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Composition and spatio-temporal distribution of tree seedlings in an evergreen broad-leaved forest in the Ailao Mountains, Yunnan

Hede Gong, Xiaojun Yang, Yuewei Ma and Xiping Cheng*
Ecotourism Faculty, Southwest Forestry University, Kunming 650224, Yunnan, China
Corresponding author e-mail: xipingcheng@yahoo.co.jp
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Abstract
Ailao Mountain National Nature Reserve covers 504 km^2 and is one of the largest tracts of evergreen broad-leaved forests in China. A 6-ha plot was established in the reserve in 2008 for the purpose of monitoring long-term dynamics of the forest. Tree seedlings were sampled in this plot to understand their composition and spatio-temporal distribution. Five of the top 10 seedling species in terms of importance values were the same as 5 of the top 10 adult tree species with the highest importance values. Both abundance and species richness of tree seedlings dropped between the end of the rainy season and the end of dry season, likely due to drought stress. Seedlings in canopy gaps were richer in species, more abundant in terms of density, and experienced lower mortality as compared to those under the forest canopy, suggesting that forest gaps facilitate the recruitment of seedlings in the forest.

Key words: Abiotic stress, Drought stress, Forest gap, Regeneration, Survival

Abbreviations: DBH: diameter at breast height; **ha:** Hectare (10000 m^2); **RGR:** Relative growth rate**; SLA:** Specific leaf area

Introduction
In forest, the seedling individuals of some tree species exist in the shading environment in the form of seedling bank, and they will not obtain the opportunity of successful regeneration until the appearance of the forest gap of the crown cover (Uhl *et al.*, 1988; Webb, 1989). Therefore, the emerging of forest gap is of significance to the settlement of the tree seedlings and the updating of the forest (Popma *et al.*, 1988). Yan and Cao (2008) reported based on their studies on the tropical rain forest in Xishuangbanna, the growing indicators of the *Pometia tomentosa* seedlings in the middle of the forest gap are optimized as compared to those under the cover crown and at the edges of the forest gap, which means that the relatively strong sunshine in the middle of the forest gap is in favour of the growth of the settled seedling. After the occurrence of disturbance, the environmental conditions under the forest have played an important role for the seed germination and the seedling settlement, but the early growth rate of the seedlings could strongly influence or even determine the successful settlement of the seedling (Huston and Smith, 1987). At the early stage of the growth of the seedlings, the carbohydrate and mineral substances stored in the cotyledon are not enough to meet the growth requirement of the seedlings. Therefore, the slight environmental stress would kill them (Kozlowski, 2002).

Water is one of the key factors influencing the growth of the seedlings, and the water threat may obviously restrain the updating and growth of them. The specific leaf area (SLA) of the seedlings may reduce with the increasing water stress so as to increase the CO_2 absorption in unit leaf area, and improve the water using rate in case of soil water shortage (Burslem *et al.*, 1996). Lambers and Poorter (1992) believed that the plants may reduce the SLA of the seedlings to adjust the distribution of the photosynthate in leaves to avoid the damages to leaves due to drought. The plants can also withstand the water threat by changing the distribution of the biomass in different organs and improving the net assimilation efficiency. The transfer of the biomass distribution to root system could ensure the comprehensive access of the root system to the nutrients and water to improve the concentration of the nitrogen compound and enhance the photosynthesis capacity of unit leaf area (Lambers and Poorter, 1992). Under the shade environment, if a plant has a higher relative growth rate (RGR) than another plant, it may have a lower relative growth rate under the full exposure conditions (Thomas and Bazzaz, 1999), which means that the growth of plants may be quite different under different exposure conditions.

Despite the fact that the photosynthetically active radiation under the crown cover and most of the small forest gaps is very weak, the occurrence frequency of the large forest gaps with high transmittance is very low, so it is unnecessary for the updating of most of the trees, and the seedling of the trees could form the strategy of using the low lighting under forest for the successful settlement and the development to the mature stage (Osunkoya *et al*., 1994). Yu *et al*. (2007) reported that different illumination intensities have varying influences on the growth of *Pometia tomentosa* seedling in tropical rain forest: under the weak illumination environment the seedlings will survive for a long time and grow slowly, but under the forest gap environment, it will have a high relative growth rate.

A forest dynamic monitoring sample plot with an area of 6 ha was established in the core area of the broad-leaved evergreen forest in Ailaoshan natural reserve in 2008. Based on the seedling positioning survey data of 750 small sample quadrates with the size of 1×1 m and the seedling dynamic monitoring data of 120 small sample quadrates with the size of 1×1 m, the seedling composition and distribution of the forest type in different seasons are analyzed, aiming at initially understanding the supplement law of the seedlings in the plot and providing theoretical reference for revealing the seasonal dynamics of the tree seedlings in the broad-leaved evergreen forest and protecting the diversity of species.

Materials and Method

Survey method

***Sample plot construction*:** Ailaoshan broad-leaved evergreen forest sample plot with the area of 6 ha is established according to the technical code used by Tropical Forest Research Center of the US Smithsonian Tropical Research Institute in building the 50 ha sample plot in Barro Colorado Island of Panama in 1980. The whole sample plot has a size of 200 m from east to west and 300 m from south to north, and has been divided into 150 quadrates with the dimension of 20×20 m. We have verified and recorded all of the arbors with the diameter at breast height (DBH) $\geq$ 1 cm, and numbered all of the trees and measured their DBHs and the physical locations.

***Seedling positioning survey*:** In each 20×20 m quadrate, five 1×1 m small quadrates were selected randomly (750 in total, accounting for 1.25% of the total area, which are all in the environment under cover crown) to research and record the quantities and types of the arbor seedling (height $\leq$ 50 cm) in the quadrate. The initial research was made in October, 2008 (end of the rainy season) and the review was made in April, 2009 (the end of the dry season).

***Seedling dynamic monitoring*:** Ten representative forest gaps with the actual area of 100–200 m^2 were selected (Li *et al*., 2003), and one 1×1 m small sample quadrate was established in the center and the each edge of the gap in the direction of east, west, south and north from the center to the edges of the gap, and the 1×1 m small sample quadrates were also established in the above direction at the places 10 meters to the edges of the forest edges. In total, 120 seedling monitoring small quadrates were established, representing the environments in the forest gap center, the forest gap edge and under the forest, respectively. The arbor seedling in the small sample quadrates were recorded in terms of types, quantities and heights, and the review was made every two weeks. The monitoring lasted for 1 year (from December 8, 2008 to December 8, 2009).

Data analysis

Importance value = (relative density + relative frequency + relative dominance)/3 (Sun *et al.,* 2002). The total quantity of the sample quadrates used to calculate relative frequency is 150 (20×20 m).

Seedling importance value = relative abundance + relative frequency (Li *et al*., 2009)

Relative abundance = (abundance of a seed/the sum of abundances of all seeds) ×100

Relative frequency = (frequency of a seed/the sum of abundances of all seeds) ×100

Seedling death rate = (initially checked quantity – reviewed quantity) ×100/initially checked quantity (Liu *et al*., 2008)

The data were analyzed using Excel and SPSS data processing software (http://www.spss.com.cn/).

Results and Discussion

***Seedling distribution and seasonal change characteristics*:** In the 750, 1×1m small sample quadrates, 3493 seedlings were recorded in the initial survey conducted in October, 2008 (the end of the rainy season), which belonged to 49 species of 36 genera of 21 family. There were 8 species with the quantity of the seedlings of more than 100. The species with the largest quantity is the *Machilus gamblei* (1195) and the next is *Symplocos ramosissima* (861). According to the statistics of the 750 sample quadrates, the densities of the seedlings of the two species were larger than 1/m^2.

In terms of the relative frequency of the seedlings, the largest one belonged to *S. ramosissima* (26.96%), which was followed by |*M. gamblei* (11.87%). The *S. ramosissima* also had the largest importance value (51.61), which was followed by *M. gamblei* (46.08) (Table 1). The top ten tree categories in terms of importance value and the seedlings of five tree categories could be seen in the top 10 seedling composition table (Table 2), (including *S. ramosissima*, *Lithocarpus hancei*, *Camellia forrestii*, *Ilex coralline* and *Schima noronhae*). These 5 seedling species were the major species with the DBH of more than 1cm. The similar results were obtained in the 20 ha sample plot in the Xishuangbanna tropical rain forest (Li *et al*., 2009) and the 25 ha sample plot in the Changbaishan broad-leaved korean pine forest (Zhang *et al*., 2009).

In the same small sample quadrates, 3,056 seedlings were recorded in April, 2009 (end of the dry season). Compared to the end of the rainy season, 6 species disappeared and 1 species added. The overall death rate of seedlings was 12.61%. Among the top ten seedlings in term of importance value (calculated according to the data from the survey conducted at the end of the rainy season), the death rates of the seedlings of 8 species were higher than 10%. The death rate of *Illicium burmanicum* is the highest one (18.60%), and that of the *Schefflera shweliensis* is the lowest one (1.60%). *S. ramosissima* is the major arbor species with the DBH of more than 1 cm as well as the seedling species with the largest importance value during the seedling positioning survey. However, its quantity reduced to 730 from the 861 at the end of the rainy season, and the number of the small sample quadrates with such seedlings also reduced to 398 from 445. On the contrary, the quantity of the seedlings of the *Ilex coralline* increased by 12.84% (Table 1).

The *Machilus gamblei* with the advantageous seedling quantity is not one of the top 10 tree categories in terms of importance value. Maybe because the squirrels do not like eat the seeds of *M. gamblei,* the seedlings with large density could be easily formed surrounding the parent plant. However the influences of drought and density limitation, these seedlings can hardly developed saplings. The seeds of *Castanopsis wattii* and *Lithocarpus xylocarpus*, which are dominant in the tree layer, could be easily eaten by squirrels and the seeds will hardly germinate under the cover crown due to the hardened shells, therefore the quantity of the seedlings is small. This could prove that the quantities of the seeds and the newly increased seedlings in the forest were not directly related to the dominance of the tree species in the forest. From October, 2008 to April, 2009, the death rate of seedlings under forest reached 12.51%, which is much lower than the 26.49% in the Xishuangbanna tropical rain forest (Li *et al*., 2009). Possible reason may be that the annual rainfall in the plot is higher than that in Xishuangbanna (Ailaoshan - 1931 mm and Xishuangbanna - 1400 mm), but the annual average temperature was lower (Ailaoshan - 11.3, Xishuangbanna - 21.5). Especially, the temperature at the end of dry season is lower than that in Xishuangbanna, which could reduce the evaporation of the moisture in soil and favoir the existence of seedlings. Despite such facts, in the forest, the quantities of the seedlings and the sample quadrates with seedlings at the end of dry season are smaller than those at the end of the rainy season (Table 1), which means that the drought threat may be the major factor contributing to the death of the seedlings, and the degree of drought has not reached that in Xishuangbanna. The seedlings of *Schefflera shweliensis* and *Ilex coralline* had lower death rates, and the quantity of the later had even increased, indicating that such seedlings had better abilities to withstand wet and drought.

Features of seedling dynamics

In the 120 seedling dynamic survey small quadrates, 578 seedlings were monitored in total. During the monitoring, 205 seedlings germinated, and 97 were dead (Table 3), accounting for 38.54% of the newly germinated seedlings. The month with the largest quantity of the newly germinated seedlings was September (the end of the rainy season), and the month with the smallest quantity of the newly germinated seedlings was March. In January, the quantity of the dead seedlings was the smallest (Fig. 1). The relationship between the newly added seedlings and the rainfall of each month is not obvious (P=0.19), and the quantity of the dead seedlings is not closely related to the monthly rainfall (P=0.13).

The quantity of the categories of the newly added seedlings was 26, 18 of which were in the middle of the forest gap, 16 at the edges of the forest gap and 14 under the cover crown (Table 3). The top 4 tree categories in terms of individual quantity were *Padus perulata*, *S. noronhae*, *S. ramosissima* and *I. burmanicum*, accounting for 66.83% of the quantity of the newly added seedlings. The number of the categories of the dead seedlings was 24, and the top 4 tree categories in terms of individual death quantity were *M. gamblei*, *Padus perulata*, *S. ramosissima* and *I. burmanicum*, accounting for 71.04% of the total quantity of the dead seedlings.

Table 1. Quantitative characteristic of the top ten seedling species with the highest importance values in evergreen broad-leaved forest dynamic plots in the Ailao Mountains

Rank	Species	No. of seedlings		No. of quadrats present		Relative frequency	
		I	II	I	II	I	II
1	*Symplocos ramosissima*	861	730	445	398	26.96	26.31
2	*Machilus gamblei*	1195	1055	196	183	11.87	12.10
3	*Lithocarpus hancei*	161	136	125	113	7.57	7.47
4	*Camellia forrestii*	163	145	124	118	7.51	7.80
5	*Schefflera shweliensis*	188	185	112	108	6.78	6.05
6	*Ilex corallina*	148	167	108	122	6.54	5.46
7	*Neolitsea polycarpa*	120	101	91	86	5.51	3.31
8	*Litsea elongata*	117	98	57	55	3.45	3.21
9	*Schima noronhae*	66	55	43	38	2.60	1.80
10	*Illicium burmanicum*	43	35	32	27	1.94	1.15

Rank	Species	Relative density		Important Value		Mortality rate (%)
		I	II	I	II	
1	*Symplocos ramosissima*	24.65	23.89	51.61	50.20	15.21
2	*Machilus gamblei*	34.21	34.52	46.08	46.62	11.72
3	*Lithocarpus hancei*	4.61	4.45	12.18	11.92	15.53
4	*Camellia forrestii*	4.67	4.74	12.18	12.54	11.04
5	*Schefflera shweliensis*	5.38	7.14	12.16	13.19	1.60
6	*Ilex corallina*	4.24	8.06	10.78	13.52	–12.84
7	*Neolitsea polycarpa*	3.44	5.68	8.95	8.99	15.83
8	*Litsea elongata*	3.35	3.64	6.80	6.85	16.24
9	*Schima noronhae*	1.89	2.51	4.49	4.31	16.67
10	*Illicium burmanicum*	1.23	1.78	3.17	2.93	18.60

I = First survey ; II = second survey

Table 2. Top ten tree species with the highest importance values in evergreen broad-leaved forest dynamics plot of Ailao Mountains

Rank	Species	Relative density	Relative frequency	Relative dominance	Importance value
1	*Lithocarpus hancei*	7.86	5.01	27.48	13.45
2	*Castanopsis wattii*	4.46	4.75	16.06	8.42
3	*Camellia forrestii*	14.11	5.19	1.02	6.77
4	*Vaccinium duclouxii*	11.17	4.48	3.06	6.24
5	*Lithocarpus xylocarpus*	1.99	3.70	12.10	5.93
6	*Symplocos ramosissima*	9.88	4.52	1.84	5.41
7	*Symplocos sumuntia*	9.17	4.97	1.46	5.20
8	*Schima noronhae*	1.48	3.29	7.31	4.03
9	*Machilus yunnanensis*	3.21	4.97	3.38	3.86
10	*Ilex corallina*	3.21	3.62	3.62	3.48

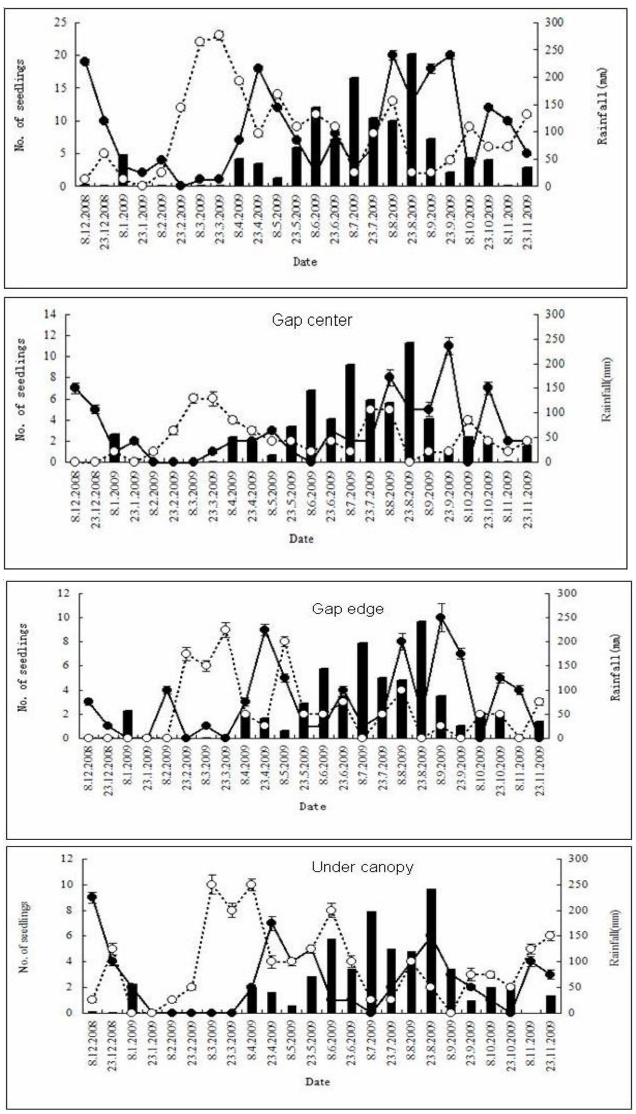
Table 3. Number of recruitment and death of tree seedlings in different habitats of evergreen broad-leaved forest dynamic plots in the Ailao Mountains between December 2008 and December 2009

Habitat	Seedlings at initial census		Recruited seedlings		
	Numbers	No. of dead (%)	Numbers	No. of dead (%)	No. of species
Gap center	154	29 (18.83%)*	71	23 (32.39%)*	18
Gap edge	166	29 (17.47%)*	75	22 (29.33%)*	16
Under canopy	258	46 (17.83%)*	59	34 (57.63%)*	14
Total	578		205		26

Each habitat includes 40 plots (1 m × 1 m). * Different habitats in the same row mean significant difference at 0.01 levels.

The seedling death rates and germination rates in three environments were quite different (P<0.01). From the quantities we can see that the quantity of the newly germinated seedlings in the environment under the cover crown is the smallest one, but the quantity of the dead seedlings is the largest one. The death rate of the newly germinated seedlings reached 57.63% (Table 3). The quantity of the *S. ramosissima* with the DBH of more than 1cm in the 6 ha sample plot is only smaller than those of the *Camellia forrestii* and the *Vaccinium duclouxii*, and its seedlings were increased by 19, 8 and 4 in the middle of the forest gap, the edges of the forest gap and under the crown, respectively, and 13, 4 and 7 were died, respectively.

Fig. 1 Dynamics of numbers of seedlings and rainfall every half month in three habitats (2008.12–2009.12).



|: Rainfall; ●: Recruitment; ○: Death

The species with the largest quantity of the increased seedlings in the middle of the forest gap is *S. ramosissima* and the species with the largest quantity of the increased seedlings at the edges of the forest gap and under the crown is *P. perulata*.

Compared to the environment under the cover crown, the quantities and categories of newly increased seedlings in the forest gap and at the edges of the forest gap are more, and the quantity of the dead seedlings is smaller. The death rate of the newly increased seedlings under the crown was significantly (P< 0.01) high (57.63%). It indicates that the illumination environment may restrain the survival of the seedlings, and the forest gap environment is better for the survival of the seedlings and the maintenance of the diversity (Liu and Wu, 2002; Enoki and Abe, 2004). In addition, the soil moisture content, litter layer, the slope grade, the slope direction, the coverage of crown and the activities of animals may also influence the dynamics of the seedlings (Poorter and Rose, 2005; Wright *et al*., 2005). At the end of the dry season, the quantity of the newly increased seedlings was minimum and the quantity of the dead seedlings was maximum, which demonstrated the important influence of the seasonal drought on the survival of the seedlings (Yan and Cao, 2008; Li *et al*., 2009).

In the middle of the forest gap, the number of the increased seedlings of *S. ramosissima* was the highest, which means that these seedlings can survive under the high illumination environment more easily. Although there were 12 *Padus perulata* trees in the sample plot, they were distributed in the places near the forest gap, so these seedlings had the maximum presence at the edges of the forest gap and under the crown. It indicates that the seedlings of *P. perulata* cannot compete with the seedlings of other species (such as *S. ramosissima*) in the middle of forest gap.

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