Seasonal comparison of soil temperature and moisture in pits and mounds under vine maple gaps and conifer canopy in a coastal western hemlock forest

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Schmidt, M. G., Ogden, A. E. and Lertzman, K. P. 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**. Can. J. Soil Sci. **78**: 291–300. In this study we attempted to determine if vine maple priority gaps show similar trends in temperature and moisture status to those reported in the literature for treefall gaps and whether temperature and moisture status differed between microtopographic positions (pits and mounds). Biweekly measurements of mid-day soil and air temperature, moisture contents at 30-, 50- and 80-cm depths, and depths to the groundwater table were made in pit and mound locations within six vine maple priority gaps paired with six conifer canopy sites. Trends did not follow those found in treefall gaps: vine maple gaps had similar mid-day temperature and moisture status to the surrounding conifer forest. Larger gaps had higher mid-day air temperatures in the summer, higher mid-day soil temperatures in the spring and summer, and greater amounts of throughfall in the spring and summer than smaller gaps. Trends in mid-day soil temperature and moisture status for pit and mound microtopography followed those reported in the literature. Pits were significantly cooler in summer and warmer in winter than mounds and pits were wetter than mounds in all seasons. This study suggests that soil microtopography has an effect on soil climate that overwhelms the influence of vine maple gaps.

Key words: Vine maple, canopy gap, soil moisture, soil temperature, microtopography, pits and mounds

Schmidt, M. G., Ogden, A. E. et Lertzman, K. P. 1998. **Comparaisons saisonnières de la température et de la teneur en eau du sol dans les emplacements en creux et en buttes, dans les trouées à érable circiné et sous conifères de la forêt côtière à pruche de l'Ouest**. Can. J. Soil Sci. **78**: 291–300. Nous avons cherché à déterminer si les trouées à érable circiné manifestent les mêmes régimes thermiques et hydriques que ceux observés dans les trouées de châblis et, deuxièmement, si des différences existent à cet égard entre les emplacements microtopographiques (creux et buttes). La température du sol, la température de l'air, les teneurs en eau du sol à 30, 50 et 80 cm de profondeur et la profondeur du niveau de la nappe étaient mesurées vers midi toutes les 2 semaines dans des emplacements en creux et des emplacements en butte dans six trouées à érable circiné appariées à six placettes sous couvert de conifères. Les tendances observées ne suivaient pas celles observées dans les trouées de châblis : les trouées à érable circiné manifestaient une température et un bilan hydrique semblables à ceux du couvert forestier environnant. Les grandes trouées révélaient une plus haute température atmosphérique et un bilan hydrique plus abondant en été, une température plus élevée du sol au printemps et en été et un pluviolessivat plus abondant au printemps et en été que les petites trouées. Les écarts de température et d'état hydrique du sol observés entre les creux et les buttes concordaient avec les données rapportées dans la bibliographie. Les creux étaient statistiquement plus frais en été mais plus chauds en hiver que les buttes. Ils étaient également plus humides toutes saisons confondues. Il ressort de nos observations que l'effet de la microtopographie du sol l'emporte sur celui des trouées à érable circiné.

Mots clés: Érable circiné, trouée de couvert forestier, teneur en eau du sol, température du sol, microtopographie, creux et buttes

Research has been conducted in a variety of forest types concerning the increase in energy and moisture reaching the ground surface due to the loss of biomass following the creation of a treefall canopy gap (Chazdon and Fetcher 1984; Poulson and Platt 1989; Canham et al. 1990). The most conspicuous environmental change in canopy gaps is a localized increase in light levels (Pickett and White 1985). Since the forest canopy moderates temperature extremes by intercepting solar radiation, air and soil temperatures in canopy gaps often differ from those in the closed forest. The forest canopy prevents the soil from reaching excessively high temperatures in the summer, and reduces the rate of heat loss from the soil during winter months (Pritchett and Fisher 1987).

Canopy gaps can also influence soil moisture and groundwater table levels since rates of throughfall, evaporation, and transpiration differ in and around gaps as compared with those in a closed canopy forest (Pickett and White 1985). A reduction in the amount of vegetation present on a site to intercept and transpire water following removal of the forest canopy can result in an increase in soil moisture and water table levels (Pritchett and Fisher 1987). In tropical forests, moisture levels in the upper 10 cm of soil have been observed to be consistently and significantly higher in gaps than beneath intact canopies (Lee 1978; Denslow 1987). When soil in the rooting zone is moist, a vegetated surface can be cooler than when the soil is dry because of greater evapotranspirational cooling.

Gap size determines whether a gap will have an environment much different from that of the closed canopy forest; small gaps in either tall or open canopies can have little effect (Pickett and White 1985). As opening size decreases, temperatures remain more constant (Geiger 1965).

Some canopy openings in coastal temperate forests contain the hardwood species vine maple (*Acer circinatum*), and some vine maple gaps show no evidence of having been formed by treefall (Spies et al. 1990; McGhee 1996). In some of these gaps, vine maple has been persistent since the time of stand establishment, resisting the regeneration of taller canopy dominants and subsequent canopy closure (McGhee 1996). These persistent openings in the forest canopy, which are not created by treefall, have been called priority gaps (McGhee 1996). It is thought that priority vine maple gaps originate when vine maple colonizes a site first, and establishes a dense mat of stems early in stand development that is large enough to prevent the subsequent regeneration of the sites by conifers and resists canopy closure (McGhee 1996). As the stand develops around these vine maple patches, a canopy gap appears in the mid- to late-successional stages. Ogden and Schmidt (1997) found that vine maple gaps may improve the nutritional status of the sites that they occupy within conifer forests. They found that vine maple gaps compared with closed canopy conifer forest had significantly higher pH, and higher concentrations of Ca, Mg and K in the forest floor and a tendency for lower C/N ratios (P = 0.14) and higher total N concentrations (P = 0.17) in the surface mineral soil. They also found that vine maple litter decomposed faster than conifer litter, but found no differences in decomposition rates of the same litter type between vine maple gap and conifer canopy plots.

In much of the coastal BC forest, the microtopography is highly variable with microtopographic highs (mounds) and lows (pits). This microtopographic variability may be due to a combination of the uprooting of trees prior to stand establishment, and undulations in the basal till underlying the area creating low microsites and high microsites. Microtopography can have considerable influence on soil temperature and moisture, with pits typically being cooler in the summer, warmer in the winter, and moister all year round than mounds (Beatty 1984; Beatty and Stone 1986; Peterson et al. 1990).

The objective of this study was to compare variation in soil temperature and moisture on a seasonal basis in pits and mounds under vine maple gaps and conifer canopy in Coastal Western Hemlock Forest. We attempted to determine if vine maple priority gaps influence soil temperature and moisture in the same way as has been reported in the literature for treefall gaps, and if microtopography in these forests influences soil temperature and moisture as reported in the literature. If soil temperature and moisture do differ between gap and closed canopy sites and between pit and mound microsites, this may suggest that important processes that are influenced by soil temperature and moisture, such as rates of N mineralisation and litter decomposition, may also differ between these sites and microsites. Differences in soil temperature and moisture between pit and mound microsites have implications for sampling strategies for temperature and moisture in terrain with microtopographic variation.

MATERIALS AND METHODS

Study Area

The research was carried out in a stand dominated by western hemlock (*Tsuga heterophylla*) that was logged approximately 80 yr ago. The stand is in the Seymour Demonstration Forest in the North Shore Mountains of the Coast Range (49°22′30″N, 123°00′25″W). The dominant tree species in the stand, on a stem-per-hectare basis, are western hemlock (54%), Douglas-fir (27%) and western redcedar (*Thuja plicata*) (19%) (McGhee 1996). Canopy trees average 50.9 cm in diameter and 40 m in height (McGhee 1996). The study area is transitional between the moist maritime (CWHmm) and dry maritime (CWHdm) subzones of the Coastal Western Hemlock biogeoclimatic zone. Mean annual precipitation is approximately 2088 mm (Meidinger and Pojar 1991), with most falling between October and March and a pronounced dry period occurring in late summer. Less than 15% of total precipitation occurs as snowfall. Mean annual temperature is 7.8°C, with mean monthly temperatures remaining above 0°C (Meidinger and Pojar 1991). The soils are dominantly Orthic Humo-Ferric Podzols (Agriculture Canada Expert Committee on Soil Survey 1987), Mor is the dominant humus form, and the parent material consists of compact basal till. The ground surface is characterized by pit and mound microtopography (Peterson et al. 1990) that is slightly to moderately mounded (mounds are 0.3 to 1 m high, and 3 to > 7 m apart; Luttmerding et al. 1990). The pit and mound microtopography may be the result of windthrow events prior to stand establishment, or may be the result of undulations in the basal till underlying the area creating low microsites and high microsites. For a detailed description of the study area see Ogden (1996).

Sampling Design

Measurements were made in pit and mound microsites in six plots in vine maple gaps paired with six plots in the surrounding conifer forest within the study stand. Paired plot comparisons are commonly used in evaluating differences in resources between canopy gaps and the surrounding closed canopy forest (Schemske and Brokaw 1981; Mladenoff 1987; Shelley 1988; Vitousek and Denslow 1986). Each conifer canopy plot was established at a distance of 25 m from a vine maple plot. The conifer canopy plots contained no evidence of vine maple (dead or alive) within 20 m of their centers and were dominated by conifers that made up the relatively closed canopy.

The six vine maple gaps were chosen using three criteria: a canopy gap area between 15 and 180 m^2; a vine maple clone that appeared to be healthy; and a paired conifer canopy plot with similar slope angle, slope position, aspect and elevation. Canopy gap area is defined as the vertical projection onto the ground of the opening in the forest canopy (Lertzman and Krebs 1991) and expanded gap area is defined by the boles of the trees whose canopies define the canopy gap (Runkle 1982). The expanded gap area for

Table 1. Characteristics of the study plots

Site	Site type	Expanded gap size (m^2)	Canopy gap size (m^2)	D/H ratio	Slope (%)	Aspect (°)	Elevation (m)	Horizon at 10 cm[z] Pit	Horizon at 10 cm[z] Mound	Microtopography[y] (degree of mounding)
1	Gap	87	26.1	0.13	14	97	200	F,Ah	Bf	Slightly
2	Gap	198	72.4	0.23	15	140	240	F	F	Micro
3	Gap	63	15.4	0.10	9	116	210	Bm	Bf	Moderately
4	Gap	222	52.6	0.20	9	154	240	F,Bf	Bf	Slightly
5	Gap	187	45.1	0.18	19	70	210	Ae,Bm	Bm,Bf	Moderately
6	Gap	355	177.6	0.35	7	80	250	Ah,Bm	Bm	Slightly
1	Canopy	6	–	–	12	98	210	Bf	Bf	Moderately
2	Canopy	15	–	–	20	93	210	F	Bf	Slightly/moderately
3	Canopy	18	–	–	15	122	240	F,Bf	Bf	Slightly
4	Canopy	25	–	–	4	110	200	F	F	Micro
5	Canopy	15	–	–	15	95	250	Bm, Bf	Bm, Bf	Moderately
6	Canopy	10	–	–	11	120	200	F	F	Moderately

[z]Horizon within which soil temperature was measured. In each plot two measurements were made in pits and two were made in mounds. If the horizon differed for the two measurements at the same microsite type, then both horizons are indicated.
[y]Description of microtopography according to Luttmerding et al. (1990): micromounded (mounds are <0.3 m high; slightly mounded (mounds are 0.3 to 1 m high, and >7m apart); moderately mounded (mounds are 0.3 to 1 m high, and 3 to 7 m apart).

the vine maple gaps ranged from 63 to 355 m^2 (Table 1). All plots were chosen such that there was no evidence of recent treefall in or near the plots. Characteristics of the study plots are presented in Table 1.

The ratio of the diameter of the gap to the height of the trees surrounding the gap (D/H ratio) of the vine maple gap plots ranged from 0.10 to 0.35 (Table 1). The D/H ratios were calculated using gap area measurements of McGhee (1996) and tree height estimates on forest cover maps (Greater Vancouver Regional District 1988). The D/H ratio is an expression of opening size and can provide an indication of the influence of the gap on the microclimate of the understory (Geiger 1965); as the size of an opening decreases, temperatures remain more constant. Light increases with increased opening size, reaching a maximum when D/H = 2 (Pickett and White 1985).

Vine maple gap and conifer canopy plots were considered to be main plots and were approximately 4 m by 4 m in size. Within each main plot, measurements of midday air and soil temperature, soil moisture and depths to the groundwater table were taken in both pit and mound microsites. The pit and mound microsites were considered to be subplots.

Measurement of Midday Temperature and Moisture Status

Midday air and soil temperature, throughfall, soil moisture and groundwater table measurements were made on a biweekly basis over a 1-yr period. Measurements were made on 25 sampling dates from 7 January to 14 December 1994. Midday soil temperature measurements were made at four locations on each plot: two measurements were made in a pit and two measurements on a mound. Copper-constantan thermocouple wire was installed to a depth of 10 cm from the surface of the forest floor, and temperature readings were made using a digital voltmeter. The horizon that occurred at the 10 cm depth was recorded for pit and mound microsites (Table 1). Most of the soil temperature measurements were made in mineral soil horizons, but some were made in the lower part of the forest floor. Mid-day air temperature readings were taken at 20 cm above the soil surface at each thermocouple location.

Beneath the foliage of vine maple in each gap plot and in the center of each conifer plot, a throughfall gauge was situated 10 cm above the soil surface to measure inputs of moisture to the soil. A Campbell Pacific Nuclear 503 Depth Moisture Gauge was used to determine soil moisture at various depths (Campbell Pacific Nuclear Corporation 1978). Using an auger, two 5.08-cm-diameter aluminum access tubes were installed at each site, one in a pit and one in a mound, to a depth of 1 m. Readings of moisture content were taken at depths of 30, 50 and 80 cm from the surface of the forest floor. Two groundwater wells were installed in each plot, one in a pit and one in a mound. Using an auger, the wells were installed to a depth of 1 m beneath the soil surface or as deep as possible if installation to 1 m was not possible. Wells were constructed from 5.08-cm-diameter PVC tubing with holes drilled at 2.54-cm intervals to allow for flow of water into the wells. A nylon stocking was placed around each well to prevent debris from entering into the well, and each well was covered with a cap to prevent material from falling in from above.

Statistical Analyses

The sampling period was divided into the four seasons: winter (21 December 1993 to 21 March 1994), spring (21 March to 21 June 1994), summer (21 June to 21 September 1994) and autumn (21 September to 21 December 1994) and the number of biweekly measurements in each season were 6, 6, 6 and 7 respectively. For each plot the mean value for each parameter (midday air and soil temperature, throughfall, soil moisture and depth to groundwater table) was calculated for each season.

The data were analyzed using analysis of variance (ANOVA, Steele and Torrie 1980) with the aid of SYSTAT (Wilkinson 1996). The data were analyzed as a split-plot design with 6 blocks, vine maple gap and closed canopy

Table 2. Mean soil and air temperatures, throughfall rates, moisture contents and depths to the groundwater table in four seasons in vine maple gap and conifer canopy sites and in pit and mound microsites. Results (*P* values) of analysis of variance testing for effects of site type (vine maple gap or conifer canopy); microsite type (pit or mound) and site type × microsite type on climatic parameters in four seasons

	Mean values								*P* values		
	Gap pit		Gap mound		Canopy pit		Canopy mound		Site type	Microsite type	Site type × microsite type
Midday air temperature (ºC)											
Winter	5.03	(0.25)[z]	5.00	(0.22)	4.93	(0.23)	4.86	(0.20)	0.22	0.16	0.52
Spring	12.02	(0.69)	12.04	(0.61)	12.17	(0.60)	12.24	(0.49)	0.10	0.35	0.55
Summer	16.67	(0.55)	16.75	(0.61)	16.81	(0.44)	16.92	(0.46)	0.11	0.022*	0.74
Autumn	4.07	(0.04)	4.04	(0.03)	3.98	(0.12)	3.97	(0.15)	0.21	0.38	0.80
Midday soil temperature (ºC)											
Winter	4.80	(0.19)	4.70	(0.31)	4.96	(0.15)	4.60	(0.12)	0.80	0.001**	0.03*
Spring	8.52	(0.37)	8.53	(0.25)	8.48	(0.25)	8.56	(0.24)	0.99	0.21	0.30
Summer	13.27	(0.45)	13.32	(0.33)	13.18	(0.23)	13.57	(0.30)	0.62	0.018*	0.05*
Autumn	5.39	(0.40)	5.14	(0.61)	5.59	(0.41)	4.87	(0.41)	0.90	0.001**	0.04*
Throughfall (cm per 2-wk period)											
Winter	5.27	(2.32)	–	–	4.33	(0.51)	–	–	0.35	–	–
Spring	5.61	(1.88)	–	–	4.93	(0.68)	–	–	0.45	–	–
Summer	3.04	(0.90)	–	–	2.47	(0.35)	–	–	0.19	–	–
Autumn	6.85	(1.55)	–	–	6.32	(1.16)	–	–	0.48	–	–
Moisture content at 30 cm depth (cm^3 cm^{-3})											
Winter	0.19	(0.03)	0.17	(0.04)	0.21	(0.03)	0.17	(0.06)	0.65	0.12	0.78
Spring	0.18	(0.02)	0.21	(0.14)	0.19	(0.04)	0.17	(0.06)	0.68	0.86	0.41
Summer	0.17	(0.03)	0.15	(0.04)	0.18	(0.04)	0.16	(0.06)	0.78	0.29	0.82
Autumn	0.19	(0.02)	0.17	(0.04)	0.21	(0.04)	0.18	(0.06)	0.62	0.16	0.81
Moisture content at 50 cm depth (cm^3 cm^{-3})											
Winter	0.25	(0.06)	0.19	(0.04)	0.25	(0.06)	0.21	(0.07)	0.67	0.011*	0.71
Spring	0.22	(0.04)	0.18	(0.04)	0.22	(0.06)	0.19	(0.06)	0.84	0.028*	0.65
Summer	0.21	(0.04)	0.17	(0.04)	0.21	(0.06)	0.18	(0.06)	0.97	0.030*	0.87
Autumn	0.24	(0.06)	0.19	(0.04)	0.24	(0.07)	0.21	(0.08)	0.84	0.042*	0.56
Moisture content at 80 cm depth (cm^3 cm^{-3})											
Winter	0.29	(0.04)	0.26	(0.06)	0.29	(0.06)	0.23	(0.06)	0.63	0.015*	0.38
Spring	0.27	(0.04)	0.25	(0.06)	0.28	(0.05)	0.22	(0.06)	0.70	0.033*	0.36
Summer	0.26	(0.04)	0.24	(0.06)	0.26	(0.05)	0.22	(0.06)	0.70	0.045*	0.36
Autumn	0.29	(0.06)	0.26	(0.06)	0.29	(0.05)	0.24	(0.06)	0.74	0.020*	0.30
Depth to groundwater (cm)											
Winter	70.8	(14.2)	88.3	(10.5)	73.2	(19.3)	94.3	(10.6)	0.48	0.000**	0.60
Spring	86.3	(12.4)	94.4	(8.9)	87.9	(12.1)	97.3	(6.1)	0.17	0.001**	0.73
Summer	93.6	(9.1)	98.1	(4.6)	94.4	(11.1)	99.1	(2.2)	0.002**	0.045*	0.94
Autumn	75.3	(14.6)	91.6	(8.5)	78.9	(16.5)	96.2	(9.4)	0.27	0.000**	0.88

[z]Values in parentheses are standard deviations.
*, ** Significant at $P < 0.05$ and $P < 0.01$ respectively.

conifer sites as whole plots, and pit and mound microsites as sub-plots. We tested for the effects of site type, microsite type and the interaction of site type and microsite type using the following model:

$$Y_{ijkl} = u + B_i + S_j + M_k + SM_{jk} + e_{ijkl}$$

where Y is a measure for the lth experimental unit in the ith block, jth site type and kth microsite type; u is the mean; B is block (paired plots; $i = 1, 2 ...6$); S is site type (gap/canopy factor; vine maple gap or conifer canopy; $j = 1, 2$); M is microsite type (pit/mound factor; pit or mound; $k = 1, 2$) and e is random error within site type × microsite type combination. Unfortunately, the power of the statistical tests is likely to be relatively low due to small sample size, small effect size, and the high within-plot sample variability (Toft and Shea 1983). For each time period, Pearson correlations were used to investigate relationships between the environmental parameters and the expanded gap size for vine maple gaps, between the environmental parameters and site characteristics (slope, aspect, elevation) for all plots, and among the environmental parameters for all plots. Bonferroni adjusted probabilities were used to allow for multiple tests (Wilkinson 1996).

RESULTS

Midday Air and Soil Temperature

No significant differences were found in air or soil temperature between vine maple gap sites and conifer canopy site types in any season (Table 2, Fig. 1). There were lower air temperatures in the spring ($P = 0.10$) and summer ($P = 0.11$) and higher air temperatures in the autumn ($P = 0.21$) and winter ($P = 0.22$) in the vine maple gap plots as compared with the conifer canopy plots (Table 2).

Air temperature was significantly lower in the pit microsite as compared with the mound microsite in the

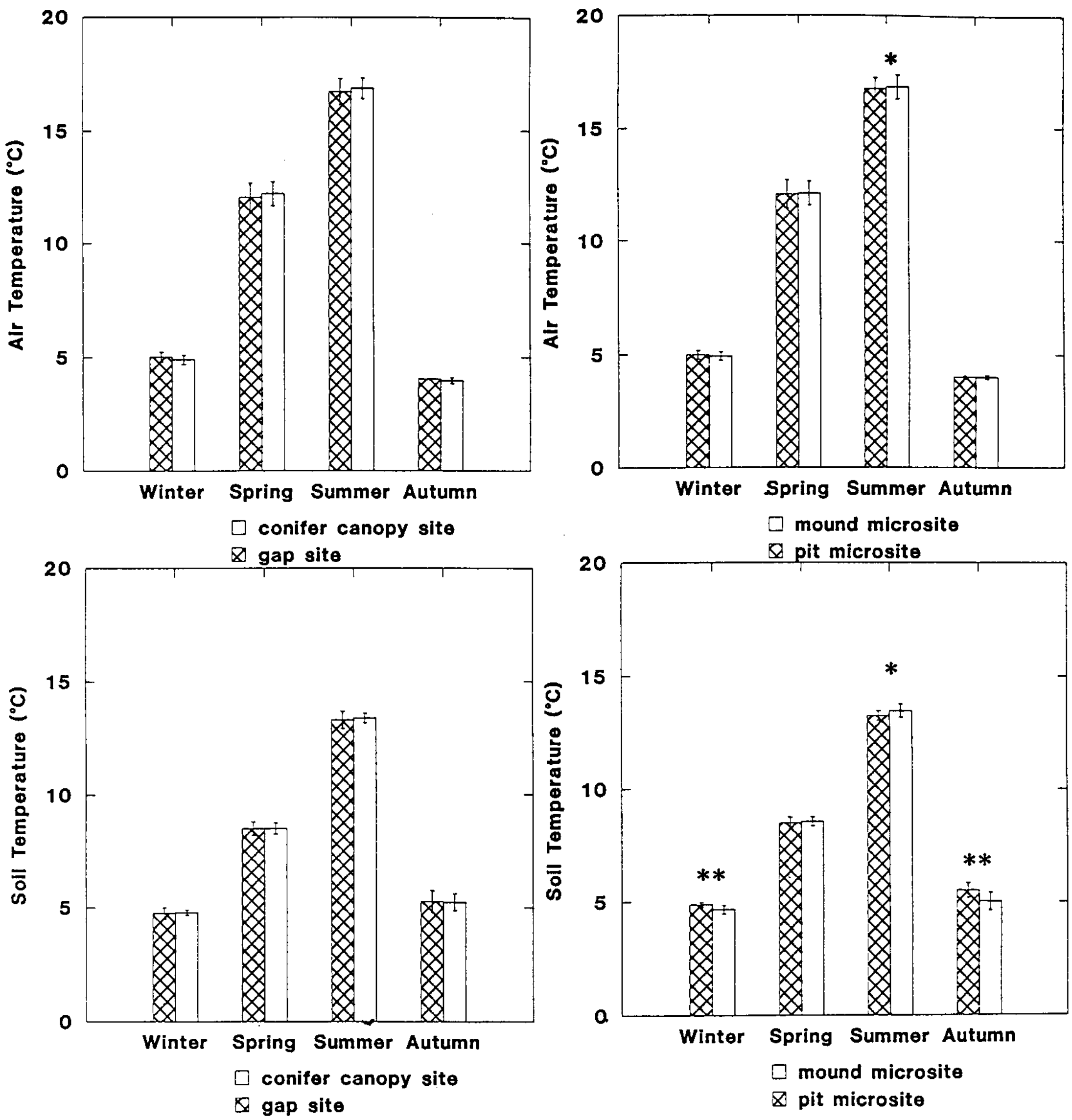

Fig. 1. Seasonal mean air and soil temperature in vine maple gap and conifer canopy sites, and in pit and mound microsites. Data are pooled for pit and mound microsites to compare gap and canopy sites and for gap and canopy sites to compare pit and mound microsites. Error bars represent one standard deviation from the mean. *, ** Significantly different value for a property between site types, or between microsite types at $P < 0.05$ and $P < 0.01$.

summer and it was higher in the pit microsite in the winter ($P = 0.16$, Table 2, Fig. 1). Soil temperature was significantly higher in the pit microsite as compared with the mound microsite in the winter and autumn, and it was significantly lower in the pit microsite in the summer (Table 2, Fig. 1). There was a significant interaction between site type and microsite type for midday soil temperature in the winter, summer and autumn (Table 2). The effect of microsite on midday soil temperature at 10-cm depth appears to be more pronounced on canopy sites as compared with gap sites.

Air temperature was positively correlated with expanded gap size in the summer ($r = 0.79$, $P = 0.01$). Soil temperature was positively correlated with expanded gap size in the spring ($r = 0.74$, $P = 0.05$) and summer ($r = 0.72$, $P = 0.06$). Plots with a south-east facing aspect had significantly higher soil temperatures than those with a north-east facing aspect in the winter ($r = 0.60$, $P = 0.04$) and the autumn ($r = 0.61$, $P = 0.03$). Soil temperature was positively correlated with moisture contents at the 50 and 80 cm depths ($r = 0.59$, $P = 0.06$; and $r = 0.63$, $P = 0.02$, respectively) and the depth to groundwater table ($r = 0.61$, $P = 0.04$) in the winter, and with the moisture contents at the 30 and 50 cm depths ($r = 0.68$, $P = 0.006$; and $r = 0.63$, $P = 0.02$, respectively) and the depth to groundwater table ($r = 0.67$, $P = 0.008$) in the autumn. Soil temperature was positively correlated with air temperature in the spring only ($r = 0.63$, $P = 0.02$).

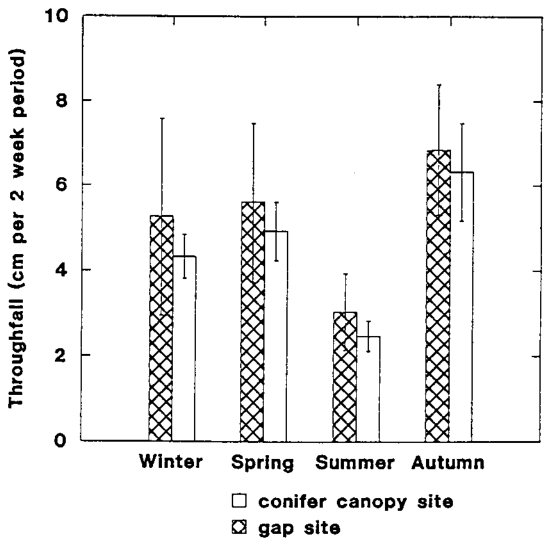

Fig. 2. Seasonal mean throughfall values in vine maple gap and conifer canopy sites. Data are pooled for pit and mound microsites to compare gap and canopy sites and for gap and canopy sites to compare pit and mound microsites. Error bars represent one standard deviation from the mean. *, ** Significantly different value for a property between site types, or between microsite types at $P < 0.05$ and $P < 0.01$.

Throughfall and Soil Moisture Content

There were no significant differences in throughfall amounts between vine maple gap and conifer canopy plots in any season. However, throughfall amounts were higher in vine maple gap plots as compared with conifer canopy plots in all four seasons (Table 2, Fig. 2.).

There were no significant differences in soil moisture content at any of the three depths measured (30, 50 and 80 cm) between vine maple gap and closed canopy plots (Table 2, Fig. 3). The moisture content at 30 cm depth was higher in the pit microsites as compared with the mound microsites in the autumn ($P = 0.16$) and winter ($P = 0.12$) (Table 2). Soil moisture content was significantly higher in the pit microsite as compared with the mound microsite at both the 50 and 80 cm depths in all four seasons (Table 2, Fig. 2).

The larger the expanded gap the greater the amount of moisture received as throughfall in the spring ($r = 0.75$, $P = 0.04$) and summer($r = 0.70$, $P = 0.08$)). Soil moisture values were not significantly related to expanded gap size in any of the time periods. Southeasterly facing sites had higher soil moisture values at the 30 cm depth than northeasterly facing sites in the summer. The moisture contents at the 50 and 80 cm depths were negatively correlated with the depth to groundwater table in the winter, spring and autumn (r values range from –0.63 to –0.77, P values range from <0.001 to 0.02).

Depth to Groundwater Table

The groundwater table was significantly shallower in the summer and was shallower in the spring ($P = 0.17$) and autumn ($P = 0.27$) in vine maple gaps as compared with the conifer canopy plots (Table 2, Fig. 4). The groundwater table was significantly shallower in the pit microsites as compared with the mound microsites in all four seasons (Table 2, Fig. 4). Sites with steeper slopes had deeper depths to the groundwater table in the winter ($r = 0.57$, $P = 0.08$), spring ($r = 0.61$, $P = 0.03$) and autumn ($r = 0.61$, $P = 0.03$).

DISCUSSION

Influence of Vine Maple Gaps on Soil Temperature and Moisture Status

MIDDAY AIR AND SOIL TEMPERATURE. Since the vine maple gaps which we studied have a lesser amount of biomass per unit area than the surrounding closed canopy forest, we expected light intensity to be higher and consequently midday air and soil temperatures to be higher in the vine maple gaps than in the closed canopy forest. No significant differences in midday air or soil temperature between vine maple gaps and the closed canopy forest were found.

In treefall gaps in tropical forests (Denslow 1987) and temperate forests (McGee 1976; Ash and Barkham 1976; Pontailler 1979), canopy openings were found to have higher light intensities, and higher air and soil temperatures than the surrounding closed forest. It would appear that the vine maple gaps behave differently than treefall gaps with regards to air and soil temperature regimes.

A number of factors may help to explain the lack of significant differences in air and soil temperatures between vine maple gap and closed canopy forest. Counter to what one might expect, light intensity may not be greater near the ground surface in vine maple canopy gaps than in the conifer canopy forest (McGhee 1996). Using hemispherical photographs taken at 1.3 m above the ground in midsummer, McGhee (1996) found no significant differences in total incoming solar radiation in vine maple gaps as compared with conifer canopy plots. This result suggests that vine maple foliage may create essentially the same light environment that a closed canopy of conifers creates. The lack of differences in the amount of solar energy reaching the forest floor in vine maple gaps and the conifer canopy forest may partially account for the lack of differences in soil and air temperature between these site types.

The relatively small size of the vine maple gaps may also partially account for the lack of significant differences in midday soil and air temperature. The D/H ratios (gap diameter to height of the surrounding canopy) for five of the vine maple gaps were quite low (0.10–0.23) while one of the gaps had a relatively high ratio of 0.35. Canham et al. (1990) found that, because of low D/H ratio (approximately 0.15), single-tree gaps in old-growth Douglas-fir/western hemlock forest in Oregon had little effect on understory light regimes. They found that in four other forest types (northern hardwoods, spruce-fir, southern hardwoods and tropical rain forest) the D/H ratios of single-tree gaps were higher (approximately 0.30 to 0.39) and resulted in significant overall increases in understory light levels. In very small gaps, the development of extremes in surface temperatures is hindered by shade from surrounding trees (Smith 1986).

Evapotranspirational cooling may partially explain the finding of a non-significant trend towards slightly lower air

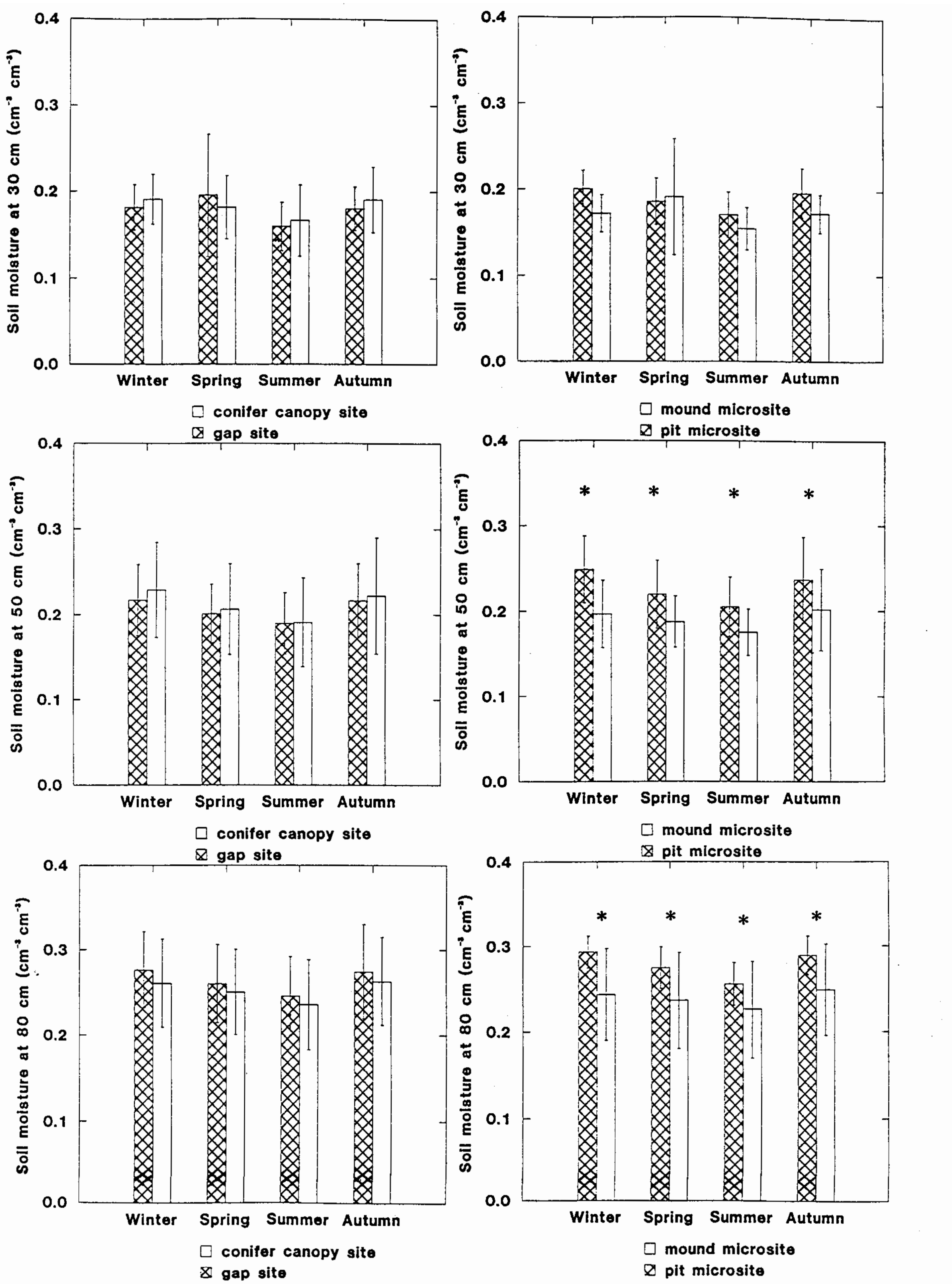

Fig. 3. Seasonal mean soil moisture contents at 30, 50 and 80 cm soil depths in vine maple gap and conifer canopy sites, and in pit and mound microsites. Data are pooled for pit and mound microsites to compare gap and canopy sites and for gap and canopy sites to compare pit and mound microsites. Error bars represent one standard deviation from the mean. *, ** Significantly different value for a property between site types, or between microsite types at $P < 0.05$ and $P < 0.01$.

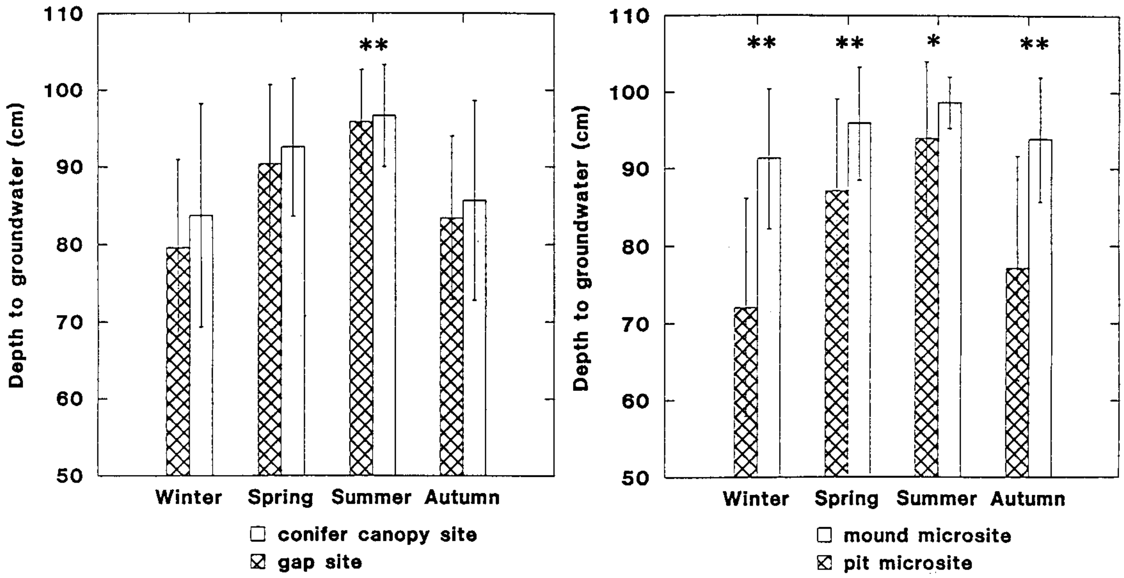

Fig. 4. Seasonal mean depths to the groundwater table in vine maple gap and conifer canopy sites, and in pit and mound microsites. Data are pooled for pit and mound microsites to compare gap and canopy sites and for gap and canopy sites to compare pit and mound microsites. Error bars represent one standard deviation from the mean. *, ** Significantly different value for a property between site types, or between microsite types at $P < 0.05$ and $P < 0.01$.

temperatures in vine maple gaps compared with the conifer canopy forest in the summer. The lower mean seasonal midday air temperatures in gaps in the summer may be due to high transpirational demands of vine maple at this time of year, as observed by Drew (1968), leading to cooler air temperatures.

Midday air and soil temperatures in vine maple gaps were related to expanded gap size: mean seasonal air temperatures were significantly higher in larger gaps than smaller gaps in the summer; and mean seasonal surface soil temperatures were significantly higher in larger gaps than smaller gaps in the spring and summer. The effect of expanded gap size on air and soil temperatures was consistent with the observation of Smith (1986) who notes that the development of extremes in surface temperatures in and around gaps is hindered by side shade; whereas, in larger gaps environmental conditions are similar to conditions in larger cleared areas. The results are also consistent with those of Denslow (1987), who found that in a tropical forest differences between gap and understory light levels were lower in small gaps than in large gaps, and of Canham et al. (1990), who found that in an old-growth forest in Oregon as gap size increased, the mean and range of light levels within gaps also increased.

Mid-day soil temperature was positively correlated with moisture content at 50 and 80 cm in the winter and at 30 and 50 cm in the autumn. The high specific heat of water accounts for its moderating influence on soil temperature in the winter (Pritchett and Fisher 1987).

Soil Moisture Status

The amount of throughfall was hypothesized to be greater in vine maple gaps than in the closed canopy because there is less total leaf area in the gap plots and therefore less interception by vegetation. Unexpectedly, throughfall did not differ significantly between vine maple gap plots and closed conifer canopy plots throughout the year, though there was a non-significant trend for greater amounts of throughfall in vine maple gaps than in the closed canopy plots in the summer. The results differed from those concerning treefall gaps in which higher throughfall levels are commonly found in gaps as compared with the surrounding closed canopy forest (Pickett and White 1985). The lack of significant differences in throughfall in our study may have resulted from the 2-wk collection intervals during which evaporation may have been higher in gaps than beneath the closed canopy. A more frequent data collection interval and a larger sample size are suggested for future work. The lack of difference in throughfall may also be due to the relatively small size of the vine maple gaps as indicated by their low D/H ratios.

We hypothesized that soil moisture levels would be higher in vine maple gaps than in the surrounding forest because of expected higher levels of throughfall and lower levels of transpiration in the gaps. Results, however, showed that soil moisture contents at all measured depths (30, 50 and 80 cm) were not significantly different between vine maple gap and conifer canopy plots in any season. These results were not consistent with those of Denslow (1987) and Lee (1978) who found that moisture levels in the upper soil horizons are consistently and significantly higher in treefall gaps than in the adjacent forest.

As previously discussed, throughfall amounts were not different between gap and canopy plots and thus inputs of moisture into the soil were likely similar in both site types. Furthermore, the high transpirational demands associated with vine maple may have offset the lower biomass found in vine maple gaps. Drew (1968) found that vine maple is capable of rapidly depleting soil moisture to a depth of 60 cm during July and August because of its extensive, vigorous root system and high transpiration rate.

Groundwater table levels were hypothesized to be higher in vine maple gaps than beneath the closed canopy throughout the year since we expected the gaps to have less interceptional and transpirational surface area. Lower total leaf area usually results in greater amounts of precipitation reaching the forest floor, less moisture being lost due to transpiration, and an increase in water table levels (Pritchett and Fisher 1987). Groundwater table levels were significantly shallower in vine maple gaps in the summer, and showed a trend towards being higher than in the conifer canopy plots in the spring. The results from soil moisture and groundwater depth measurements are not in agreement with each other. The moisture measurements indicate no differences in soil moisture status between the two site types, whereas the groundwater measurements suggest that vine maple gaps may be wetter sites. As discussed earlier, there was a non-significant trend towards higher levels of throughfall in the vine maple gaps than in the conifer canopy forest in the summer and this may partially explain the higher water tables in gaps. Furthermore, the lower total leaf area on the vine maple gaps may have resulted in decreased transpiration and thus higher water tables. Another possibility is that the sites where vine maple gaps occur are inherently wetter than the surrounding forest; however the sites were chosen to have similar slope, aspect and elevation and it is unlikely that they have inherent moisture differences. A study at the landscape level of vine maple gap location and estimated soil wetness may help to answer the question of whether the vine maple gaps occur on inherently wetter sites.

Expanded gap size was not related to groundwater table levels in vine maple gaps. Groundwater table levels were likely related more to subsurface drainage patterns than to vine maple expanded gap size. Groundwater table levels in the winter were related to percentage slope. Plots located on steeper slopes had significantly deeper groundwater table levels than plots on less steep slopes.

Influence of Microtopography on Soil Temperature and Moisture Status

Microtopography had a significant influence on both soil temperature and moisture status. Pits had lower midday soil temperatures in the summer and higher midday soil temperatures in the winter compared with mounds. Therefore, the pits have a lower amplitude of fluctuations in temperature than the mounds. The pits had significantly higher moisture contents at the 50 and 80 cm depths and shallower groundwater tables, indicating that the pits were wetter than the mounds. Higher moisture contents in pits are likely due to the lower elevation of pits relative to mounds. Temperature differences between pits and mound are probably due to the elevated moisture content in pits. Due to the high specific heat of moist soil and to evaporative cooling (Pritchett and Fisher 1987), the soil moisture moderates soil temperatures and results in pits being cooler in the summer and warmer in the winter than mounds.

The trends in soil temperature and moisture between pit and mound microsites were similar to those found in the literature. Beatty (1984) and Peterson et al. (1990) found lower soil temperatures in the summer, higher soil temperatures in the winter, and higher soil moisture contents in pits as compared with mounds. In a study of seven sites chosen at different positions on the north- and south-facing slopes of a moderately rolling till knob, Macyk et al. (1978) found the temperature to be lowest and the moisture content to be highest at the lowest slope position in the landscape.

CONCLUSIONS

The results of this study suggest that midday soil temperature and moisture in vine maple priority gaps and within the closed canopy forest are similar. The only significant difference between the two site types was a shallower groundwater table in the vine maple gaps in the summer. There were also a few non-significant trends: lower midday air temperatures in the gaps in the spring and summer; and more throughfall and shallower depths to the groundwater table in the gaps in the summer; and a shallower groundwater table in the gaps in the summer. There were no significant differences in midday soil temperature at 10 cm depth or moisture content at 30, 50 and 80 cm depths. These results suggest that trends in microclimates that have been found in treefall gaps do not appear to occur in vine maple gaps. This may imply that other processes that are influenced by treefall gaps, such as increased decomposition and mineralisation, may not be as greatly influenced by vine maple priority gaps. The lack of differences in soil temperature and moisture status may partially explain the lack of differences in decomposition rates of vine maple litter and of conifer litter between vine maple gap and conifer canopy plots (Ogden and Schmidt 1997). The ecological role of vine maple priority gaps appears to be different than that of treefall gaps.

In contrast with the lack of differences between vine maple gap and closed conifer canopy plots, there were many differences between pit and mound microsites. Compared with mounds, pits had significantly: lower mid-day air temperatures at 20 cm above the soil surface in the summer; higher soil temperatures in the autumn and winter and lower soil temperatures in the summer; higher soil moisture contents at 50 and 80 cm depths in all four seasons; and shallower depths to groundwater in all four seasons. Clearly, the effect of microtopography on soil temperature and moisture in this study was much greater than the effect of the presence of a vine maple gap. This study emphasises the need for researchers to consider microtopographic differences when setting up soil sampling schemes in forests with variable microtopography. This study confirm results of earlier studies that found a significant influence of microtopography on soil temperature and moisture (Macyk et al. 1978; Beatty 1984; Peterson et al. 1990).

The lack of significant differences in soil moisture and midday soil temperature between vine maple gaps and the surrounding conifer canopy forest may be due to a number of factors. The vine maple gaps had quite low diameter to height ratios (D/H ratio) and the microclimate of gaps with low D/H ratios is moderated by the shade of surrounding trees (Canham et al. 1990). Vine maple foliage may have a significant moderating effect on soil temperature and moisture status. It is possible that there were significant differences between vine maple gaps and the surrounding conifer forest that were not detected due to low power of the statistical tests associated with small sample size (Toft and Shea 1983). Further research, therefore, with a larger sample size may be warranted.

ACKNOWLEDGMENTS

Dave Johnson, Brian Roberts and Chad Wardman assisted in the field work. Rachel McGhee provided data concerning the paired plots (expanded gap size). The Greater Vancouver Regional District staff gave permission to carry out this research in the Seymour Demonstration Forest. Financial assistance for this research came from Forest Renewal BC and the Natural Sciences and Engineering Research Council.

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