J. Mt. Sci. (2012) 9: 706–714
DOI: 10.1007/s11629-012-2304-y

Effects of Forest Gaps on Some Microclimate Variables in *Castanopsis kawakamii* Natural Forest

HE Zhongsheng, LIU Jinfu*, WU Caiting, ZHENG Shiqun, HONG Wei, SU Songjin, WU Chengzhen

College of Forestry, Fujian Agriculture and Forestry University, Fuzhou 350002, China

Key Laboratory of Fujian Universities for Ecology and Resource Statistics, Fuzhou 350002, China

**Corresponding author, e-mail: fjljf@126.com; Tel: +86 13003877896;*

First Author, HE Zhongsheng, e-mail: jxhzs85@126.com; Tel: +86 13067268912

Abstract: The objective of this study was to understand the effects of forest gap and variations in different seasons, gap size, locations and diurnal variations on forest microclimate and soil water content. Spatial and temporal distribution features of air temperature (T_A), soil temperature (T_S), relative humidity (h) and soil water content (Ψ) were measured in *Castanopsis kawakamii* natural forest gaps created by a severe typhoon or fallen dead trees. The results showed that: (1) the variations of T_A, h, and T_S in four seasons were extremely significant. The variations of Ψ in four seasons were extremely significant except for those between spring and summer. (2) The diurnal variations of T_A and T_S were expressed with a single peak curve. The diurnal variations of h and Ψ presented a high-low-high trend. (3) The variations of T_A, h, and T_S were extremely significant among the large, medium and small gaps in *C. kawakamii* natural forest. Medium gaps had the highest T_A and the lowest h while small gaps were just contrary to medium gaps. The variations of Ψ were extremely significant for large, medium and small gaps except those between the medium and large gaps. (4) The T_A, h, T_S and Ψ were decreased from the gap center, canopy gap, expanded gap to understory. These results will help further our understanding of the abiotic and consequent biotic responses to gaps in the mid-subtropical broadleaved forests, which also provide a theoretical basis for the scientific management and population restoration of *C. kawakamii* natural forest.

Received: 10 January 2012
Accepted: 20 May 2012

Keywords: *Castanopsis kawakamii*; Forest gaps; Air temperature; Relative humidity; Soil temperature; Soil water content; Evergreen broadleaved forest

Abbreviations: $\boldsymbol{T_A}$, air temperature; $\boldsymbol{T_S}$, soil temperature; $\boldsymbol{h}$, relative humidity; $\boldsymbol{\Psi}$, soil water content

Introduction

Forest gap plays a vital role in the dispersion of seed dispersal, seedling recruitment, species diversity, forest regeneration and habitat stability within forest ecosystems (McCarthy 2001; Hill et al. 2005; Shure et al. 2006). It strongly influences the forest dynamics, nutrient release, forest management and regeneration (Runkle 1990; McCarthy 2001; Prescott 2002). While many studies concentrate on forest structure, vegetation dynamics and nutrient cycling alone, microclimatic conditions also play an important role in ecological processes (Ritter et al. 2005). The most direct and important consequence of forest gap formation is to improve the light conditions of growth environment, and change the local environment temperature and humidity conditions (Gray et al. 1997; Härdtle et al. 2003; Ritter et al. 2005). Light increase within the forest gap results in the increase of air and soil temperature and thus affects environmental factors including the relative humidity and soil water content. Temporal and small-scale spatial variations of microclimates in and around forest gaps have been studied in different forest ecosystems (Peterken 1996; Splechtna et al. 2005; Ediriweera et al. 2008; Latif et al. 2010). As the forest gap studies vary in their study site conditions, it is difficult to make generalizations as the results may be contradictory. Case studies are necessary to enhance our understanding of the effects of forest gaps on microclimates and soil water content (Gray et al. 2002; Ritter et al. 2005). Further evidence is needed concerning the seasonal, diurnal dynamics of microclimates and the effects of gap sizes on the differences between forest gaps and forest understory.

Castanopsis kawakamii Hayata is one of the valuable and rare plants in the Southern China forest region, whose distribution is comparatively narrow, only in Fujian, Guangdong, Guangxi, and Taiwan, of China (Liu et al. 2009). With high species diversity and complex community structure, *C. kawakamii* natural forest in Fujian province of China is an almost pure forest with an area above 700 ha and a population age over 100 years, which is a transitional type between central and southern subtropical evergreen broadleaved forests (Liu et al. 2011a; He et al. 2011). Many scholars have launched a lot of research work relevant to *C. kawakamii* successively, which mainly focused on the community dynamics (Liu et al. 2003; Liu et al. 2009; Liu et al. 2011b; He et al. 2011), carbon balance (Yang et al. 2007; Yang et al. 2009) and nutrient cycling (Zhang et al. 1995a; Zhang et al. 1995b) in recent decades. These studies are an important documentation of patterns of succession in *C. kawakamii* natural forest ecosystem, and they have made vital contributions in natural forest management and conservation. However, this forest is in a decline stage, as a result of over mature population, species competition and human disturbance, leading to severe fragmentation in canopy layer and forest gaps. Considering the effects of microclimates on forest dynamics and succession, it is necessary and significant to conduct the studies about forest gaps in this area. All these characteristics would bring environmental differences in *C. kawakamii* natural forest gaps, thus affect the seed germination, the photosynthesis and growth of seedlings and samplings, and finally influence the restoration and regeneration of *C. kawakamii* population.

The main objective of this study was to study the effects of forest gaps on some microclimate variables, T_A, h, T_S and Ψ of the season dynamics, daily variations, different gap sizes and different locations in *C. kawakamii* natural forest. The authors also state the spatial and temporal distribution features of T_A, h, T_S and Ψ in *C. kawakamii* natural forest gaps, which will provide a foundation for further studies in *C. kawakamii* natural forest gaps and natural forest regeneration.

1 Materials and Methods

1.1 Study site and stand history

This study was conducted in *C. kawakamii* Natural Reserve, Sanming city, Fujian province of China (latitude 26°07'~26°12' N, longitude 117°24'~117°29' E), whose altitude is between 180~604 m (Figure 1). It borders Daiyun Mountain on the Southeast, with Wuyi Mountain on the

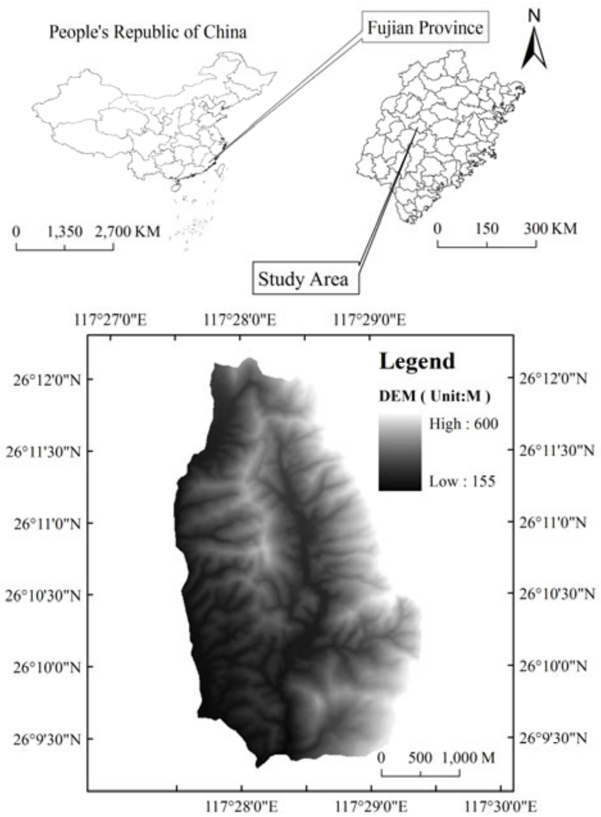

Figure 1 Geographic location of *C. kawakamii* nature reserve

Northwest. The region has a middle subtropical monsoonal climate, with a mean annual temperature of 19.5 °C (average of 40 years data collected from the Sanming Climatological bureau, China) and daily mean extremes of –5.5 °C and 40 °C. Annual precipitation is 1,500 mm, with 75% occurring between March and August. Annual average relative humidity is 79%, and mean velocity of wind is 1.6 m/s. Soil types under this climax natural forest vegetation are mainly dark-red earth type, and one of red earth and purple soil is the second. The soil thickness is greater than 1.0 m, and the soil layer has abundant humus and is rich in soil nutrition. The *C. kawakamii* Nature Reserve is a subtropical evergreen broadleaved forest dominated by over mature *C. kawakamii* (average age over 100 years), *Castanopsis carlesii*, *Pinus massoniana* and *Schima superba*, which is the largest and purest *C.kawakamii* natural forest. (Liu et al. 2009).

1.2 Forest gap and the measuring point selected

Forest gap sizes were calculated with elliptical method by using major and minor axis values (Runkle 1985). Forest gap sizes of 100 to 250 m^2 were categorized as small forest gaps, 250 to 400 m^2 as medium gaps, and above 400 m^2 as large gaps. Three small gaps, six medium gaps and three large gaps of microclimate variables were observed in the natural forest. Two observation sample lines were set along the S-N, E-W mutually vertical orientations within the gap central point in the forest gap. Considering the edge affect of the forest gap, six unequal interval observation points were set for each observation sample line, which were respectively located in the gap center (point 1), canopy gap (point 2, 3, 4, and 5), expanded gap (point 6, 7, 8, 9) and forest understory (point 10). Point 2 and 6, 3 and 7, 4 and 8, 5 and 9, respectively, represented canopy gap and expanded gap of east, south, west and north directions.

1.3 Measurement of ecological and environmental factors and data processing

Air temperature (T_A) and relative humidity (h) at 1.5 m above the soil surface, soil surface temperature (soil temperature 0, T_S 0), soil temperature at 5 cm below the soil surface (soil temperature 5, T_S 5) and soil temperature at 10 cm below the soil surface (soil temperature 10, T_S 10) and soil water content (Ψ) were measured in twelve natural forest gaps. We measured four seasons, each season measured 6-12 sunny days from 8:00 h to 18:00 h and recorded the microclimates per hour, as spring in March, summer in July, autumn in October and winter in December. The environmental variables were measured with TES-1360A handheld digital thermo-hygrometers, 6300 needle soil thermometer and TZS - IIW soil moisture and temperature measuring instrument, Magellan eXplorist 600 GPS, etc. The significant difference of T_A, h, T_S and Ψ was established by Pearson correlation statistics. All statistical tests were conducted in Excel 2003 and SPSS 11.5, and significant level was determined when $P < 0.05$.

2 Results

2.1 Microclimate variations of four seasons in *C. kawakamii* natural forest gaps

The variations of T_A and h in four seasons were extremely significant ($P < 0.01$). The difference between the highest and lowest T_A was 0.23 °C in spring, which was the largest change among four seasons, 0.17 °C in summer, 0.22 °C in autumn and 0.14 °C in winter, respectively. The difference between the highest and lowest h was 5.41% in spring, 1.29% in summer, 0.69% in autumn and 0.87% in winter. The highest and lowest T_A mostly occurred in the gap center and understory, respectively. In spring, T_A was the highest in gap centre and lowest in forest understory and h was highest in the south direction and lowest in the north direction of expanded gaps. In summer, T_A had a decline trend from the gap center to canopy gap, expanded gap and understory; h in gap center was the highest, whereas h in east-south directions was lower than the west-north directions of canopy gaps, mainly because of the gradually diminished direct solar radiation and small environmental heterogeneity. In autumn, T_A in east-north directions was much higher than the west-south

Table 1 The average T_A and h of four seasons in *C. kawakamii* natural forest gaps at 10 points

Season	T_A, h	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P9	P 10
Spring	T_A	24.85	24.81	24.74	24.64	24.75	24.75	24.77	24.65	24.75	24.62
	h (%)	49.91	52.07	50.19	52.57	48.98	48.60	53.95	48.78	48.54	48.86
Summer	T_A	31.34	31.34	31.29	31.24	31.21	31.31	31.27	31.23	31.19	31.17
	h (%)	70.99	69.86	69.70	70.25	70.64	70.30	69.92	70.36	70.11	70.46
Autumn	T_A	22.48	22.46	22.27	22.27	22.43	22.45	22.26	22.30	22.40	22.37
	h (%)	80.89	80.57	80.89	80.96	80.87	80.42	80.63	81.11	81.00	80.77
Winter	T_A	12.52	12.38	12.49	12.40	12.40	12.38	12.44	12.42	12.39	12.35
	h (%)	51.08	50.47	50.59	50.69	50.69	50.32	50.21	50.88	50.26	50.63

Notes: T_A as air temperature, h as relative humidity, the same below.

Table 2 The average T_S and Ψ of four seasons in *C. kawakamii* natural forest gaps at 10 points

Seasons	T_S, Ψ	P 1	P2	P 3	P 4	P 5	P 6	P 7	P 8	P9	P 10
Spring	T_S 0	19.45	19.39	19.10	19.08	19.13	19.25	19.00	18.86	18.91	18.80
	T_S 5	19.45	19.30	19.01	18.80	18.94	18.96	19.28	18.81	18.85	18.73
	T_S 10	19.11	18.90	18.66	18.70	18.73	18.77	18.92	18.58	18.52	18.60
	Ψ (%)	19.57	19.51	19.39	19.52	20.26	19.03	18.53	19.81	19.86	18.35
Summer	T_S 0	25.81	24.95	25.19	25.25	24.99	25.29	25.00	25.23	24.98	24.96
	T_S 5	26.63	26.21	26.07	26.11	25.97	26.11	25.98	26.21	25.93	25.99
	T_S 10	25.96	25.68	25.54	25.53	25.42	25.53	25.45	25.65	25.37	25.43
	Ψ (%)	20.62	18.96	19.35	20.21	19.19	18.95	19.20	19.44	18.82	19.31
Autumn	T_S 0	21.04	21.05	20.97	21.04	21.01	21.03	21.04	20.99	21.03	20.97
	T_S 5	21.12	21.16	21.10	21.16	21.16	21.13	21.20	21.13	21.15	21.08
	T_S 10	20.95	20.84	20.92	20.98	20.87	20.97	21.02	20.99	20.98	20.92
	Ψ (%)	10.96	10.34	10.67	10.42	9.12	10.27	9.80	9.22	9.35	9.95
Winter	T_S 0	11.14	11.37	11.40	11.37	11.31	11.44	11.37	11.58	11.30	11.46
	T_S 5	11.69	12.01	11.92	11.87	11.83	12.10	11.91	12.22	11.86	12.04
	T_S 10	12.28	12.62	12.47	12.48	12.39	12.76	12.56	12.84	12.45	12.62
	Ψ (%)	13.92	12.84	12.68	13.90	12.95	13.76	13.77	13.25	12.23	13.23

Notes: T_S 0 as soil temperature 0, T_S 5 as soil temperature 5, T_S 10 as soil temperature 10, Soil water content as Ψ, the same below.

directions in canopy gaps and expanded gaps; h in east direction was lower than the west-north directions in canopy gaps and expanded gaps. In winter, T_A in east direction of canopy gaps and expanded gaps was higher than other directions; h in gap center was the highest, which was 51.08%; h in canopy gaps was higher than that in expanded gaps. (Table 1)

The changes of T_S in three soil layers of *C. kawakamii* natural forest gaps were T_S 0 > T_S 5 > T_S 10 in spring, T_S 5 > T_S 10 > T_S 0 in summer, T_S 5 > T_S 0 > T_S 10 in autumn and T_S 10 > T_S 5 > T_S 0 in winter, respectively. Soil water content (Ψ) in spring and summer were higher than that of autumn and winter. In spring, T_S0, T_S 5 and T_S 10 were the highest in the gap center, whereas T_S 0, T_S 5 were the lowest in forest understory; Ψ in north direction of canopy gaps was the highest (20.26%) and in forest understory the lowest (18.35%); T_S10 was significantly lower than T_S 0 and T_S 5 (P < 0.01). In summer, the variations of T_S 0, T_S 5 and T_S 10 were the largest among four seasons; T_S 0, T_S 5 and T_S 10 were the highest in gap center and the lowest in forest understory or north direction of expanded gaps; Ψ in gap center was the highest (20.62%) and in north direction of expanded gaps the lowest (18.82%); T_S 5 and T_S 10 were significantly higher than T_S0 (P < 0.01). In autumn, T_S 0 and T_S 5 changed gently and kept a stable tendency, while T_S 10 presented some certain volatility; T_S 0, T_S 5 and T_S 10 were the lowest in forest understory; Ψ in the gap center was the highest (10.96%) and in north direction of canopy gaps the lowest (9.12%); the difference between T_S 5 and T_S10 was extremely significant (P < 0.01). In winter, T_S 0, T_S 5 and T_S 10 in the west direction of expanded gaps were the highest and gaps center the lowest; Ψ in gap center was the highest and in forest understory the lowest. T_S 0 and T_S 5 were significantly lower than T_S 10 (P < 0.01). There were extremely significant differences among T_S0, T_S5 and T_S10 due to effects of seasons (P < 0.01). Highly significant differences of Ψ existed among four seasons except for spring and summer (P < 0.01). (Table 2)

2.2 Diurnal microclimate variations in *C. kawakamii* natural forest gaps

Diurnal variations of T_A could be fitted with a single peak convex curve, which were highly significant in a day (P < 0.01). By contrast, diurnal variations of h appeared in a single peak concave curve (Figure 2). T_A was low in the morning and evening and reached the maximum peak at noon. T_A tended to increase rapidly from 8:00 h to 13:00 h, and then reached the peak at 15:00 h, after which T_A decreased gradually. Relative humidity was relatively high in the morning and evening and reached the minimum peak at 14:00 h. Relative humidity tended to decrease rapidly from 8:00 h to 12:00 h, and then decreased slowly till 16:00 h, after which h rose gradually.

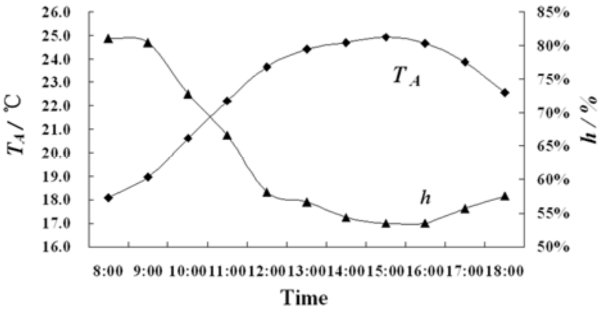

Figure 2 Diurnal variations of average T_A and h in *C. kawakamii* natural forest gaps

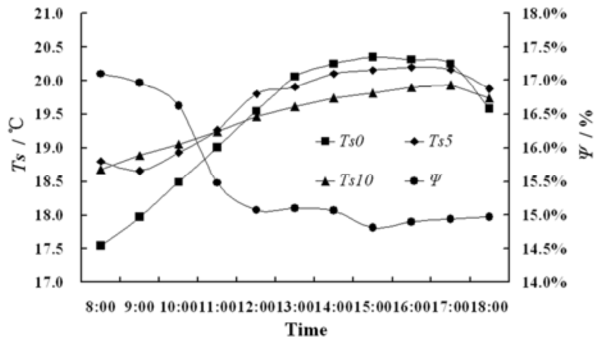

Figure 3 Diurnal variations of average T_S and Ψ in *C. kawakamii* natural forest gaps

Diurnal variations of T_S in three layers presented a single peak convex curve, which were highly significant in a day (P < 0.01). By contrast, diurnal variations of Ψ appeared in a single peak concave curve (Figure 3). T_S reached the maximum peak in the afternoon and stayed low in the morning and evening. T_S in three soil layers showed as T_S 10 > T_S 5 > T_S0 from 8:00 h to 11:00 h, which indicated that soil had heat preservation effect. T_S increased gradually from 11:00 h to 13:00 h; from 13:00 h to 17:00 h, T_S0 was the highest in three layers, next came the T_S 5 and T_S 10; after 17:00 h T_S0 decreased more rapidly than T_S 5 and T_S 10. Ψ was relatively high in the morning and evening and reached the minimum peak at 15:00 h. Ψ tended to decrease rapidly from 8:00 h to 12:00 h, and then decreased slowly till 15:00 h, after 15:00 h it rose gradually.

2.3 Microclimate variations in different size gaps of *C. kawakamii* natural forest

There were highly significant differences for T_A and h among different size gaps in *C. kawakamii* natural forest ($P < 0.01$). Average T_A in medium gaps was the highest (26.88 °C), the next was in large gaps (26.00 °C) and the last was in small gaps (25.38 °C). Average h in small gaps was the highest (69.88%), the next was in large gaps (66.62%) and the last was in medium gaps (63.99%). In large gaps, T_A in east-north directions was higher than that in south-west directions; h was the highest in gap centre and relatively low in south-east directions. In medium gaps, T_A was the highest in gap centre and the lowest in understory; h was the highest in west direction and the lowest in east direction of canopy gaps. In small gaps, T_A was relatively high in south-east directions of canopy gaps and low in north direction of expanded gaps; h was the highest in gap centre and the lowest in north direction of expanded gaps. (Table 3)

T_S and Ψ varied with different gap sizes. T_S in large gaps and medium gaps presented gradient variation in the order of T_S 0 > T_S 5 > T_S 10, and small gaps T_S 10 > T_S 5 > T_S 0. T_S in the same layer and Ψ in different size gaps had differences in *C. kawakamii* natural forest. The changes of T_S 0 of different size gaps were medium gaps > large gaps > small gaps; T_S 5 and T_S 10 in medium gaps were the highest. Average Ψ in small gaps was the highest (18.03%), the next was in middle gaps (15.33%) and the last was in large gaps (15.22%). T_S 0, T_S 5, T_S 10 and Ψ in large gaps were the highest in gap centre and Ψ was the lowest in forest understory. T_S 0, T_S 5 and T_S 10 in medium gaps were relatively high in the south direction of expanded gaps and that in forest understory were the lowest; Ψ was the highest in forest understory. T_S 0, T_S 5 and T_S 10 in small gaps were the highest in gap centre; Ψ was the highest in the west direction of canopy gaps and lowest in the north direction of expanded gaps. (Table 4)

Table 3 The average T_A and h in different size gaps of *C. kawakamii* natural forest at 10 points

Gaps	T_A, h	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10
Large	T_A	26.07	26.05	25.85	25.99	26.03	26.11	25.94	25.88	26.07	25.98
	h (%)	67.09	66.84	66.33	66.71	66.99	66.25	66.24	66.57	66.69	66.46
Medium	T_A	26.96	26.95	26.91	26.93	26.87	26.83	26.81	26.89	26.85	26.81
	h	64.02	63.34	63.72	64.40	63.88	64.15	64.24	63.93	63.85	64.36
Small	T_A	25.33	25.46	25.43	25.39	25.31	25.39	25.39	25.41	25.31	25.34
	h (%)	71.03	69.56	69.85	70.02	69.93	69.34	69.76	70.30	69.36	69.62

Table 4 The average T_S and Ψ in different size gaps of *C. kawakamii* natural forest at 10 points

Gaps	T_S, Ψ	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10
Large	T_S 0	20.31	19.93	19.47	19.64	19.63	22.16	19.42	19.42	19.61	19.62
	T_S 5	19.95	19.69	19.35	19.34	19.60	19.67	19.27	19.33	19.46	19.43
	T_S 10	19.89	19.59	19.40	19.49	19.61	19.68	19.26	19.48	19.51	19.49
	Ψ (%)	16.13	16.50	14.85	16.03	15.22	14.87	14.59	15.15	14.64	14.34
Medium	T_S 0	19.81	19.78	19.68	19.73	19.68	19.68	19.89	19.83	19.53	19.42
	T_S 5	19.72	19.76	20.14	19.60	19.57	19.63	19.73	19.77	19.47	19.44
	T_S 10	19.49	19.50	19.37	19.42	19.39	19.50	19.54	19.55	19.33	19.31
	Ψ (%)	15.91	14.58	15.50	15.49	15.21	15.82	15.14	15.11	14.96	15.56
Small	T_S 0	18.45	17.87	18.22	18.14	17.97	18.17	18.43	18.11	18.03	18.17
	T_S 5	19.61	19.50	19.47	19.42	19.26	19.43	19.58	19.55	20.48	19.52
	T_S 10	19.50	19.43	19.39	19.36	20.60	19.39	19.52	19.51	19.18	19.44
	Ψ (%)	16.66	15.98	16.23	17.04	15.88	15.48	16.43	16.34	14.80	15.42

According to the significance test of soil temperature in three layers, there were highly significant differences among T_S0 of different size gaps (P < 0.01). T_S5 in medium gaps had highly significant differences compared with T_S5 of large gaps and small gaps (P < 0.01); T_S0 and T_S5 were significantly higher than T_S10 in large gaps; highly significant differences were observed in T_S0, T_S5 and T_S10 in medium gaps (P < 0.01); highly significant differences were found between T_S5, T_S10 and T_S0 in small gaps (P < 0.01). Ψ had highly significant difference among the small gaps and medium gaps, large gaps (P < 0.05).

2.4 Microclimate variations in different locations of *C. kawakamii* natural forest gaps

T_A, h, T_S in three layers and Ψ in different locations of *C. kawakamii* natural forest gaps was gradually decreased from gap center, canopy gap, expanded gap to understory (Figures 4 and 5). T_A, h, T_S in three layers and Ψ in gap centre were the highest and in forest understory the lowest, whereas, microclimates in canopy gap and expanded gap experienced smoother changes. Microclimates in forest gaps could be affected by the temperature, vegetation, solar radiation and gaps shape, etc., which led to a regular pattern.

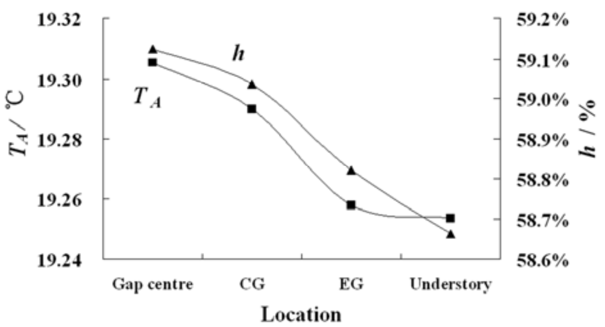

Figure 4 The average T_A and h in different locations of *C. kawakamii* natural forest gaps

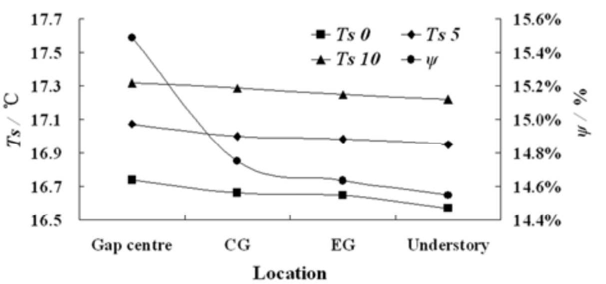

Figure 5 The average T_S and Ψ in different locations of *C. kawakamii* natural forest gaps

3 Discussion and Conclusion

Gap disturbance opens space and releases resources that develops nutrition availability, initiate vegetation succession and facilitate population regeneration (DeChantal et al. 2003; Kuuluvainen 1994; McGuire et al. 2001). Previous studies in temperate forests found that microclimate conditions such as air and soil temperature, relative humidity and soil water content were directly influenced by the formation of gaps (Abd Latif et al. 2010; Galhidy et al. 2006; Heithecker and Halpern 2006). Our research in the subtropical forest of *C. kawakamii* natural forest also supported these findings. Microclimates in *C. kawakamii* natural forest gaps had distinct spatial and temporal differences due to influences of different solar radiation in four seasons and different crown inclination ratio of gap border trees. Factors affecting the soil temperature in different seasons include the micro-topographic variability and vegetation types in forest gap and understory (Schmidt et al. 1998). Moreover, the seasonal variation of soil temperature and soil water content could affect the respiratory activities of roots, and soil microorganisms vary during the year, especially in autumn (Lavigne et al. 2004).

T_A and T_S in forest gaps were influenced directly by the amount and duration of solar radiation received. T_A was the highest and h the lowest in medium gaps in *C. kawakamii* natural forest. By contrast, T_A was the lowest and h the highest in small gaps. As T_A rose, both of the vapor pressure and saturation vapor pressure increased, whereas saturation vapors pressure rose faster than the vapor pressure, which led to the decrease of h and the increase of T_A. These findings can probably be attributed to the greater proportion of direct radiation reaching the centre of the medium gaps and large gaps, whereas, in smaller gaps, solar radiation was predominantly diffused or being transmitted through the canopy gap and expanded gap edge, leading to more gradual and less extreme changes in environmental factors. Similar findings were reported in a semi-natural deciduous forest (Ritter et al. 2005) and a mixed temperate broadleaved deciduous forest (Abd Latif et al. 2010). The results showed that medium gaps were affected mostly by environmental factors compared with small gaps and large gaps. Medium gaps, which could be exhibited more effectively the heterogeneity of microclimates in forest gaps, played a vital role in the mechanism of forest population regeneration.

T_A, h, T_S 0, T_S 5, T_S 10 and Ψ in different locations of *C. kawakamii* natural forest gaps was gradually decreased from the gap center, canopy gap, expanded gap to understory, coincided well with the findings in the deciduous forest (Ritter et al. 2005) and the moist tropical forest (Veenendaal et al. 1995), which could be the differences of solar radiation, wind interference and gas heat exchange in different locations.

The spatial and temporal characteristics of microclimates (T_A, h, T_S 0, T_S 5, T_S 10 and Ψ) were heterogeneous in *C. kawakamii* natural forest gaps, which led to abundant ecological differentiation, rich variety of forest cover and various coexistence of forest species, which may directly affect the seed germination, seedling photosynthesis and growth, soil physical and chemical properties and microbe activities in forest gaps. This study has provided some useful evidence concerning the formation of forest gaps on microclimates and soil water content in a mid-subtropical broadleaved forest and this knowledge is valuable for assessing the implications of *C. kawakamii* population for forest restoration and regeneration. Hence, more attention should be paid to microenvironment response to species diversity and succession.

Acknowledgements

This study was supported by the Key Program of Natural Science Foundation of Fujian Province of China (Grant No. 2008J0008), Doctoral Fund of Ministry of Education of China (Grant No. 200803890011) and China Postdoctoral Science Foundation (Grant No. 20070410796).

The authors wish to thank FU Daliang, NIU Jie and SHI Yingxing, as well as LIN Shan and LIN Yijun for the assistance in the field work. We also thank Professor WU Zujian and PAN Dongming for encouragement, helpful discussions and valuable suggestions during the preparations of the manuscript. Special thanks to Terrence Andrew Drury to improve the English of the manuscript. The authors also express sincere appreciation for helpful and constructive comments made by two anonymous reviewers.

References

Latif ZA, Blackburn GA (2010) The effects of gap size on some microclimate variables during late summer and autumn in a temperate broadleaved deciduous forest. International Journal of Biometeorology 54 (2): 119-129.

de Chantal M, Leinonen K, Kuuluvainen T, Cescatti A (2003) Early response of *Pinus sylvestris* and *Picea abies* seedlings canopy gap in a boreal spruce forest. Forest Ecology and Management 176: 321-336.

Ediriweera S, Singhakumara BMP, Ashton MS (2008) Variation in canopy structure, light and soil nutrition across elevation of a Sri Lankan tropical rain forest. Forest Ecology and Management 256(6): 1339-1349.

Gálhidy L, Mihók B, Hagyó A, Rajkai K, Standovár T (2006) Effects of gap size and associated changes in light and soil moisture on the understorey vegetation of Hungarian beech forest. Plant Ecology 183: 133-145.

Gray AN, Spies TA (1997) Micro-site controls on tree seedling establishment in conifer forest canopy gaps. Ecology 78(8): 2458-2473.

Gray AN, Spies TA, Easter MJ (2002) Microclimate and soil moisture responses to gap formation in coastal Douglas-fir forests. Canadian Journal of Forest Research 32: 332-343.

Härdtle W, Oheimb G, Westphal C (2003) The effects of light and soil conditions on the species richness of the ground vegetation of deciduous forests in northern Germany (Schleswig-Holstein). Forest Ecology and Management 182(1-3): 327-338.

He ZS, Liu JF, Hong W, Zheng SQ, Wu CZ, Wu ZY, Niu J, Lin YJ (2011) Study on the seedlings competition intensity in a mid-subtropical *Castanopsis kawakamii* nature forest. Journal of Tropical and Subtropical Botany 19 (3): 230-236. (In Chinese)

Heithecker TD, Halpern CB (2006) Variation microclimate associated with dispersed-retention harvests in coniferous forests of western Washington. Forest Ecology and Management 226: 60-71.

Hill SB, Mallik AU, Chen HYH (2005) Canopy gap disturbance and succession in trembling aspen dominated boreal forests in northeastern Ontario. Canadian Journal of Forest Research 35(8): 1942-1951.

Kuuluvainen T (1994) Gap disturbance, ground microtopography, and the regeneration dynamics of boreal coniferous forests in Finland: a review. Annales Zoologici Fennici 31: 35-51.

Lavigne MB, Foster RJ, Goodine G (2004) Seasonal and annual

changes in soil respiration in relation to soil temperature, water potential and trenching. Tree Physiology 24: 415-424.
Liu JF, He ZS, Hong W, ZHENG SQ, WANG ZJ (2011) Conservation ecology of endangered plant *Castanopsis kawakamii*. Journal of Beijing Forestry University 33 (5): 136-143. (In Chinese)
Liu JF, Hong W, Li JQ, Yang WH (2003) Gap natural disturbance regime in the *Castanopsis kawakamii* forest. Acta Ecological Sinica 23(10): 1991-1999. (In Chinese)
Liu JF, Hong W, Pan DM, Li JQ, Wu CZ (2009) A study on multidimensional time series model of individual age's measurement in *Castanopsis kawakamii* population. Acta Ecological Sinica 29 (4): 232-236.
Liu JF, Su SJ, He ZS, Hong W, Wu CT, Dong JX, Li LZ (2011) Spatial distribution and influencing factors of soil organic carbon in Mid-subtropical *Castanopsis kawakamii* Natural Forest. Journal of Mountain Science 29 (6): 647-652. (In Chinese)
McCarthy J (2001) Gap dynamics of forest trees: A review with particular attention to boreal forests. Environmental Reviews 9(1): 1-59.
McGuire JP, Mitchell RJ, Moser EB, Pecot SD, Gjerstad DH, Hedman CW (2001) Gaps in a gappy forest: plant resources, longleaf pine regeneration, and understory response to tree removal in Longleaf pine savannas. Canadian Journal of Forest Research 31:765-778.
Peterken GF (1996) Natural woodland. Cambridge University Press, Cambridge. pp 91-95.
Prescott CE (2002) The influence of the forest canopy on nutrient cycling. Tree Physiology 22: 1193-1200.
Ritter E, Dalsgaard L, Einhorn, KS (2005) Light, temperature and soil moisture regimes following gap formation in a semi-natural beech-dominated forest in Denmark. Forest Ecology and Management 206(1-3): 15-33.
Runkle JR (1981) Gap regeneration in some old-growth forests of eastern United States. Ecology 62(4): 1041-1051.
Schmidt MG, Ogden AE, Lertzman KP (1998) Seasonal comparison of soil temperature and moisture in pits and mounds under vine maple gaps and conifer canopy in a Coastal Western Hemlock Forest. Canadian Journal of Soil Science 78: 291-300.
Shure DJ, Phillips DL, Bostick PE (2006) Gap size and succession in cutover southern Appalachian forests: an 18 year study of vegetation dynamics. Plant Ecology 185: 299-318.
Splechtna BE, Gratzer G, Black BA (2005) Disturbance history of a European old-growth mixed-species forest-a spatial dendro-ecological analysis. Journal of Vegetation Science 16: 511-522.
Veenendaal EM, Swaine VK, Agyeman DB, Abebrese I K, Mullins CE (1995) Differences in plant and soil water relations in and around gap in West Africa during the dry season may influence seedling establishment and survival. Journal of Ecology 83: 83-90.
Yang YS, Chen GS, Guo JF, Xie JS, Wang XG (2007) Soil respiration and carbon balance in a subtropical native forest and two managed plantations. Plant Ecology 93: 71-84.
Yang YS, Guo JF, Chen GS, Yin YF, Gao R, Lin CF (2009) Effects of forest conversion on soil labile organic carbon fractions and aggregate stability in subtropical China. Plant and Soil 323: 153-162.
Zhang QS, Liang YW (1995a) Effects of gap size on nutrient release from plant litter decomposition in a natural forest ecosystem. Canadian Journal of Forest Research 25: 1627-1638.
Zhang QS, Zak JC (1995b) Effects of gap size on litter decomposition and microbial activity in a subtropical forest. Ecology 76: 2196-2204.