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边缘效应对原始花旗松林冬季温度的影响

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摘要：由林缘到林内，夏季温度有明显的梯度变化。但还未有人对其它季节的温度变化，进行研究。自 1991 年 10 至 1992 年 5 月，对林缘至原始花旗松林林内的温度，进行了连续的实地测量，并与相应的夏季温度变化加以比较。主要研究目的，是测定沿林缘两侧，是否存在有一个最小的温度阈值，当温度低于这个阈值时，林缘及林内的温度差异会消失。研究中，由林缘到 240m 的林内，设立了一条样带，并在样带 0，30，60，120，180，和 240m，6 处装设气象站，每 30min 连续记录气温、土壤温度和其他微气象指标。通过计算每点的相对温度并同实际温度加以对比，夏季和冬季的林缘效应显著性指数(Significance of edge influences，*SEI*)进行了分析。此外，计算了不同气象条件下的林缘效应深度(*DEI*)。结果表明，非夏季最小的气温阈值在 0℃左右。土温的变化则因土壤很少结冻，而存在明显不同的最小的温度阈值格局。林缘效应对土壤温度的影响，比对气温的影响更显著，但冬季和夏季之间没有太大的差异。但以 DEI 而论，林缘效应对气温的影响比较大。对非生长季节气候因子沿林缘梯度的分析。有助于进一步了解几个相关的生物和非生物过程。

关键词：边缘效应；林缘梯度；冬季微气候；温度；非生长季；原始林；SEI；DEI

Winter temperature changes across an old-growth Douglas-fir forest edge

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Abstract: Microclimatic variables collected in summer have been shown to vary greatly across forest edge-interior gradients, and therefore affect ecological patterns and processes. However, winter (October～May) microclimatic data has not been studied in relation to these gradients. We examined winter temperature gradients across old-growth Douglas-fir forest edges and compared these to corresponding summer gradients. We sought to determine whether there is a minimum temperature threshold, below which variation across edge is insignificant. Air and soil temperature were collected along transects extending from clearcut edges to 240 m into the forest. Minimum temperature thresholds were evaluated by plotting relative temperature against actual temperature for the same observation. The significance of winter temperature variation across edge gradients vs. summer temperature variation was evaluated by comparing the Significance of Edge Influence (*SEI*) index to previously calculated summer *SEI* data. Depth of Edge Influence (*DEI*) was also compared between seasons. The minimum threshold point for winter air temperature was found to lie near 0℃. Soil temperature variation exhibited different minimum threshold patterns because actual soil temperature rarely dropped below 0° C. Edge effects were more significant to soil temperature than air temperature, and not greatly different between summer and winter. However, edge influences extended farther into the forest for air temperature than soil. These findings on non-growing season climatic conditions across a forest-edge gradient should provide insight to several related seasonal biotic and abiotic processes.

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Key words: edge effects; edge gradients; winter microclimate; temperature; non-growing season; old-growth; SEI; DEI
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1. INTRODUCTION

Edge effects are created by the transition between two adjacent communities or landscape elements, and often lead to changes in both abiotic and biotic conditions[1~3]. Understanding of edge effects has evolved from simple predictions of increased species numbers to recognition of the complexity of edge influences on ecosystem structure and function[4,5]. The area of edge influence (AEI) following management or disturbance in forested landscapes is surprisingly much higher than we traditionally believed[4,6]. A recent study of 16 remnant tropical rain forest patches suggested that biomass of these forests was reduced by 12%～14% 2～4 years following harvest[7]. This reduction was primarily caused by higher mortality and slower growth near edges, indicating that fragmentation can lead to significant influences on not only species composition and abundance, but also ecosystem processes such as productivity. The cumulative effects from management practices and disturbances that result in extensive edge influences and microclimatic changes can have considerable impacts on ecosystem structure and function of many forest landscapes, including the temperate rain forests of the Pacific Northwest[8~10].

Microclimatic conditions near forest edges have been shown to affect wildlife habitat (e.g., cowbird parasitism), species distribution and abundance[11~13], tree regeneration and mortality[14,15] and physical environment[16]. Changes in temperature, moisture, solar radiation, and wind speed constrain or promote the dispersal and movement of species across edges[17] and the invasion of alien and exotic species[18]. They determine the mortality of shade-tolerant species and overstory trees[14,19]. affect water loss from bryophyte, lichens[12,20] and soils; and provide physical access for predators to interior species[21]. For example, the number of Douglas-fir (*Pseudotsuga menziesii*) seedlings (a sun-loving species) near south- and west-facing edges were appreciably promoted following a clearcut of adjacent forest, while regeneration of Pacific silver fir (*Abies amabilis*, a shade-tolerant species) was greatly limited[14]. Similarly, Silett suggested that a resulting drier edge environment is probably the major reason for lower growth rates of foliose lichens[12].

In the Pacific Northwest, elevated temperatures and light levels, low moisture, and high wind speed[16]. characterize growing-season microclimate across forest-clearcut edges. The depth of edge influences (*DEI*), as determined by Chen *et al.* [14], can reach up to 240 m into the old-growth Douglas-fir forest, depending on the variable of concern, time, edge orientation, and stand age. However, investigations on microclimatic gradients across forest edges have been limited to growing seasons in the Pacific Northwest and elsewhere. Remaining questions should explore whether there are similar microclimatic gradients during non-growing seasons, and how the magnitude and extent of edge effects differ during this period.

Motivated by these questions, our objectives were to examine winter (October～May) temperature gradients across an old growth Douglas-fir forest edge and compare winter gradients to corresponding summer gradients. These objectives supported the following hypotheses:

1) There is a minimum temperature below which temperature fluctuation is negligible.

2) Greater temperature fluctuations occur during spring and fall than in the coldest months.

3) Significance of edge influence is less in winter than in summer.

4) Depth of edge influence is less in winter than summer.

2 METHODS

2.1 Study site and data collection

Our study site is located within the T. T. Munger Research Natural Area of the Wind River Experimental Forest in southwestern Washington, in which a large canopy crane was established in 1994 by the University of Washington and the USDA Forest Service (Fig. 1). This 500 year-old Douglas-fir forest sits on gentle topography at 355 m elevation near the base of the Trout Creek Hill, an extinct volcanic cone. Soils are coarse textured inceptisols, (shotty loamy sands and sandy loams), developing in 2～3 m of volcanic ejecta over basal bedrock. Overstory trees are Douglas-fir, western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), Pacific silver fir, and grand fir (*Abies grandis*). The tallest trees approach 67 m in height, while the height of canopy trees is about 55～60 m. The forest has about 445 trees per hm^2. The understory is composed mostly of Pacific yew (*Taxus brevifolia*), vine maple (*Acer circinatum*), and Pacific dogwood (*Cornus nuttallii*). Ground vegetation includes salal (*Gaultheria shallon*), Oregon grape (*Berberis nervosa*), and red whortleberry (*Vaccinium parvifolium*)(Frankin and DeBell 1988).

An 800m south-facing edge was created when the Wind River Tree Nursery (closed in 1997) was expanded in 1972. Wire fences were used along the edge to protect the nursery from elk and deer browsing. Regenerated vegetation along the edge was cleared every two to three years. In 1988 a line transect was placed perpendicular to the edge into the interior forest. Six sampling locations were measured and marked using wire flags at 0, 30, 60, 120, 180, and 240 m from the edge into the forest to sample vegetation characteristics[14]. and growing-season microclimate[22]. as a function of edge distance. These weather stations and an additional station in the open nursery area were maintained over the 1991～1992 winter to quantify the non-growing season microclimatic gradients, with primary interest in air and soil temperatures.

Our monitoring system at each station consisted of a Campbell Scientific 21X datalogger housed in a cooler, marine batteries, and six custom-made thermocouples to record three air temperatures (E-type thermocouple) at 2 m above the ground, and three soil temperatures (T-type thermocouple) at 5 cm in the soil. One sampling location was approximately 1～2 m away from the cooler, and two locations parallel to the edge about 10～15 m on each side of the cooler. All dataloggers were programmed to sample temperatures at ten second intervals and store 30 minute averages. A laptop computer was used to download data monthly. Field data collection lasted from 10 October 1990 to 24 May 1991. Snow depth and cover were not monitored during this period but we noted snow scattered across the stand in January and February, 1992.

2.2 Analysis

Air temperature (T_a) and soil temperature (T_s) data (day, time, temperature, and station) were analyzed using SAS statistical software, v. 6.12[23]. and S-Plus 2000. Seasonal characteristics were examined by plotting temperature, by day, and by distance. Diurnal characteristics were examined by plotting temperature by time and by distance. To determine when the greatest temperature fluctuations occurred, we plotted relative (or reference) temperatures by day. Relative temperatures were defined as:

$$T_{\text{delta}} = T_i - T_{\min}$$

where T_i is the actual temperature for a given day, time, and distance, and $T_{\min}$ is the value across all sampling stations with the minimum temperature for the same day and time. Relative values allowed us to draw comparisons between days and between air and soil temperatures that we could not make with actual temperatures.

Minimum temperature thresholds were evaluated by plotting T_{delta} against the actual temperature (T_i) for the same observation (day and time). We tested the relationships with Pearson's Correlation

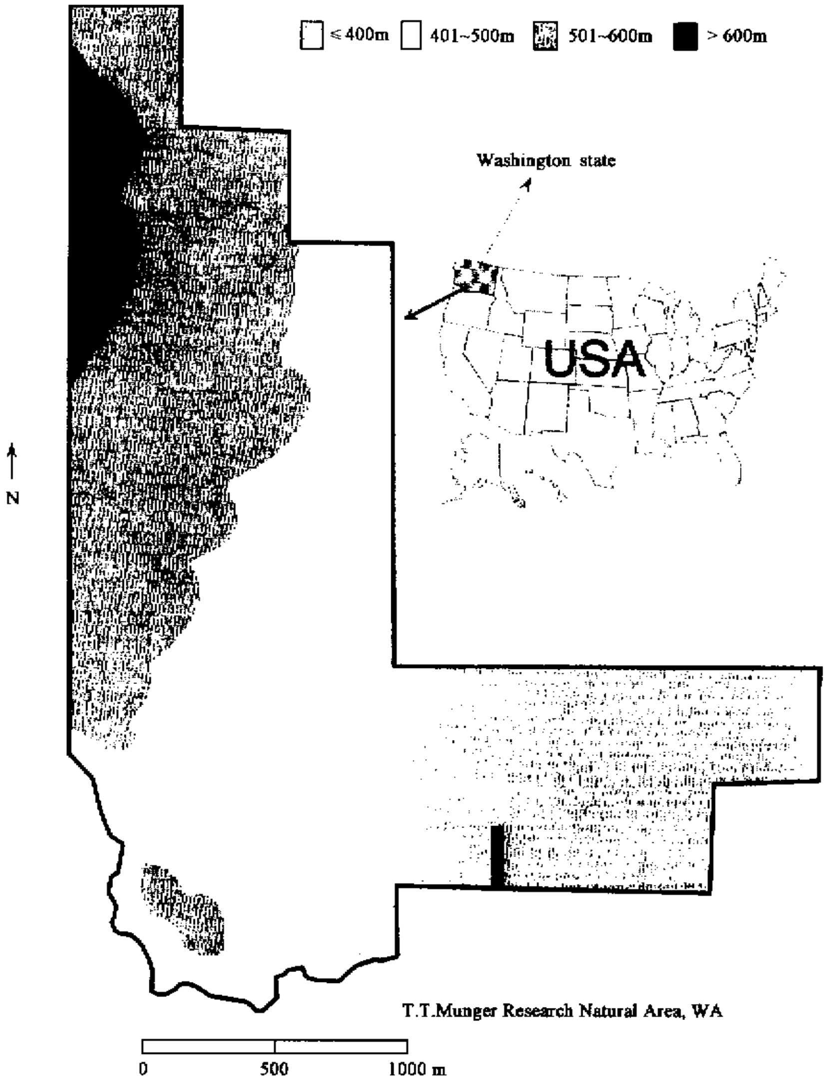

Fig. 1 Study site location. T. T. Munger Research Natural Area, Wind River Experimental Forest in SW Washington

Coefficient.

The significance of winter temperature differences across edge was evaluated by comparing the Significance of edge influence (*SEI*) index:

$$SEI = |T_5 - T_{240}$$

where T_0 is the temperature at the edge and T_{240} is the temperature at the most interior forest station. Winter *SEI* figures were then compared to summer *SEI* data calculated by Chen *et al.*

Another previously used microclimate index, *DEI*, or depth of edge influence, was employed in our study. *DEI* is described as the edge width and reflects how far into the forest edge effects extend. *DEI* limits were determined by the arbitrary 10% rule employed by Chen *et al.*[4], where the level of a variable is equal to 10% of the difference between the edge and the interior forest, or 10% of the *SEI*. When that 10% value is extended horizontally, the point at which it intersects the plot line of the particular variable is the distance of edge influence.

3 RESULTS

Seasonal winter air temperature patterns exhibited minimum temperatures (near −20℃) in late December and another mild cold spell (−6℃) in April. There was very little change in air temperature across the edge gradient from 0 to 240 m except for an isolated dip between 0 and 120 m in late April following the cold spell (Fig. 2a). Seasonal soil temperature also dropped to its lowest in late December, however, it was not less than 0℃ at its minimum. Other soil temperature lows occurred around March 9 and late April, both nearing 0℃. During these times, when soil temperatures were low we found very little temperature variation across the edge gradient. However, when soil temperatures were higher (in October, February, late March, and May, there was a noticeable edge effect between 0 m and 30 m (Fig. 2b). Only slight edge effects were evident during the spring cold spells, and no edge effect in December when temperature reached 0℃.

Diurnal winter air temperature patterns were consistent across the edge gradient ranging from lows of approximately 4℃ near 700 h, and highs of about 14℃ around 1600 h. No daily edge effect was apparent (Fig. 3a). Contrarily, diurnal winter soil temperature was noticeably higher at the edge (0 m) up to about 30 m, than interior forest. Only at this edge was there a clear diurnal pattern of high temperatures (over 20℃) in late afternoon and lower temperatures (near 10℃) in the morning. Soil temperatures from interior forest stations had only very subtle change throughout the day. The greatest edge effect in soil temperature occurred from about 1600 to 1900 h. Morning soil temperatures did not dip as drastically as morning air temperatures (Fig. 3b).

Based on our seasonal winter temperature findings across an edge gradient we decided to examine whether there was a minimum temperature below which temperature variation across an edge was insignificant. To do so, we plotted T_{delta} against T_i for the same observation (day and time). We found that when the actual air temperature was near 0℃ at a given observation, temperature difference (T_{delta}) was generally very close to the coldest station (close to 0℃ change). But, when actual air temperature was 10℃, T_{delta}, may have been up to 11℃ warmer than the minimum (Fig. 4a). So, temperature range across the edge gradient was as much as 0～17℃ at 20℃ actual, but only 0～2℃ when actual temperatures were near 0℃. The threshold point (or break in the slope of the data) for winter air temperature was found to lie between −1℃ and 1℃. In other words, −1℃ to 1℃ may be considered the minimum temperature range at which variation across forest edge becomes inconsequential. The resulting Pearson R^2 was 0.47.

Soil temperature variation exhibited different minimum threshold patterns because actual soil temperature rarely dropped below 0℃. Fluctuation across the edge increased nearly linearly with actual temperature, or not at all (Fig. 4b). For example, when soil temperature was 10℃, T_{delta} ranged from 0～10℃ across the edge gradient. At temperatures greater than 10℃, all T_{delta} observations increased linearly and were greater than 0℃. R^2 obtained from Pearson Correlation for soil temperature variation to soil temperature was 0.42.

Seasonal air and soil temperatures were lowest in December and April. Seasonal soil temperature patterns reflected those of air temperature, except when air temperature dropped below 0℃, at which time soil temperature maintained a minimum of 0℃ (Fig. 5a). More variation (T_{delta}) was found in spring and fall for both air and soil than in mid-winter (Fig. 5b). Soil temperature differences exceeded air temperature variation in October, November, February, and March, while air temperature differences greatly exceeded soil temperature variation in May.

To determine whether winter temperature variation across an edge gradient was as significant as

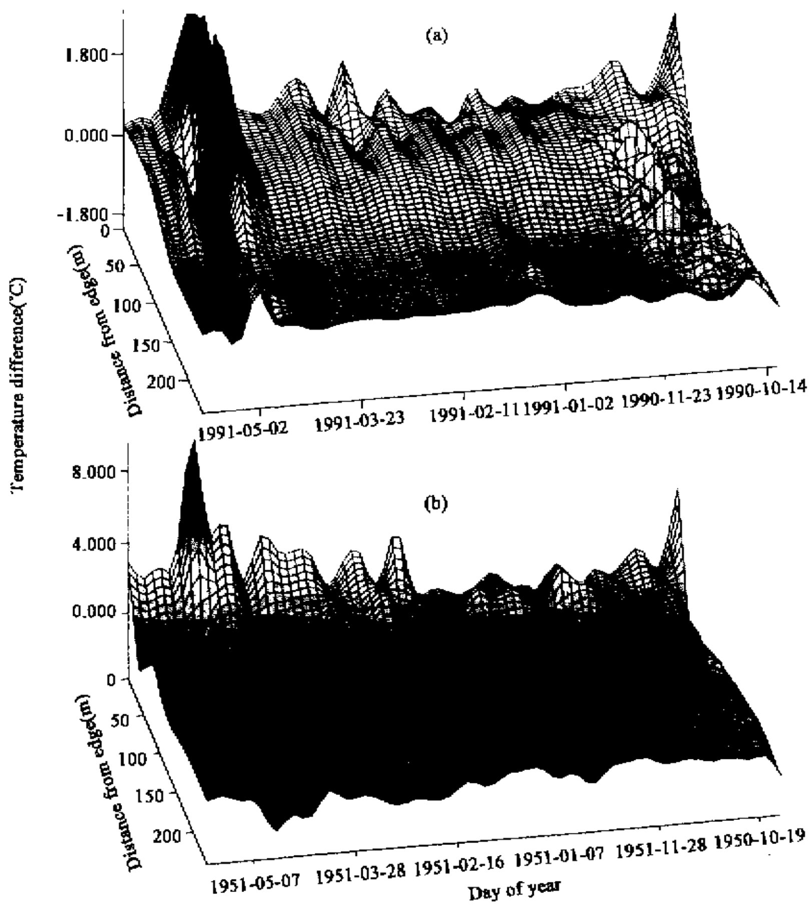

Fig. 2 Seasonal daytime (1100～1600h) winter temperature differnces (°C), 10 October 1990 through 24 May 1991, with distance from the edge into an old-growth Douglas-fir forest (0～240m), a) air temperature, and b) soil temperature

summer temperature gradients we calculated the Significance of edge influence (*SEI*) index[22]. In winter, air temperature *SEI* ranged from 0 to 8.42 (mean=0.88). In summer the air temperature *SEI* range was smaller, from 0.52 to 7.88, but within the range of winter air *SEI* (from south facing edges[22]). We found winter soil temperature *SEI* range (0 to 14.22, mean = 2.72) to be greater than winter air *SEI*. Compared to summer soil *SEI* (4.98 to 15.55°C) winter soil *SEI* was not as great (Table 1). In both winter air and winter soil temperature data, *SEI* was greater in spring than fall or winter months (Fig. 6).

Using the 10% rule (modified here to 25%) described by Chen *et al*[4]. to determine the limits of edge influence, we found that air temperature effects extended over 100 m into the forest. Winter soil temperature, on the other hand, was influenced by edge to only about 40 m into the forest (Fig. 7). Summer *DEI* followed a similar, but slightly higher pattern for both air temperature (*DEI*=60 to 120m, up to 240m), and soil temperature (*DEI* just under 60 m, Chen *et al.*)[22] (Table 1).

Table 1 Comparison between summer and winter significance of edge influences (*SEI*) and depth of edge influences (*DEI*) in T_a and T_s. summer data are from Chen *et al*[22].

	Air temperature		Soil temperature	
	Winter	Summer	Winter	Summer
SEI Range C	0～8.42	0.52～7.88	0～14.22	4.98～15.55
SEI Mean (C)	0.88		2.72	
DEI Range (m)	90～120	60～120	40～60	<60

4 Discussion

Winter microclimate is important to many forest ecological processes, especially as minimum temperatures can delay photosynthesis and production[24]. It is also useful to know how temperature varies across an edge gradient, and how minimum temperature affects temperature variation. Previous studies of growing season microclimate have shown significant air and soil temperature changes (about 2 to 4℃) from edge to forest interior[16,22,3] or across riparian edges[25]. Interestingly, our study of non-growing season temperature has shown smaller edge effects (in *SEI*) on air temperature, while soil temperature differences reflect edge influences similar to those reported by others (mean *SEI*=2.72). This suggests that winter air temperature changes across a forest edge are moderated by the lower solar angles, shorter days, and extreme lows of the winter season.

We have noted two striking findings related to minimum temperature. First, soil temperature rarely dropped below 0℃, even when surrounding air temperatures were as low as −15℃ (Fig. 5a), illustrating how the soil is insulated from extremes. Secondly, when air temperature

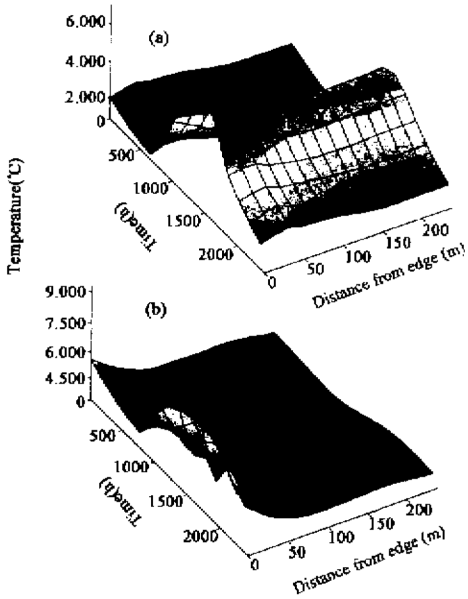

Fig. 3 Average winter temperature (℃) with distance from the edge into an old-growth Douglas-fir forest (0～240m), a) air temperature, b) soil temperature

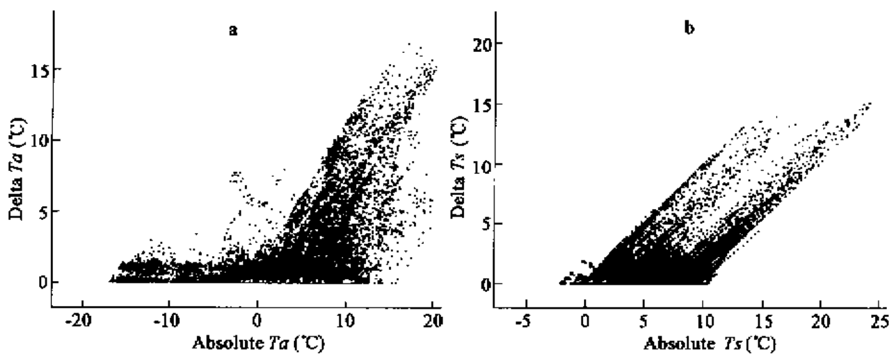

Fig. 4 Relative air (a) and soil (b) temperatures (T_{delta}, ℃) plotted against T_a and T_s (℃) to identify threshold levels for minimal temperature differences

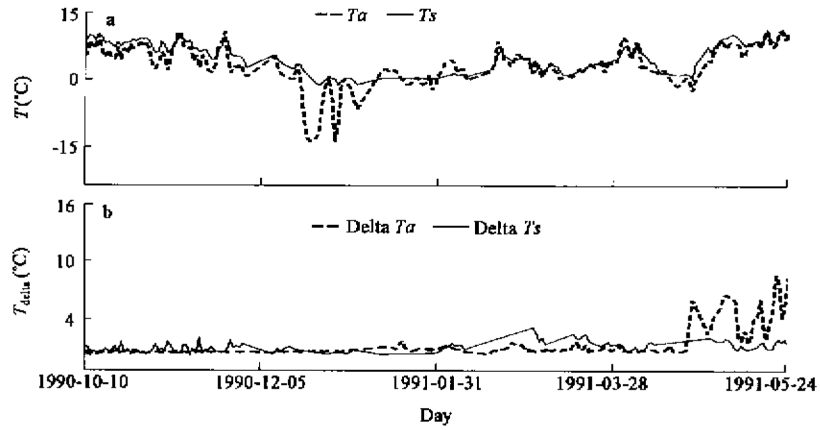

Fig. 5 Comparison of a) seasonal air and soil temperatures (℃), and b) temperature differences ($T_{delta}=T_i-T_{min}$) by day, 10 October 1990 through 24 May 1991.

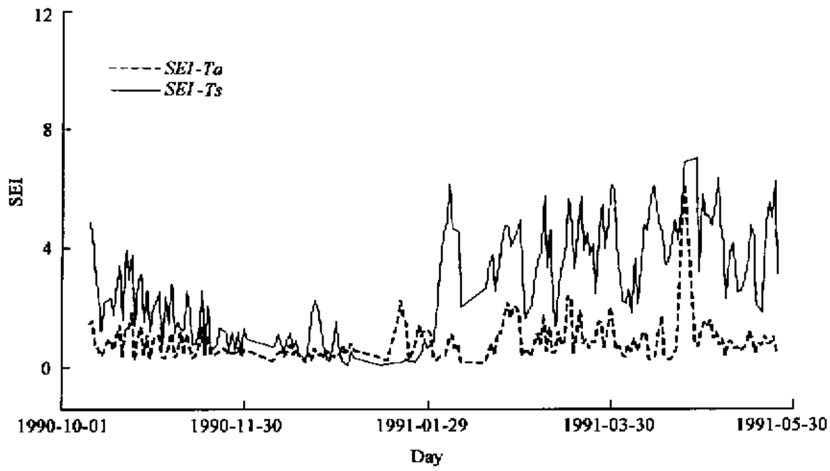

Fig. 6 Significance of edge influence (*SEI*) in winter air (T_a) and soil (T_s) temperatures (℃) by day, 10 October 1990 through 24 May 1991.

dipped below 0℃, we found temperature fluctuation across the edge gradient stabilized. In other words, at 0℃ the edge no longer influenced temperature gradients. These findings have important implications to biological processes[32~35]. For many organisms the edge may play a less important role during the coldest winter periods than during other times of the year.

Most air temperature fluctuations occurred in late spring and then, to a lesser degree, in fall. The high spring fluctuations are likely due to low solar angles combined with clear sunny days and cool nights when deciduous or herbaceous vegetation has not fully leafed out to moderate temperatures. The greatest soil temperature differences were in late February, and may reflect spring freezing and thawing conditions.

These seasonal differences were reflected in our *SEI* measurements. The significance of edge was much higher in the spring, followed by fall and then low *SEI* in the middle of winter (late November to early February). Clearly forest managers and conservationists should be aware that spring ephemerals near the forest edge may suffer the greatest change in microclimatic setting, including higher temperatures and

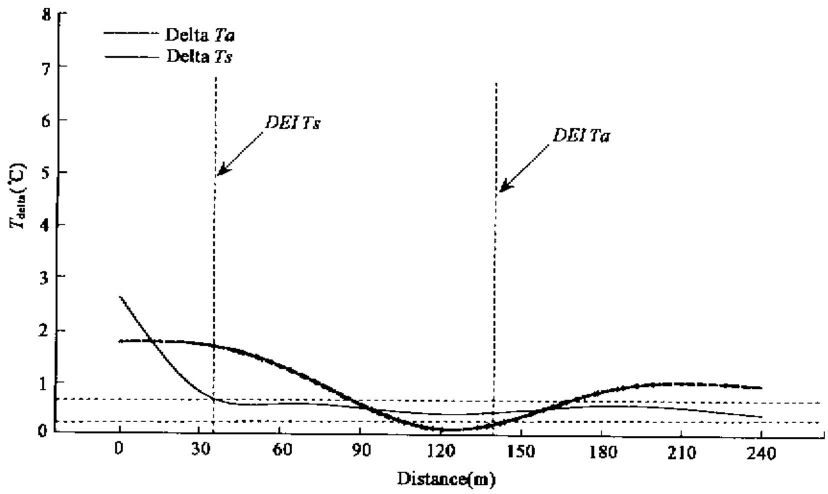

Fig. 7 Depth of edge influence (*DEI*) interpreted from relative T_a and T_s plotted against distance from forest edge. Horizontal bars indicate 25% of *SEI*. Vertical bars mark where the 25% line crosses the plotted variable, and mark the estimated limits of *DEI*[22]

more erratic temperature fluctuations.

How far into the forest might these edge influences be realized? Our estimates of *DEI* show that while the significance of edge influence is lower in winter air temperature than winter soil temperature; its influence may reach farther into the forest. We suspect this is because winds mix air molecules more than soil. Therefore, when calculating the amount of forest area impacted by edge creation, that area will be greater for air temperature than soil temperature in the non-growing season, although the strength of the influence (*SEI*) is higher in the soil.

Results of both our *SEI* and *DEI* measures are comparable to summer data. Both seasons exhibit stronger edge influences in soil temperature than air temperature, but edge influences of air temperature in both seasons extend further into the forest than soil temperature influences[22].

5 Conclusions

Our findings have shown moderate edge effects in winter air temperature, the significance of edge influence (*SEI*) being similar to that of summer air temperature. However, winter soil temperatures reflected a strong edge influence at 0 to 30 m, and higher *SEI*. Both air and soil temperatures fluctuated less during very cold periods than during milder times. While T_a dipped below −20 C, soil temperatures below 0 C were seldom recorded. We have identified a threshold point in both winter T_a and T_s near 0 C, below which temperature fluctuations were minimal. Like summer measures, depth of edge influence for air temperature can extend farther into the forest (90～140 m) than do soil temperature effects (40～60 m), due to greater mixing of air molecules. These findings on non-growing season climatic conditions across a forest-edge gradient should provide insight to several related seasonal biotic and abiotic processes.

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