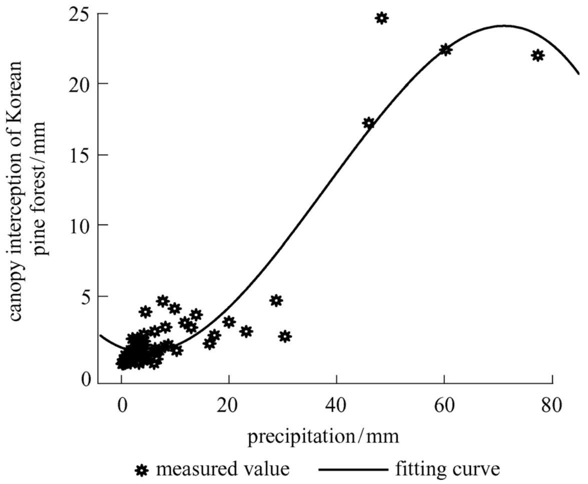

Fig. 3 Relationship between canopy interception of virgin pine forest and rainfall

Table 2 Relationship between canopy interception and outer rainfall

	equation of approximation	samples of observations	R^2	p
virgin pine forest	$P_i = -1.98P^3 + 3.19P^2 - 0.38P$	82	0.89	0.00**
secondary birch forest	$P_i = -0.51P^3 + 0.17P^2 - 1.25P$	86	0.94	0.00**

Note: ** means the test is significant at $\alpha = 0.01$.

Figure 4 shows that canopy interception in a virgin pine forest changes over time due to changes in canopy density, precipitation, intensity of rainfall and other factors. Given the incidence of these factors, the maximum ratio of interception occurs in July and the minimum occurs in May and August. Plants are in full bloom in July, allowing the canopy density and biomass to reach a maximum. However broadleaved trees are just in the process of opening their leaves in May, making the canopy very sparse and limiting its ability to intercept rainfall. This situation is prevalent especially in the secondary birch forest, so that the interception ratio in this type of forest tends to be small. Although both canopy density and rainfall are high in August, the intensity of rainfall is weak in the secondary birch forest, reducing the ability of interception and of the interception ratio as well. Comparing the two types, we can find that the interception ratio of the virgin pine forest is much higher than that of the secondary birch forest (Fig. 4).

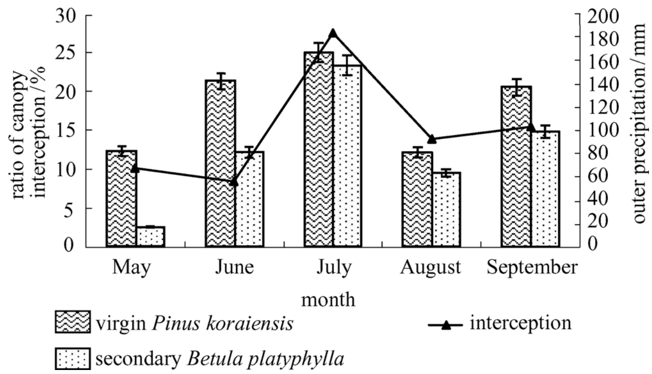

Fig. 4 Comparison of the ratio of canopy interception of the two kinds of forest and rainfall

4.3 Characteristics of throughfall

From our data we calculated that the throughfall in the virgin pine forest was as high as 304.98 mm, which is 60.5% of the total precipitation. In the secondary birch forest, the throughfall was 378.45 mm, which represents 75.1% of total precipitation. The throughfall in the pine forest is much lower because of its high canopy density and complex structure. Seasonal changes also affect throughfall due to differences in precipitation. The maximum throughfall occurred in July, while the minimum occurred in May and June (Fig. 5)

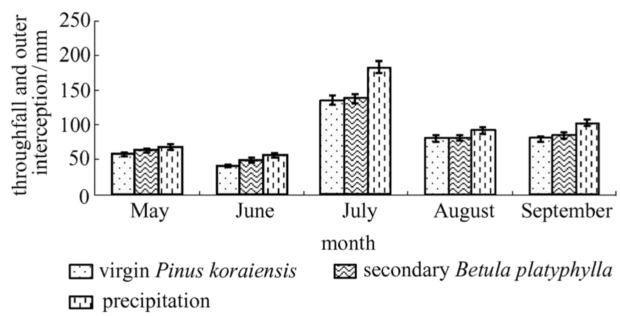

Fig. 5 Comparison of seasonal distribution of average throughfall in the two kinds of forest and outer rainfall

After analyzing various polynomial relationships between throughfall and outer rainfall, we concluded that a cubic polynomial fitting of the virgin pine forest was significant ($p < 0.01$, $R^2 = 0.98$), while a linear regression was also significant ($p < 0.01$, $R^2 = 0.97$) in the secondary birch forest (Table 3).

4.4 Characteristics of stem-flow

From our data, we calculated that stem-flow in the virgin pine forest was as high as 6.57 mm, which is 1.30% of precipitation. In the secondary birch forest, the

Table 3 Relationships between throughfall of forests and outer rainfall

	fitting equation	samples of measurements	R^2	p
virgin pine forest	$P_t = 0.92P$	77	0.85	0.00**
	$P_t = 1.09P - 0.18P^2$	77	0.85	0.00**
	$P_t = 1.23P - 0.62P^2 + 0.40P^3$	77	0.98	0.00**
secondary birch forest	$P_t = 0.99P$	79	0.97	0.00**
	$P_t = 1.09P - 0.18P^2$	79	0.85	0.00**
	$P_t = 1.70P - 1.99P^2 + 1.26P^3$	79	0.87	0.00**

Note: P means rainfall (mm), P_t throughfall (mm)

throughfall was 99.98 mm, which accounts for 16.4% of the precipitation. Again, the percentage in the pine forest is much lower because of factors such as branch angle and smooth degree (Liu, 1996). Large branch angles block the fall and collection of rainwater (Iida et al., 2005). Trunks obstruct stem-flow, leading to less stem-flows in the virgin pine forest compared to the secondary birch forest. We compared the average stem-flow ratio of individual trees in the two types of forest and rainfall and found that stem-flow of the virgin pine forest reached its minimum in June, while the maximum in the secondary birch forest was reached in July (Fig. 6). Regression analyses show that the result from a cubic polynomial of the relationship between stem-flow and precipitation ($p < 0.01$) is better than any other fit in both types of forest (Table 4).

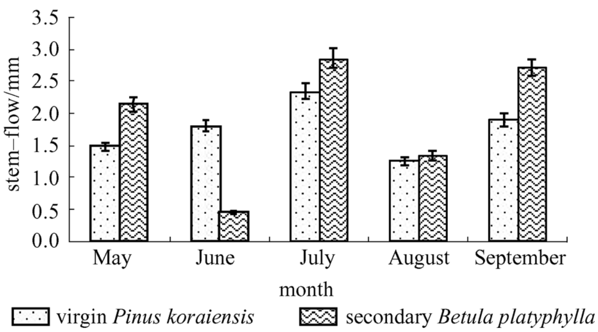

Fig. 6 Comparison of average stem-flow ratio of individual trees in two kinds of forest and outer rainfall

Table 4 Relationship between stem-flow of trees and outer rainfall

	fitting equation	no. of measurements	R^2	p
virgin pine forest	$P_t = -1.11P^3 + 2.03P^2 + 0.05P$	66	0.96	0.00**
secondary birch forest	$P_t = -1.32P^3 + 2.53P^2 - 0.29P$	78	0.97	0.00**

To discover the relationship between stem-flow and various factors, we chose height (H), diameter (D), canopy density (q), tree-crown (S), precipitation (P) as independent variables and stem-flow as the dependent variable for a multiple regression equation analysis. Results from the regression equations show that stem-flow of the virgin pine forest is related to diameter, tree-crown, height of the first living branch and precipitation. In the secondary birch forest, stem-flow is correlated with all factors. In addition, stem-flow is negatively correlated with tree-crown in the virgin pine forest, but in the secondary birch forest, it is negatively correlated with both tree-crown and canopy density. This last correlation supports the fact that stem-flow is less and the tree-crowns are larger in the virgin pine forest (Table 5).

Table 5 Relationship between stem-flow of forests and factors affecting the two types of forests

	fitting equation	no. of measurements	R^2	p
virgin pine forest	$P_t = -1.11P^3 + 2.03P^2 + 0.05P$	66	0.96	0.00*
secondary birch forest	$P_t = -1.32P^3 + 2.53P^2 - 0.29P$	78	0.97	0.00**

5 Discussion

The canopy interception of the virgin pine forest amounted to 98168 mm during the growing season (May to September, which was 19.6% of the total rainfall and 1.3 times that of the secondary birch forest). Compared with other forest types in China (11.4%–36.5%) (Wen and Liu, 1995; Cui et al., 2006; Wang et al., 2006; Wei and Wu, 2006), the ratio of the canopy of the virgin pine forest was at a medium level. Canopy interception is affected by factors such as canopy density, forest structure, biomass, precipitation and intensity of rainfall (Hashino et al., 2002; Hall and Calder, 2003; Dang, 2005; Wang et al., 2005). Generally, canopy interception increases with precipitation, which forces rainwater to pour down; it is larger in the virgin pine forest than in the secondary birch forest and also larger in multi-canopied forests than in single-canopied forests. When total outer precipitation reaches 60–80 mm, the ability to intercept rainfall, although still smaller than the force of throughfall, represents a maximum.

The throughfall of the virgin pine forest is 395.77 mm, which accounts for 78.7% of total precipitation. The stem-flow is 8.78 mm, which represents 1.74% of total precipitation. Compared with the secondary birch forest, the virgin pine forest has less throughfall but more stem-flow, which is affected by the forest structure, shrub and herb density, branch angle and degree of trunk velvet. Results show that stem-flows of different trees are relatively different from each other; for example, single stem-flow of pine, *Fraxinus mandshurica*, birch and *Larix gmelini* are 67.086, 362.774, 314.158 and 15.739 L respectively during the growing season (May to September). Clearly, stem-flow of *F. mandshurica* shows the maximum amount, which is 5–23 times the minimum amount (stem-flow of *L. gmelini*). It is therefore prudent that we take into consideration the type of tree when analyzing rainfall redistribution in conifer and broadleaved mixed forests.

Result shows that third degree polynomial equations ($p < 0.01$) describe the relation between throughfall and stem-flow. We also fitted canopy interception in the virgin pine forest and rainfall in the open field. A linear regression equation ($p < 0.01$) is a better fit for the relationship between throughfall of the secondary birch forest and outer rainfall.

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