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SNOW EVAPORATION AND THE AERODYNAMIC PROPERTIES OF AN ARTIFICIAL JUVENILE LODGEPOLE PINE STAND

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1. INTRODUCTION

In exposed areas of the foothills of the Rocky Mountains of Alberta, strong and dry winter winds can evaporate about 50 mm of the 500-700 mm of annual precipitation (Golding, 1978). This *in-situ* loss can affect the annual water yield and, potentially, the survival of seedlings in cut-over areas. Forests shelter the snowpack from the evaporative action of the wind. This protection, once removed by logging, comes back gradually with the regrowth of the trees. For management purpose it would be desirable to know the level of snow evaporation protection offered by the stand as a function of stand characteristics such as tree height and density.

In order to address this question, a small artificial pine stand was put in place close to our permanent research facility. The experiment had two principal goals: 1) to create in that stand, wind patterns comparable to those obtained in a much larger natural stand of similar height and density; and 2) to determine if wind characteristics in that stand could be related to stand parameters such as height, density or areal coverage.

2. METHODS

In the fall of 1986, 400 lodgepole pines, 2-3 m tall, were tied to angle irons pounded into the ground on a 2x2 m grid in a large grassed pasture with fetch in excess of 1 km (Fig. 1). The stand filled the western half of circle 30 m in radius. The base of the crowns had a diameter of about 1 m. Four 12-meter instrument towers were installed in and around the stand. Towers 1, 2 and 3 were installed in the stand, 5 m back from its east border. Tower 4 was erected in the field south of the stand to measure winds free of stand influence.

Through stand configuration and tower placement, the experiment was designed to measure westerly winds. In Alberta, these winds are generally associated with dry air masses that favor evaporation. All analysis presented below are based on periods with such winds.

Wind velocity and direction were measured with XY pairs of R.M Young low threshold (0.1-0.2 m sec^{-1}) gill propeller anemometers (model 27106) on tower 1 at z = 1 m, 3 m and 12 m, and on tower 2 at z = 3 m and 12 m. R.M. Young 3 cup photo chopper anemometers (model 12102, 0.35 m sec^{-1} threshold) were used to measure wind velocity on tower 3 at z = 1 m, 3 m, and 12 m. Three R.M. Young high threshold gill propeller anemometers were also placed at similar heights on tower 4, and were meant as back-up in case of failure of the anemometers on towers 2 or 3. After two weeks of comparison between readings obtained from low threshold gill propeller anemometer and from the 3 cup anemometers, the two instruments from tower 2 were lowered into the canopy at z = 0.5 m and 1.5 m.

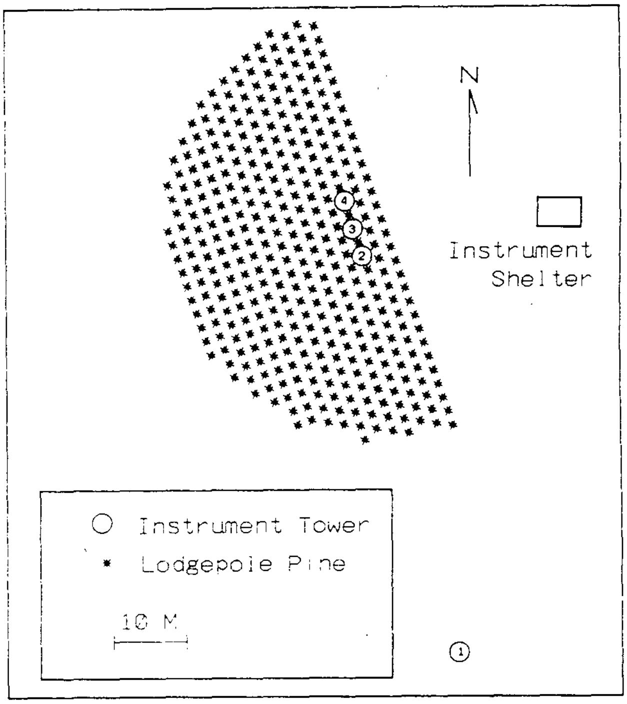

Fig. 1. Configuration of the artificial lodgepole pine stand and placement of the instrument towers.

Air temperature and relative humidity were monitored on towers 1 and 3 at z = 1 m using PCRC humidity transducers (Phys-Chem) and thermistors. All instruments were scanned every three seconds by two Campbell Scientific 21X data-loggers. An on-board program transformed the XY gill propeller anemometer readings into velocity and direction. The 20-minute average of the readings were recorded on the data-loggers and periodically transferred to tape.

Snow evaporation was measured with eight styrofoam pans, 400 cm^2 in surface area each, set in the snow at the base of the instrument towers. The pans were kept filled with snow and weighed daily at 08:00 and 16:00. During melt, the snow was replaced at least once a day. Measurements were taken from mid-January to early April of 1987.

3. RESULTS AND ANALYSIS

3.1 Wind penetration

Wind penetrating into a forest's edge slows down gradually over a certain distance until the downward flux of momentum balances out the frictional loss in energy. At that point, the wind in the forest reaches its equilibrium velocity. The penetration length necessary to reach equilibrium velocity is determined principally by the forest structure. In the context of this study, one important question was wether or not penetration depth in the artificial stand exceeded the 25 m distance between the instrument towers and the west edge.

Raynor (1971) measured a penetration depth of about 6 tree heights (H) through the trunk space of a pine forest. Meroney (1968) measured penetration depths of about 20 H in the trunk space of a moderately dense stand of plastic trees in a wind tunnel. The artificial stand created in this study was also moderately dense but, unlike the stands studied by Raynor (1971) and Meroney (1968), had a canopy extending down to the ground. It is therefore possible that the 25 m depth (10 H) offered by the stand was sufficient to slow canopy-level winds to equilibrium velocities.

Figure 2 compares average daily wind profiles obtained in the stand, at towers 2 and 3, to those obtained in the open at tower 1 during the same days. The wind profiles measured in the stand show the strong momentum absorbing effect of the trees. Wind speeds at z = 1 m were modeled over the 25 m distance between the stand edge and the tower. The calculations based on estimates of vertical momentum transfer and resistance of the trees suggest that equilibrium velocities were reached 20 m into the stand. This, the experimental results from Raynor (1971) and Meroney(1968), and additional evidence presented below with respect to wind speed reduction indicate that the wind measurements obtained in the artificial stand were representative of conditions prevailing in large natural stands of similar density and height.

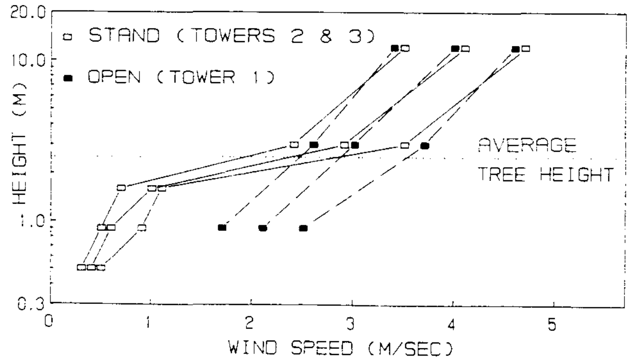

Fig. 2. Wind profiles obtained in the stand (towers 2 and 3) and in the open (tower 1) for three separate days.

3.2 Wind speed reduction

The second objective of the study was to relate wind characteristics in the stand to stand parameters. One of the characteristics that is important for snow evaporation is the wind speed reduction. Under neutral conditions, in an open field, the relation between wind speed and snow evaporation is linear. The reduction of wind speed by a stand might therefore provide a first estimate of the protection the stand offers to the snow from *in-situ* evaporation.

The wind speed at z = 1 m in the stand (tower 3) was always about 42% of that at the same level in the open (tower1). Such constant ratios have been observed by Raynor (1971) and others. Stathers (1986) measured forested-to-open wind speed ratios in stands of coniferous coastal forest regrowth at on Vancouver Island. Figure 3 shows the ratios he measured plotted against H/z, where H is the height of the stands sampled and z is the height of wind speed measurements (3 m). Also plotted is the ratio of 0.42 measured in this study. Figure 3 reveals that this study's artificial stand showed wind reduction properties similar to those of natural stand, thus supporting the point made on wind penetration and equilibrium velocity in the stand. It also shows that the capacity of a stand to reduce wind speed is related to tree height, an easily measured stand parameter.

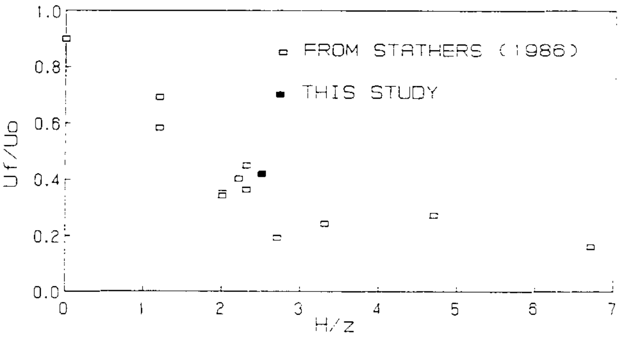

Fig. 3. Forest-to-open wind speed ratios (U_f/U_o) as a function of stand height (H) divided by wind measurement height (z). From Stathers (1986), z = 3 m, and this study, z = 1 m.

An estimate of wind speed reduction was also computed using the formula proposed by Szeicz *et al* (1979):

$$\frac{U_f}{U_o} = \left[1 + \beta \left(\frac{\delta\ H}{z} + h^* \right) \right]^{-2} \qquad (1)$$

where U_f and U_o are wind speeds in the forest and in the open (same measurement height), β is an empirical constant evaluated at 1.16, H is the tree height, Z is the height of the instruments, h^* is an empirical value for factoring in boulders, shrubs or other ground irregularities, and δ is a stand density index. The term h^* was omitted in this calculation because of absence of any ground irregularity in the pasture. The density term δ was calculated as:

$$\delta = \frac{\pi}{4} \frac{(CBD)^2}{A} \qquad (2)$$

where CBD is the average crown base diameter and A is the average ground surface area occupied by each tree. The calculation yielded a wind speed ratio of 0.40 at z = 1 m, compared to the value of 0.42 measured in this study. This close agreement reveals the predictability of the wind reduction capacity of open stands.

3.3 Roughness length

Roughness length, z_0, is another parameter linked to snow evaporation, that could be used to integrate stand characteristics in a predictable manner and that could be indexed to snow evaporation in the stand.

In the open field, the roughness length was determined form the wind profile measured at tower 1. The snowpack in the field barely covered the 10 cm high stubble which, with the sun cups created a surface whose roughness could vary from 0.4 cm to 1.2 cm depending on the level of melt or the depth of a recent snowfall.

The roughness length induced by the stand was not well represented by the above-canopy measurements (z = 12 and 3 m) on tower 3. The minimum fetch requirement of about 100 times the height of the instrument suggested by Male and Gray (1981) was obviously not met for either of these measurement points. However, wind measurements in the canopy (z = 0.5 m, 1.0 m and 1.5 m) revealed a near logarithmic profile (Fig. 2), instead of the exponential form usually proposed for canopy flow (Kawatani and Meroney, 1970; Businger, 1975). Using the wind measured at those three points, and the standard logarithmic wind profile equation without displacement height, roughness height was estimated as 16 cm for wind speeds greater than 3 m sec^{-1} at z = 12 m. For comparison, the roughness length formula proposed by Lettau (1969) yielded a z_0 of 30 cm when the trees were assumed to be solid cones, and 15 cm when an estimated tree porosity of 50% was factored in.

3.4 Snow evaporation

Evaporation from snow within the artificial stand was about 30% of that measured in the open field at tower 1. Computations using the bulk aerodynamic approach (Moore, 1983) and the bulk form of Richardson number to correct for atmospheric stability yielded estimates of snow evaporation within 10% of the daily rates measured in the open at tower 1. The same equations overestimated evaporations rates from snow within the stand by 50% or more. Obviously, conditions within the stand violated some of the assumptions for the derivation of the bulk aerodynamic formula.

4. CONCLUSION

The wind conditions created by the artificial stand are similar to computed and measured equilibrium conditions in larger, natural stands. Some of its aerodynamic properties such as wind speed reduction and roughness length, are predictable and can be estimated from common measurements like tree density and height. The problem now remains to relate these predictable characteristics to the sheltering effect of the trees on snow evaporation.

As mentioned above, wind speeds in the stand at z = 1 m were 42% of those in the open. In a sense, this value represents the upper possible limit of snow evaporation in the stand relative to that in the open. The 16 cm roughness length computed for the stand indicates an additional resistance to vertical turbulent transfer of water vapour. It is not clear at the moment how the these two parameters can be used to accurately predict the reduction in snow evaporation in open stands.

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