Spatiotemporal distribution pattern of soil temperature in forest gap in *Pinus koraiensis*-dominated broadleaved mixed forest in Xiao Xing'an Mountains, China

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Abstract

By using regular grid and transect methods, plot and sub-plots were established in the forest gap of *Pinus koraiensis*-dominated broadleaved mixed forests in Xiao Xing'an Mountains, China. The surfacial, maximum and minimum temperature(T_s, T_{max}, and T_{min}), and the temperature at 5, 10, 15, and 20cm soil depths were measured from May to September 2006 to illustrate their spatiotemporal distribution patterns. The results showed that high-value regions of daily T_s were not at the gap center, but at north-western and eastern sides of the gap, with an asymmetric distribution. Their mean difference between daily T_{max} and T_{min} was bigger in the trees early and late growth periods, but relatively smaller in fast growth period. As for daily and monthly mean soil temperatures over soil depths, a bimodal behavior was observed in east-west direction. Daily and monthly mean temperature exhibited no apparent and single peak behavior in north-south direction, except in May, respectively.

Key Words

Pinus koraiensis-dominated broadleaved mixed forest, forest gaps, soil temperature, distribution pattern.

Introduction

Forest gaps exist widely in forest ecosystems, are in an important phase of forest cycle regeneration. Environmental heterogeneity caused by gap formation, its impact on species distribution, population dynamics and species diversity in forest gaps, and its important roles in forest succession, regeneration and growth have been widely concerned (Poulson and Platt 1989; Beckage *et al.* 2000; Fownes and Harrington 2004; Pedersen and Howard 2004; Diaci *et al.* 2005). Microclimatic difference between and within canopy gaps (De Freitas and Enright 1995), light index and its application in Sweden (Dai 1996), microclimate (Carlson and Groot 1997), states of partially microclimatic factors after gap formation and soil moisture response (Canham *et al.* 1990; Gray *et al.* 2002; Clinton 2003; Raymond *et al.* 2006) were systematically performed. Over the past decade, our researches on forest gaps gradually increased in China (Zang RG *et al.* 1999), but so far, those on microclimate in gaps have been not yet fully developed, particularly on spatiotemporal distribution patterns of soil temperature after gap formation is still rare. Only a fewer researchers investigated the microclimate in gaps, their researches mainly dealt with light, spatiotemporal distributions of air and soil temperature (Zang RG *et al.* 1999; Zhang YP *et al.* 2001)) as well as other microclimatic factors (Liu WJ *et al.* 2000a; Zhang YP *et al.* 2002, 2003; Zhu JJ *et al.* 2007), and microclimatic difference (Liu WJ *et al.* 2000b). However, studies on spatiotemporal distribution of soil temperature are still scarce (Zhang YP *et al.* 2001; Zhu JJ *et al.* 2007). In vast temperate regions, studies on the changes in soil temperature after gap formation are even rarer (Li Y *et al.* 2007; Zhu JJ *et al.* 2007). Therefore, measurement plot and sub-plots were established, spatiotemporal distribution pattern of soil temperature in this forest gap was analyzed in order to provide basic data for researches on environmental heterogeneity and regeneration in canopy gaps, sustainable ecosystem management.

Materials and methods

Study site and experimental design

Investigations were performed from May to September 2006 in a gap created naturally in *Pinus koraiensis*-dominated broadleaved mixed forests in Xiao Xing'an Mountains, in Liangshui National Nature Reserve (47°06′49″–47°16′10″N, 128°47′8″–128°57′19″E) of Northeast Forestry University, in Dailing District, Yichun City, Heilongjiang Province, China. For a more in-depth description of this Reserve, see Duan *et al.* (Duan *et al.* 2009). The study site is located in broad-leaved *Pinus koraiensis* forests at an elevation of 420 m, with negative slope, a slope grade of 10–15°, a northern aspect. The plot area was 20 m×20 m. Canopy gap was irregularly shaped with about 200 m^2 area, naturally created by multiple gap-makers at unknown time in the past. The reason for gap formation is more complicated, such as breakdown, snag, and tree-fallen. Tree species surrounding the gap boundary are mainly *Pinus koraiensis* and *Betula costata* with their average height of 17.5 m. For the details of this site, see Duan *et al.* (Duan *et al.* 2009). Measurements done from May to September 2006 in this study area included surfacial, maximum and minimum temperature in a grid design (Figure 1), and the temperature at 5, 10, 15, and 20 cm soil depths along two perpendicular transects (Figure 2).

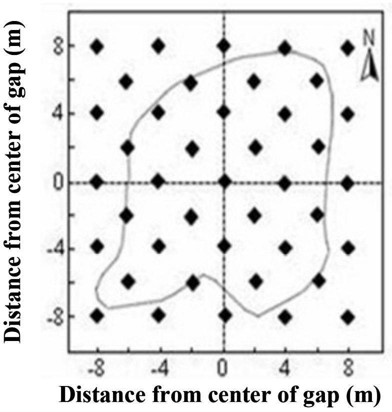

Figure 1. Locations of measurement plots of T_s, T_{max} and T_{min}. The black line indicates the approximate contour of the gap.

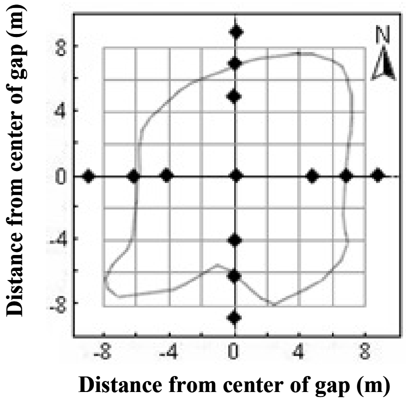

Figure 2. Locations of measurement plots of soil temperature at 5, 10, 15, and 20 cm soil depth. The black line indicates the approximate contour of the gap.

Soil temperature measurements

41 locations of measurement sub-plots were selected in the forest gap and around its edge by using regular grid and transect methods, surfacial, maximum and minimum thermometer were placed at each location (Figure 1). Other 13 locations of measurement sub-plots were located at gap center (GC), gap edge (GE), expanded gap edge (EG), understory (US) along two transects running North-South and West-East directions through gap center. Bended-tube thermometers were installed in each location to measure the temperature at 5, 10, 15, and 20cm soil depths (Figure 2). Measurement was done from 6:00h to 18:00h for 6-10 days monthly, time interval was 2 hours.

Data progressing

Soil temperature, which was not directly measured in other locations in the gap, was assessed by estimation of spatially local Kriging interpolation from geographical statistics (Wang SP *et al.* 2003). SPSS 11.5 and GS+For Windows 3.11 softwares were used for basically and spatially statistical analysis on the data, respectively. SURFER 7.0 software (Golden Software 1999) was used for estimation of spatially local Kriging interpolation and further mapping of soil temperature.

Results

Spatiotemporal distribution pattern of soil temperature in forest gap

Daily spatial distribution pattern of soil surface temperature in forest gap

Daily spatial distribution pattern of T_s in forest gap in July was set as an example (Figure 3). In general, within a day, the high-value region of T_s happened with the sequence of north-western, northern and eastern sides of the gap, T_{max} within the high-value region was 27.0 ^oC (14:00h)$>$25.0 ^oC (12:00h)$>$23.0 ^oC (10:00h)$>$22.0 ^oC (16:00h).

Monthly spatial distribution pattern of soil surface temperature in forest gap

For the distribution of T_s, all high-value regions in months appeared in eastern side of the gap, but their T_{max} was different, relatively higher from June to August; the secondary high-value regions occurred in northwestern side of the gap every month, but their gradients were all smaller. All high-value regions of T_s were not in the central gap, but in eastern and northwestern side of the gap, their distribution was asymmetric (Figure 4).

Spatiotemporal distribution pattern of difference between daily Tmax and Tmin in forest gap

In the early growing season (May), the diurnal range of T_s was bigger, reached 21.0 ^oC in northwestern side of the gap (Figure 5). That was smaller from June to August than that in May, there was a decreasing tendency; while in the late growing season, it was larger in September than in August. Comparatively higher mean difference between daily T_{max} and T_{min} in our study area was all located in northwestern and eastern side of the gap.

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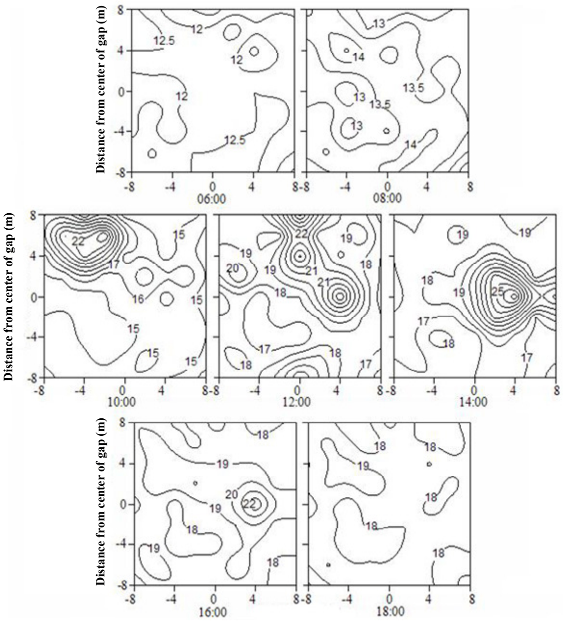

Figure 3. Diurnal spatial distribution pattern of soil surface temperature in the gap (□).

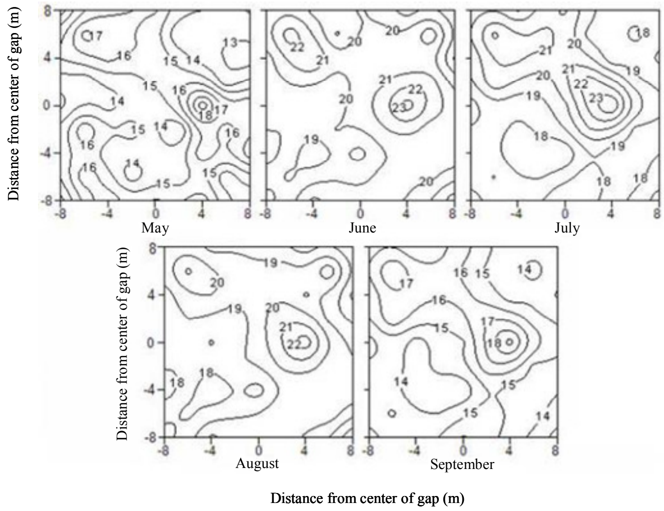

Figure 4. Monthly spatial distribution pattern of soil surface temperature in the gap (□).

Soil temperature along different directions in forest gap

The diurnal variation in soil temperature along different directions

A bimodal behavior of soil temperature at all locations was observed in east-west direction (Figure 6), their bimodal values were respectively located in expanded gap edge in western side and in canopy gap edge in eastern side; An unapparent single peak behavior at all locations was found in north-south direction, the positions of their bimodal values changed weakly over time and shifted between in canopy gap edge in northern side and in the center of gap, but in general, the soil temperature in northern side was larger than that in southern side. By contrast, it was comparatively smaller under understory. The magnitude of change in soil temperature at 5 cm depth was the highest (2 ~7 ^{o}C) in daytime, the lowest at 20cm depth (0 ~2 ^{o}C).

The monthly variation in soil temperature along different directions

Generally, a bimodal behavior was observed in east-west direction every month (Figure 7), bimodal values occurred in gap edge in eastern side and in expanded gap edge in western side, respectively, bimodal value in the eastern side was larger than that in western side. Monthly mean soil temperatures except in May in north-south direction exhibited an unapparent single peak behavior, bimodal value appeared in the central gap and in expanded gap edge in northern side over time, and meanwhile soil temperature in northern side was slightly higher than that in southern side.

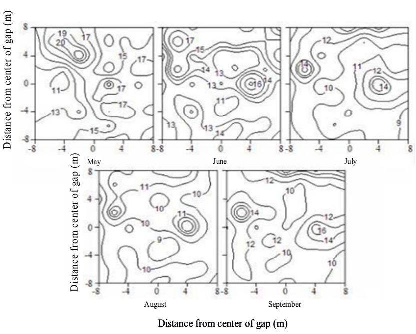

Figure 5. Spatial distribution of difference between daily Tmax and Tmin in the gap.

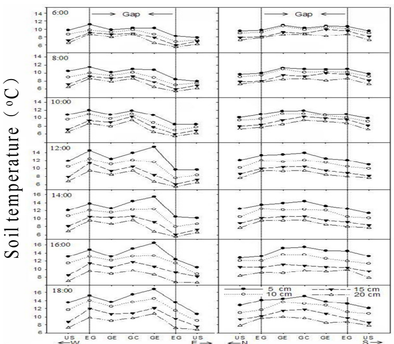

Figure 6. Diurnal variation of soil temperature at different directions in the gap.

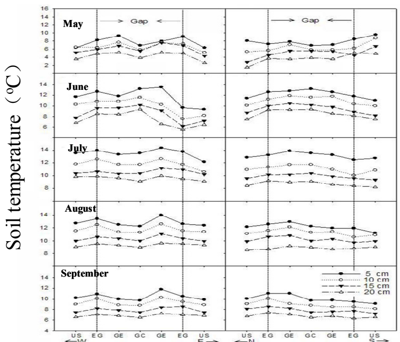

Figure 7. Monthly variation of soil temperature at different directions in the gap.

Conclusion

For the high-value regions of T_s in the gap, there was apparent diurnal variation, with the sequence of north-western, northern and eastern sides of the gap, those were all located in north-western and eastern side with an asymmetric distribution every month; Mean difference between daily T_{max}-T_{min} was larger in the tree's early and late growth periods, but relatively smaller in fast growth period. Comparatively higher diurnal range was all in north-eastern and eastern side of the gap; As for daily and monthly mean soil temperatures at 5, 10, 15, and 20 cm depths, a bimodal behavior was observed in east-west direction, daily bimodal values were respectively located in expanded gap edge in western side and canopy gap edge in eastern side, monthly bimodal values occurred in gap edge in eastern side and expanded gap edge in western side, respectively; Daily and monthly mean temperature exhibited no apparent and single peak behavior in north-south direction, except in May, respectively.

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References
Beckage B, Clark JS, Clinton BD *et al.* (2000) A long-term study of tree seedling recruitment in southern Appalachian forests: The effects of canopy gaps and shrub understories. *Canadian Journal of Forest Research* **30,** 1617-1631
Canham CD, Denslow JS, Platt WJ *et al.* (1990) Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. *Canadian Journal of Forest Research* **20,** 620-631
Carlson DW, Groot A (1997) Microclimate of clear-cut, forest interior, and small opening in trembling aspen forest. *Agricultural and Forest Meteorology* **87,** 313-329
Clinton BD (2003) Light, temperature, and soil moisture responses to elevation, evergreen understory, and small canopy gaps in southern Appalachians. *Forest Ecology and Management* **186,** 234-255
Dai XB (1996) Influence of light condition in canopy gaps on forest regeneration: A new gap light index and its application in a boreal forest in east-central Sweden. *Forest Ecology and Management* **84,** 187-197
De Freitas CR, Enright NJ (1995) Microclimatic difference between and within canopy gaps in a temperate rainforest. *International Journal of Biometeorology* **38,** 188-193
Diaci J, Pisek R, Boncina A (2005) Regeneration in experimental gaps of subalpine *Picea abies* forest in the Slovenian Alps. *European Journal of Forest Research* **124,** 29-36
Duan WB, Wang J, Li Y (2009) Microenvironmental heterogeneity of physical soil properties in a broad-leaved Pinus koraiensis forest gap. *Frontiers of Forestry in China* **4**, 38–45
Fownes JH, Harrington RA (2004) Seedling response to gaps: Separating effects of light and nitrogen. *Forest Ecology and Management* **203,** 297-310
Gray AN, Spies TA, Easter MJ (2002) Microclimatic and soil moisture response to gap formation in coastal Douglas-fir forests. *Canadian Journal of Forest Research* **32,** 332-343
Golden Software (1999) 'Surfer 7® —A Program for Contouring and 3D Surface Mapping for Scientists and Engineers'. (Golden, Colorado).
Li Y, Duan WB, Chen LX *et al.* (2007) Microenvironmental variation feature of soil surface temperature in a broad-leaved Korean pine forest gap. *Science of Soil and Water Conservation* **5,** 81-85 (in Chinese)
Liu WJ, Li QJ, Zhang GM *et al.* (2000a) Microclimatic characteristics of canopy gaps in *Shorea chinensis* forest in Xishuangbanna. *Chinese Journal of Plant Ecology* **24**, 356-361 (in Chinese)
Liu WJ, Li QJ, Zhang GM *et al.* (2000b) The microclimatic differences between and within canopy gaps in the dry-hot season in *Shorea chinensis* forest. *Acta Ecologica Sinica* **20**, 932-937 (in Chinese)
Pedersen BS, Howard JL (2004) The influence of canopy gaps on overstory tree and forest growth rates in a mature mixed-age, mixed-species forest. *Forest Ecology and Management* **196,** 351-366
Poulson TL, Platt WJ (1989) Gap light regimes influence canopy tree diversity. *Ecology* **70,** 553-555
Raymond P, Munson AD, Ruel JC *et al.* (2006) Spatial patterns of soil microclimate, light, regeneration, and growth within silvicultural gaps of mixed tolerant hardwood-white pine stands. *Canadian Journal of Forest Research* **36,** 639-651
Zang RG, Liu JY, Dong DF (1999) Gap Dynamics and Forest Biodiversity. Beijing: China Forestry Press, (in Chinese)
Zhang YP, Dou JX, Ma YX *et al.* (2003) Temporal-spatial distribution characteristics of microclimate in tropical secondary forest canopy gap in Xishuangbanna**.** *Chinese Journal of Applied Ecology* **14**, 2129-2135 (in Chinese)
Zhang YP, Ma YX, Liu YH *et al.* (2001) Characteristics of spatial distribution of microclimate in the gap of ever-green broad-leaved forest in the north of Ailao Mountain in Yunnan**.** *Journal of Beijing Forestry University* **23**, 80-83 (in Chinese)
Zhang YP, Wang JX, Ma YX *et al.* (2002) The temporal-spatial distribution of temperature on the surface roughtness of the tropical secondary gap in Xishuangbanna, Yunnan Province. *Scientia Silvae Sinicae* **38**, 1-5 (in Chinese)
Zhu JJ, Tan H, Li FQ *et al.* (2007) Microclimate regimes following gap formation in a montane secondary forest of eastern Liaoning Province, China. *Journal of Forestry Research* **18**, 167-173
Wang SP, Sun ZQ, Wu J *et al.* (2003) Spatial heterogeneity of characteristic functional parameter of soil water movement: Mathematical approaches, sampling scheme, influencing factors. *Science of Soil and Water Conservation* **1**, 95-98 (in Chinese)