ANTHROPOGENIC REDUCTION IN FOREST TREE CANOPY AS A CRITICAL FACTOR IN CRYOPEDOGENESIS

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INTRODUCTION

In the industrially-damaged lands in the vicinity of Sudbury, Ontario, the reduction in species richness and poor growth has been attributed in large part to acid, metal-contaminated soils (Amiro and Courtin 1981). Amiro and Courtin defined nine plant communities in the vicinity of Sudbury. One of these, the Birch Transition Community, lies immediately adjacent to the unvegetated Barren Community where damage has been greatest. It is characterized by widely-spaced individuals of white birch (Betula papyrifera) and red maple (Acer rubrum). Both species are stunted in their growth, are highly coppiced, and the openings between the trees are largely devoid of vegetation. Even though both white birch and red maple produce an abundance of seed, few birch seedlings and no red maple seedlings are to be found. James (1982) has suggested that the establishment of seedlings may be impeded not only by chemical factors in the soil but also by the physical factor of frost action.

The present study seeks to explain the nature, intensity and cause, or causes, of frost action in Birch Transition Community.

METHODS

Measurements were carried out on a number (between two and six) of paired sites. Each pair of sites consisted of an area with visible signs of frost disturbance and an adjacent "control" plot where disturbance was minimal or absent.

Vertical displacement of the soil was measured with reference to a rigid bar whose ends were anchored to bedrock to prevent movement of the bar with respect to the soil. Readings were taken at sunrise to ensure that no thawing had taken place owing to solar heating.

Soil temperature was measured with 0.6 mm diameter copper-constantan thermocouples buried at 1, 2, 5, 10, and 25 cm at each disturbed and control site. Readings were taken at sunrise.

Soil moisture was determined gravimetrically from both disturbed and control sites in 10 cm intervals from the surface to a depth of 50 cm. Moisture was expressed as grams of water per gram oven dry weight of soil ($g.g^{-1}$).

Soil texture analyses were obtained using the method of Bouyoucos (1951) for silt and clay, and a modification of Piper's (1962) sedimentation method for the various sand fractions.

RESULTS AND DISCUSSION

A survey was performed on four of the major communities in the vicinity of Sudbury, Ontario to ascertain the proportion of ground that was disturbed by frost action (Fig. 1). Frost action was greatest in the Barren Community (B) followed by the Birch Transition Community (BT). The amount of disturbance was less again in the Maple Transition Community (MT) and least in the Birch Maple Community (B-M). Percent disturbance was found to vary inversely with vegetation density. The Barren Community was almost devoid of vegetation whereas the Birch-Maple Community had an almost unbroken tree canopy cover.

The Birch Transition Community was chosen for detailed study because it is one of the most wide-spread forest types in the Sudbury area. Furthermore, it is a community that is receiving intensive study, both ecologically and physiologically, because there appears to

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be little tree growth and no evidence of succession towards a lusher and more diverse forest.

Where there are openings in the forest canopy the soil forms hummocks whose surface is disturbed to a greater or lesser degree. These areas are unvegetated except for a moss crust which is discontinuous and normally more frequent on the edges of the hummock than in the centre. The hummocks are thought to have formed as a result of heaving caused by segregated ice formation. Furthermore, needle ice is common on the bare, mineral soil that is typical of the hummock centres. These areas of bare mineral soil form an excellent seedbed for the seeds of birch and maple but the seedlings never survive because of surface instability.

Measurements (9 December 1981; 2 December 1982) of vertical displacement (± 1 standard deviation) across frost hummocks and adjacent control areas shows that the amount of movement was more than twice as great for hummocks as it was for control sites (Fig. 2). The vertical movement in one, individual hummock was more than 16 cm. Movement was greater in 1981 than in 1982 owing to colder conditions prior to the establishment of permanent snow.

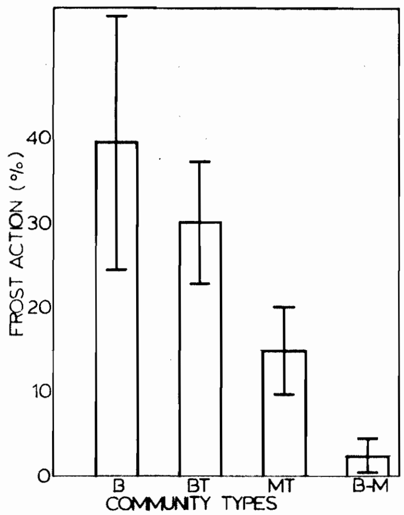

Figure 1

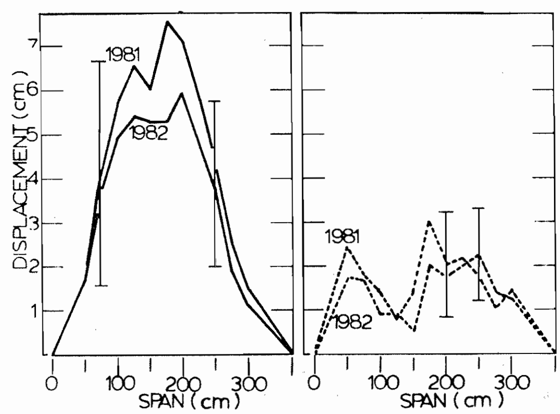

Figure 2

The mean maximum vertical displacement (±1standard deviation) of frost-disturbed (closed circles) and control areas (open circles) have been plotted against time (Fig. 3). Mean minimum monthly air temperatures (triangles) are also shown. Onset of displacement began in October and corresponded to a return to below-freezing temperatures. It should be noted, however, that the greatest displacement occurred in late November and early December at a time when mean minimum temperatures were not particularly low. The rate of displacement was reduced considerably during the next measurement interval inspite of a steep drop in minimum temperatures. The reason was the establishment of a permanent snow-pack in mid-December (arrow). Subsidence of the displaced soil took place with snowmelt and a return to above freezing temperatures, at least during daylight hours. Although night-time frosts were still experienced during this period, no evidence of renewed frost action was noted.

Measurements of mean soil moisture of disturbed (closed circles) and control (open circles) sites taken periodically during the fall (Fig. 4) indicate that there was no change in moisture throughout the profile before frost (October 5) and with diurnal frost (November 13). With the onset of progressive soil freezing (November 25), however, the water content of the upper 10 cm of the soil increased significantly and was most marked for the disturbed sites. By December 9, the upper portion of the soil on both disturbed and control sites contained more water but there was no longer any difference between sites. The presence of segregated ice lenses in the upper layers of the soils demonstrated that water had been drawn to the freezing front from the unfrozen layers below.

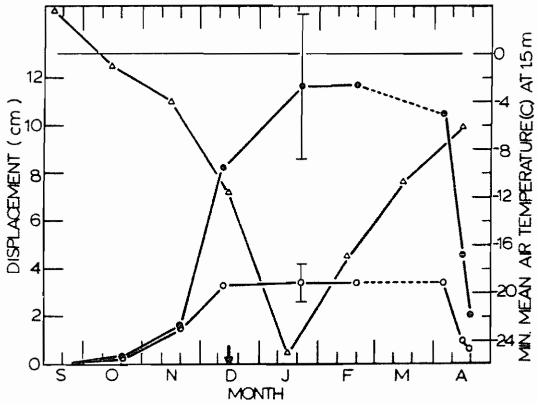

Figure 3

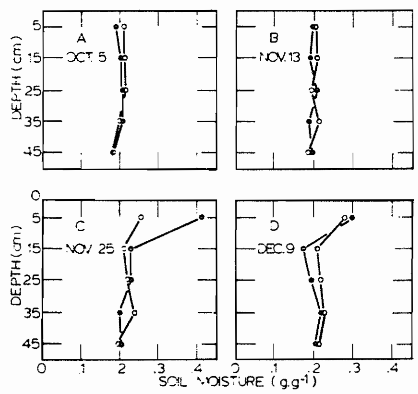

Figure 4

Schramm (1958) stated that silt plus very fine sand constituted the 'heavable fraction' of a soil and that a content in excess of 30% would cause the soil to heave. With the exception of one of the control sites all soils, both disturbed and control, from the surface to a depth of 50 cm, contained heavable material well in excess of 30%.

The effect of frost action upon tree seedlings is dramatic. Maple seedlings become established on the exposed mineral soil of hummocks and in cracks in the moss during the summer but are heaved completely out of the soil by needle ice in late Autumn before the establishment of permanent snow.

White birch appears to be more tolerant of frost action but is found only in areas where there is little or no needle ice. Individuals are found characteristically on the edge of hummocks where cracks in the moss provide a seedbed but where frost action is not too severe. Such "trees" may be at least 7 years old and yet no higher than 15 cm. Normally trees of this age are between 3 and 5 m in height. The reason is attributed to annual root pruning of the fine feeder roots as a result of frost action thus causing the tree to be dwarfed. This natural situation is somewhat analagous to the horticultural practice of "Bonsai" developed by the Japanese.

Frost action in the vicinity of Sudbury is most common where there are openings in the forest canopy and it is presumed therefore that reradiative cooling of the surface is an important aspect of the process. Moreover, the soils are comprised of large amounts of fine-textured material and contain abundant water in the Fall. Water moves freely by capillarity and this is a factor both in the formation of segregated ice and needle ice. The reasons for the spatial distribution of frost heaving, over distances as short as 1 m, are not known.

The overall effect of disturbance is to prevent or impede the establishment of seedlings in the open and unvegetated spaces between trees. These openings are characterized by extremes of temperature which lead to death of seedlings, because of drought in summer and because of frost heave in late fall before the establishment of a snowpack. The result is that the amelioration of the microclimate by means of canopy closure that could lead to vegetation succession, will not occur and the Birch Transition community will remain in a state of arrested development.

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