Effects of forestry practices on forest microclimate

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Abstract

The Fallingsnow Ecosystem Project was initiated in northwestern Ontario in 1993 to assess the effects of alternative conifer release practices on ecosystem processes and components. Treatments included two herbicides, glyphosate (G) and triclopyr (T), and two cutting treatments, manually with brushesaws (B), and mechanically with a Silvana (S) Selective mower. Treatments were applied to 4 clearcut blocks, each 30-60 ha, harvested between 1986 and 1988, and planted with spruce. Clearcut controls (C), 5-7 yrs old in 1993, constituted a 5th treatment, and unharvested forest (F) controls, approximately 100 yrs old and consisting of mixedwood species adjacent to each block, constituted a 6th treatment. Study objectives were to quantify treatment-related microclimatic differences and to assess the duration of these differences. Weather stations, programmed to continuously monitor light, air and soil temperatures, and relative humidities were deployed on a maximum of 3 blocks from 1994 through 1998 in the C, B, G, and F treatments. Repeated measures ANOVA’s were used to assess seasonal (June through October) treatment differences in 1998 for 2 replicated blocks. Analyses revealed significant treatment differences for 20 of 22 measured parameters. Release treatments were characterized by more light, higher air and soil temperatures, and lower humidities 5 years after treatments. Less light and higher humidity were observed for the unharvested forest compared with the clearcut control 12 years after harvesting. Seasonal air temperature extremes, for daily highs and lows, were associated with the glyphosate treatment, where non-woody vegetation was dominant. Mean daily high soil temperatures remained highest for the glyphosate treatment, and higher than for all other treatments. These data suggest that the effects of routine forestry practices in altering forest microclimate are longer-lasting than anticipated. Changes in forest microclimate are likely contributing to global warming and to global environmental change. The extent and significance of these contributions are yet to be determined.
1 Introduction

Recently a number of studies [1] have been devoted to documenting the consequences of conifer release treatments on forest ecosystem processes and their impacts on important forest species. These studies, including microclimate [2, 3], have clearly elucidated the positive impacts of improved seedling microclimate on enhanced soil nitrogen mineralization [4] and greater seedling photosynthesis and growth [5]. Additionally, these studies [1] have confirmed that forest habitat is sometimes improved for a number of non-crop species such as birds [6] and that key ecosystem processes such as nutrient cycling [7] are not adversely affected. Despite these endeavors, little thought and time and energy have gone into considering the potential impacts of these favourable climatic changes on global warming or on global environmental change. Therefore, the focus of this paper is devoted to this topic. Specifically, the intent is to document the nature and duration of climate changes associated with routine forestry practices, and to suggest how these changes may be impacting global warming and global environmental change at a forest landscape level.

2 Methods

2.1 Research site

This study is a component of the Fallingsnow Ecosystem Project [1], located near Thunder Bay, Ontario in northwestern Ontario. Detailed descriptions of the experimental design for this project [8, 9] are provided elsewhere. Briefly, the project was initiated in 1993 and uses a randomized complete block design, with four 28-52 ha spruce blocks that were cut and planted 4-7 years before the study began. Each block contains five postharvest treatment plots including two herbicides (i.e., glyphosate, Tradename = Vision, manufactured by Monsanto and triclopyr, Tradename = Release, manufactured by Dow-Elanco), two cutting alternatives (i.e., manual release with brushsaws and motor-manual release with a tractor mounted Silvana Selective cutting head), and a control (no treatment). Unharvested forests adjacent to each block constituted a sixth treatment. The various treatments were designed to control overstory trembling aspen (Populus tremuloides Michx.) and other non-conifer species.

2.2 Meteorological monitoring

Treatment-related meteorological parameters were monitored continuously throughout the 1998 growing season (June-October). Eight weather stations were deployed on blocks 2 and 3 in the unharvested forest (F), clearcut control (C), brushsaw (B), and glyphosate (G) treatments. The stations were equipped to monitor photosynthetically-active radiation (PAR) and air temperatures at 0.25 and 2 m above the forest floor and soil temperatures at 5 and 15 cm depth [2, 3]. Li-Cor LI-1000 dataloggers were programmed to monitor sensors continuously and to record integrated (PAR), mean, maximum, and minimum
values on a 24 h basis starting at midnight. Li-Cor (Li-Cor Inc., Lincoln, Nebraska) quantum and temperature sensors were used. Vaisala humidity sensors were used.

2.3 Vegetation assessments

Vegetation heights and leaf area indices (LAI) of competing vegetation were measured annually [5, 10] in late summer or early fall, prior to leaf senescence, at 5 sub-plot locations/treatment/block. Sub-plots corresponded with the locations of permanently established meteorological stations, soil moisture probes, lysimeters, and permanently monitored white spruce seedlings. Twenty-five white spruce seedlings were located at each location. Leaf area indices of competing vegetation around each seedling were determined using a Li-Cor LAI-2000 Plant Canopy Analyzer (PCA). Additional measurements of leaf area were made at each unharvested forest site in 1998. LAI was measured around the base of each seedling (crown edge) or meteorological installation with the PCA sensor, equipped with a 90° lens cap, facing out from the seedling or installation in north, south, east, and west directions. Measurements were subsequently recomputed to exclude data collected by rings 3 through 5 of the PCA sensor. By limiting radiation measurements of the PCA sensor to a zenith angle of 43°, leaf area estimates were restricted to overstory vegetation.

2.4 Data analysis

Lines (5th degree polynomial) were fitted to seasonal meteorological data using CSS Statistica (StatSoft, Tulsa, Oklahoma) graphics software. Analyses of variance (ANOVA's) were performed on seasonal meteorological parameters using daily measures of these parameters for each treatment [11]. Daily means for the two treatment blocks were used in the analyses. Seasonal means for the various parameters were then correlated with leaf area values at each of the meteorological stations. CSS Statistica software was used to perform statistical analyses.

3 Results

3.1 Vegetation characteristics

In 1998, vegetation heights for the four meteorologically monitored treatments ranged from approximately 1.2 m for the glyphosate treatment to nearly 30.0 m for the unharvested forest. Heights for the clearcut control and brushsaw treatments were 6.1 m and 2.3 m, respectively. Leaf area indices for sub-plots where meteorological equipment was located varied according to treatment. For the three clearcut treatments, leaf area was highest for the control treatment (3.9 m²/m²), intermediate for the brushsaw treatment (2.5 m²/m²), and lowest for the glyphosate treatment (0.9 m²/m²). Leaf area of the unharvested forest overstory was 4.1 m²/m².
3.2 Meteorological parameters

Light conditions (PAR) at 2 m were highest seasonally for the two clearcut release treatments, glyphosate and brushsaw, where vegetation was less developed and lowest for the unharvested forest and clearcut control treatments, where vegetation was most developed (Figure 1, Table 1). At 0.25 m, light conditions were similar for the forest, control, and brushsaw treatments (Figure 2, Table 1). Concurrently, seasonal (June 2 through October 14) air temperature extremes (daily maximum and minimum values, °C) were associated with the glyphosate treatment (Figures 3 & 4, Table 1). The lowest humidity values were also observed for the glyphosate treatment (Figure 5, Table 1). Soil temperatures were generally highest for the glyphosate treatment (Figure 6, Table 1).

3.3 Effects of vegetation development on meteorological parameters

Available light (PAR), air temperatures, and soil temperatures were negatively correlated with leaf area (Figure 7, $y = 25.894 - 1.076x$), decreasing as leaf area increased (forest and control treatments), and increasing as leaf area decreased (brushsaw and glyphosate treatments). Concurrently, relative humidity was positively correlated with leaf area, increasing as leaf area increased (forest and control treatments) and decreasing as leaf area decreased (brushsaw and glyphosate treatments). Most correlations were significant and modest ($r = -0.75$, PAR, 2 m; $r = -0.83$, PAR, 0.25 m; $r = -0.77$, air, 0.25 m; $r = 0.72$, humidity, 2 m; $r = 0.70$, humidity, 0.25 m), accounting for 49% to 69% of observed variance.

3.4 Observed differences between daily maximum and minimum values

Differences between daily maximum and minimum values for measured meteorological parameters were greatest for the glyphosate treatment (Figure 8, Table 2). The biggest observed differences were for air temperatures and humidities at 0.25 m and soil temperatures at 5 cm depth. Based upon seasonal means, maximum and minimal air temperatures differed by 18.2°C, humidities by 60%, and soil temperatures by 3.8°C. This compared with of 9.5°C, 43%, and 2.4°C for the unharvested forest treatment, differences approaching 2-fold for the two treatments.
Figure 1: Daily photosynthetic radiation at 2 m

Figure 2: Daily photosynthetic radiation at 0.25 m
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Figure 3: Maximum air temperature at 2 m

Figure 4: Minimum air temperature at 0.25 m
Figure 5: Minimum relative humidity at 2 m

Figure 6: Maximum soil temperature at 15 cm depth
Table 1: Mean seasonal (June 2 through October 14) values for various meteorological parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Location</th>
<th>Forest</th>
<th>Control</th>
<th>Brushsaw</th>
<th>Glyphosate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum PAR (umol . s⁻¹ . m⁻²)</td>
<td>2 m</td>
<td>619 d</td>
<td>789 c</td>
<td>1629 b</td>
<td>1852 a</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>395 c</td>
<td>437 c</td>
<td>699 b</td>
<td>1376 a</td>
</tr>
<tr>
<td>Daily PAR (mol . m⁻² . d⁻¹)</td>
<td>2 m</td>
<td>2.2 c</td>
<td>3.0 c</td>
<td>27.2 b</td>
<td>34.0 a</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>0.8 c</td>
<td>1.5 bc</td>
<td>2.5 b</td>
<td>18.0 a</td>
</tr>
<tr>
<td>Maximum air temperature (°C)</td>
<td>2 m</td>
<td>19.9 b</td>
<td>21.2 b</td>
<td>21.6 ab</td>
<td>22.9 a</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>21.0 c</td>
<td>21.8 bc</td>
<td>23.0 b</td>
<td>26.0 a</td>
</tr>
<tr>
<td>Minimum air temperature (°C)</td>
<td>2 m</td>
<td>12.7 a</td>
<td>11.8 ab</td>
<td>10.8 b</td>
<td>10.8 b</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>11.5 a</td>
<td>10.3 a</td>
<td>8.5 b</td>
<td>7.8 b</td>
</tr>
<tr>
<td>Maximum humidity (%)</td>
<td>2 m</td>
<td>92 a</td>
<td>91 ab</td>
<td>91 ab</td>
<td>90 b</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>98 b</td>
<td>98 b</td>
<td>99 ab</td>
<td>100 a</td>
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<tr>
<td>Minimum humidity (%)</td>
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<td>58 a</td>
<td>53 b</td>
<td>52 ab</td>
<td>43 c</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>55 a</td>
<td>49 b</td>
<td>46 b</td>
<td>40 c</td>
</tr>
<tr>
<td>Maximum soil temperature (°C)</td>
<td>5 cm</td>
<td>15.1 b</td>
<td>15.2 b</td>
<td>15.6 a</td>
<td>16.2 a</td>
</tr>
<tr>
<td></td>
<td>15 cm</td>
<td>13.5 b</td>
<td>13.4 b</td>
<td>13.0 b</td>
<td>14.3 a</td>
</tr>
<tr>
<td>Minimum soil temperature (°C)</td>
<td>5 cm</td>
<td>12.8 a</td>
<td>12.0 ab</td>
<td>11.3 b</td>
<td>12.4 a</td>
</tr>
<tr>
<td></td>
<td>15 cm</td>
<td>12.9 ab</td>
<td>12.4 b</td>
<td>13.2 a</td>
<td>13.3 a</td>
</tr>
</tbody>
</table>

Mean values followed by the same letter are not significantly different at the 5% level according to Tukey’s test.
Figure 7: Maximum air temperature at 0.25 m vs. LAI of surrounding vegetation

Figure 8: Air temperature difference (Maximum minus Minimum) at 0.25 m
Table 2: Mathematical differences between mean seasonal max/min values.

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Brushsaw</th>
<th>Glyphosate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature ($^\circ$ C)</td>
<td>2 m</td>
<td>7.2</td>
<td>9.4</td>
<td>10.8</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>9.5</td>
<td>11.5</td>
<td>14.5</td>
<td>18.2</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>2 m</td>
<td>34</td>
<td>38</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>0.25 m</td>
<td>43</td>
<td>49</td>
<td>53</td>
<td>60</td>
</tr>
<tr>
<td>Soil temperature ($^\circ$ C)</td>
<td>5 cm</td>
<td>2.4</td>
<td>3.2</td>
<td>4.3</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>15 cm</td>
<td>0.6</td>
<td>1.0</td>
<td>0.6$^1$</td>
<td>1.0</td>
</tr>
</tbody>
</table>

$^1$ Block 3 only

4. Discussion

4.1 Comparison with prior results

Fewer significant treatment differences were observed in 1996 [3] than in 1998. This is thought to have resulted largely from a difference in statistical approach. Meteorological data collected in 1995 and 1996 were analyzed using a randomized complete block design where seasonal block means for the various treatments were treated as replicates [12]. This approach differs from the repeated measurements approach initially used in 1994 [2] and again in 1998 [11], and results in fewer statistically significant differences.

4.2 Implications for global warming and global climate change

Changes in forest microclimate are likely contributing to global warming and to global climate change. The extent and significance of these contributions are yet to be determined. This is in large part due to the need for new methodology to properly assess the impacts of forestry practices on global climate and to place these contributions in perspective with other factors. Clearly, results from the present study suggest that the effects of routine forestry practices in altering forest microclimate are much longer-lasting than previously anticipated.

To properly assess these effects on global climate, these and other data for differing forest ecosystem types will need to be addressed on a landscape scale. Similar meteorological data is required for other major forest ecosystems including other boreal, temperate, sub-tropical, tropical, and rainforest (temperate and tropical) forest sites. As these data are acquired, they must be analyzed in a meaningful way which scales up stand observations to a landscape level for major forest ecosystem regions of the world.

Such efforts have not been a major focus of forestry research largely because of the forest community’s preoccupation with harvesting, forest production, forest renewal, and forest sustainability. Our tendencies to view forest sustainability narrowly with a primary focus on future fiber production has also limited our ability to conduct broader forest sustainability research which does and should include the impacts of forestry practices on global
climate. In addition, our current focus on climate change in terms of how it will impact future fiber production, forest insect and disease problems, and forest fire hazard is a prime example of this narrow thinking. If current forestry practices prove to be negative to global climate, then future sustainability is threatened regardless of our abilities to enhance fiber production.

Assuming that some emphasis is placed upon collecting the necessary data to accurately determine the current impacts of forestry practices on global climate, then the problem becomes largely one of properly interpreting these data. Data presented in this paper (Table 2) clearly show the differential impacts of differing routine forestry practices in affecting air and soil temperatures and relative humidity. The differential between daily maximum and minimum values, particularly for temperatures, is a measure of heat transfer from the Earth’s surface to the surrounding atmosphere. The mathematics of this process is defined by the science of thermodynamics involving such topics as mass heat transfer and boundary layer conductance, a realm not especially familiar to most foresters or even forestry researchers. Therefore, it is clear that this is an interdisciplinary research problem which requires the talents of forest ecologists, meteorologists, physicists, modelers, and likely physical chemists to fully solve.

Assuming that such a team can be assembled (this is most likely a problem of funding), then we will need to know for each ecosystem type, a quantification of heat transfer for key treatments (practices) such as those presented in this paper. Specifically, some sort of measure of atmospheric warming per unit of area on the ground is needed. For example, we need to know how much atmospheric temperatures rise daily per hectare of land mass for key practices such as clearcut harvesting, partial cutting (i.e., shelterwoods, etc.), and various forms of forest tending, including brush cutting and herbicide use. Once this is known, it should then be possible using geographic information systems (GIS) to scale this up to the landscape level for key forest ecosystems, and to further scale this process globally.

Regrettably, the current paper stops short of achieving this objective even for one forest ecosystem type. However, if this paper can serve as a catalyst for the above-defined process to begin, it will have more than achieved its objective.

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References


