The chemistry of artificial snow and its influence on the germination of mountain flora

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Abstract A field and laboratory study on the effect of natural snow meltwaters and artificial snow meltwaters on the germination of the seeds of two species of tree (yellow birch [Betula alleghaniensis Britton] and white spruce [Picea glauca]) was carried out at Mont-Sainte-Anne, a ski resort, northeast of Quebec City, Canada. A survey of ground cover was also completed on transects between slopes covered with natural snow and those covered with both artificial and natural snow. The results of the laboratory study suggest that the chemical composition of the artificial snow meltwaters does not play a major role in the germination of yellow birch and white spruce. However, the rate of growth subsequent to germination may be affected as the results of the ground cover survey indicate that some plants prefer the edge of the ski slope with artificial snow to natural snow and vice versa.

INTRODUCTION

Artificial snow for skiing was first used in the form of crushed lake ice during the Christmas season of 1947 at Mohawk Mountain in Connecticut, USA (Erickson, 1980). In the last two decades the use of artificial snow manufactured by snow cannons using water nozzles and pressurized air techniques has increased significantly in many countries. Artificial snow tends to stabilize ski conditions and to prolong the ski season. Most mountain resorts in North America now invest considerable amounts of money in snow-making equipment and in operating snow canon systems. In eastern Canada, for example, much of the economy of ski resorts depends on the use of artificial snow. In the case of Mont-Sainte-Anne northeast of Quebec City, the resort has over 50 ski slopes and is a major employer in the region. Over 85% of the ski-slope area receives a cover of artificial snow (Bouchard, 1989). Before the installation of snow-making equipment the season varied between 109-167 days with an annual ski utilization of 250 000 skier-days. The more stable ski conditions produced by artificial snow result in prolonged ski seasons of approximately 164 days and utilization by up to 670 000 skier-days (Devarennes, 1994).

The different physical and chemical characteristics of artificial snow to those of natural snow, and the frequent grooming of the snow cover, have raised some concern about the ecological impacts of snow-making on mountain ecosystems. However, the
impact of artificial snow on such ecosystems has not been reported. One of the areas of concern is the chemical composition of artificial snow and its effect on the germination and growth of mountain flora. The salinity of meltwaters from artificial snow is extremely high compared to natural snow as snow cannons use either river water or ground waters. It is known that many plants start to germinate before snow cover disappears (Richardson & Salisbury, 1977). In addition, high salinity can reduce the success rate of germination (Weir et al., 1982).

In 1992 we carried out a study on the physical, chemical and ecological characteristics of artificial snow at Mont-Sainte-Anne, Quebec. The study involved two series of germination tests on the seeds of two species of tree common to the mountain, yellow birch (Betula alleghaniensis Britton) and white spruce (Picea glauca). The first test was carried out in situ at the end of the spring melt, the second in the laboratory. In addition, two transects of a ground cover survey were completed.

**METHODOLOGY**

**Study site**

Mont-Sainte-Anne (47°01'N, 71°07'W, 800 m a.m.s.l) is situated 30 km from Quebec City along the north shore of the St. Lawrence River. The mountain is a part of the Laurentian chain of Precambrian origin which stretches along the southern reaches of the Province of Quebec, Canada. Hardwood forest (maples and yellow birch) cover the lower slopes and coniferous forest (spruces and white birch) the upper slopes.

Artificial snow is manufactured by an automatic system using 18 York (Model 40) snow canons and a manual system using Leitner (one-barrel) and Ratnick (Snowgiants, two-barrel) canons. Water is pumped from the Sainte-Anne River at the base of the mountain and forced through the canon system at a pressure of 5000-6000 kPa and a maximum rate of 0.22 m$^3$ s$^{-1}$.

**Field procedures and sampling**

Natural snow was taken from an area with no artificial snow. Artificial snow was collected during the snow-making operations. Both snows were sampled by clean plastic scoops, placed in plastic bags (Whirlpak) and kept at -10°C.

Two plantations (0.72 m$^2$) for the germination of yellow birch and white spruce were staked out in spring. The first was set on a ski slope which had been covered with artificial snow for 8 continual ski seasons, the other on a slope always covered with natural snow. Each plantation contained 8 plots (0.09 m$^2$), 4 of which were planted with yellow birch seed and 4 with white spruce seed. The ground cover was removed, the seeds covered with sand and the plantation surrounded by netting. The plantation was weeded every four weeks and the seedling count taken at the end of summer.

A ground cover survey was carried out in summer. It consisted of two transects (60 m) and covered the area between the edges of two parallel ski slopes, one of which was always covered with natural snow during the ski season and the other with artificial snow. The count and identification of vegetation (<0.3 m high, or >0.3 m if the breast-height diameter was <0.01 m) were recorded (presence or absence only not
numbers) for sample areas of $1 \text{ m}^2$ ($1 \text{ m} \times 1 \text{ m}$) at every other meter along each transect. Total presence per 10 m length (i.e. total presence per 5 grid squares of $1 \text{ m}^2$) was then calculated.

**Laboratory procedure**

Germination tests on yellow birch and white spruce seeds (1600 seeds per test) were carried out in pre-sterilized germination flats (200 seeds per flat) in a sterile air chamber (Conviron G-30) under artificial light (exposure, 8 h at 30°C; darkness, 16 h at 20°C). Germination substrates were Kimpak tissue humidified with samples of either natural snow meltwaters, artificial snow meltwaters or autoclaved tap water. Both filtered and unfiltered samples were used. Yellow birch germination was considered successful if cotyledons showed within 21 days. White spruce germination was tested in two ways. The first method was exactly the same as that for yellow birch. The second applied a pretreatment of 21 days at 4°C to the seeds before subjecting the treated seeds to normal germination conditions.

**Analyses**

The conductivity and pH of melted snow samples were measured by the use of an Acumet pH meter (Fisher). Values (25°C) were determined by automatic temperature correction. Samples were filtered through Nucleopore filters (0.2 μm) and the filtrates analyzed for major anions (Cl$, $ NO$_3^-$, PO$_4^{2-}$, SO$_4^{2-}$) by ion-chromatography (Dionex 300SX), major cations (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$) by atomic absorption (Varian AA-20), and NH$_4^+$ by formation of indophenol and colorimetric analysis (Technicon-II).

Germination data were treated statistically using SAS (ANOVA).

**RESULTS AND DISCUSSION**

Table 1 shows the density, grain size, and chemical composition of natural snow and artificial snow. Sodium (52.2 meq m$^{-3}$) and Cl$^-$ (47.1 meq m$^{-3}$) were the major cation and anion, respectively, in natural snow (conductivity, 7 ± 3 μS cm$^{-1}$), Ca$^{2+}$ (354.6 meq m$^{-3}$) and HC0$_3^-$ (439.8 meq m$^{-3}$) in artificial snow (conductivity, 87 ± 9 μS cm$^{-1}$). Initial meltwaters from natural snow were acid (pH, 4.0) but those from artificial snow were alkaline (pH, 8.4-9.0).

The results for the germination of yellow birch and white spruce in both the laboratory and field studies are shown in Fig. 1. The success rate for each species was not significantly different between the plantation on a ski slope with natural snow cover and the ski slope with a cover of artificial snow. The success rate of germination and seedling development in natural surroundings is extremely variable. Although the range of success rates at the end of the summer was low (1%, yellow birch; 16%, white spruce), the seeds may have germinated but subsequent seedling growth may have failed. In the laboratory study the success rates of each species were not significantly different among all the experimental substrates of meltwaters and autoclaved water.
Table 1 Density (kg m$^{-3}$), grain size (m$^{10^{-3}}$), conductivity (μS cm$^{-1}$) and the chemical composition (meq m$^{-3}$) of natural snow ($n=3$) and artificial snow ($n=23$) Mont-Sainte-Anne, Quebec, 1992.

<table>
<thead>
<tr>
<th>Density/size</th>
<th>Natural</th>
<th>Artificial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.25 ± 0.05</td>
<td>0.45 ± 0.04</td>
</tr>
<tr>
<td>Grain size</td>
<td>0.30 ± 0.1</td>
<td>0.30 ± 0.1</td>
</tr>
<tr>
<td>Conductivity</td>
<td>7.1 ± 3.0</td>
<td>87.3 ± 9.1</td>
</tr>
<tr>
<td>H$^+$</td>
<td>20.3 ± 7.0</td>
<td>0.01 ± 0.01</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>52.2 ± 13.0</td>
<td>97.0 ± 13.0</td>
</tr>
<tr>
<td>K$^+$</td>
<td>6.0 ± 5.3</td>
<td>7.8 ± 1.2</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>24.6 ± 9.0</td>
<td>354.6 ± 42.9</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>3.9 ± 1.1</td>
<td>158.0 ± 45.2</td>
</tr>
<tr>
<td>NH$^+_4$</td>
<td>9.4 ± 2.0</td>
<td>6.0 ± 4.6</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td>47.1 ± 7.1</td>
<td>55.9 ± 9.7</td>
</tr>
<tr>
<td>NO$_3^-$</td>
<td>23.1 ± 2.0</td>
<td>19.3 ± 3.0</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>13.2 ± 1.1</td>
<td>88.1 ± 10.7</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
<td>-</td>
<td>439.8 ± 89.7</td>
</tr>
<tr>
<td>CO$_3^{2-}$</td>
<td>-</td>
<td>21.7 ± 15.2</td>
</tr>
</tbody>
</table>

tested. Success rates (% per 21 days) were high (48%, yellow birch; 83%, white spruce, for both normal treatment and pretreatment conditions).

The success rates in the field cannot be compared to those in the laboratory. In the field study the criteria to measure the rate of success are different from those in the laboratory. The field study relates seedling survival to conditions after the melt has
terminated when meltwater is in contact with soil, and the conditions during the ensuing summer. Devarennes (1994) has shown that solute content of soil waters differ depending on whether the soils are exposed to natural or artificial snow meltwaters.

The laboratory study eliminates the environmental factors found in the field (e.g. soil-meltwater interactions, ambient physical and meteorological conditions) except for the initial contact between meltwater and seeds. In addition, the laboratory study uses initial cotyledon development as a criterion of successful germination and not seedling seasonal survival. The field study does show, however, that seedling survival rates are very low in natural conditions.

The ground cover survey covered the spatial distribution of 26 species of herbaceous plants and 10 tree and bush species. Figure 2 records the distribution of 2 of the 4 species which showed a preference to grow either close to the ski slope with artificial snow (Trillium erectum) or the slope with natural snow (Clintonia borealis, Dryopteris phegopteris, and Oxalis montana).

![Ground cover transect, Mont-Sainte-Anne, Quebec](image)

**Fig. 2** Distribution of two species of ground cover plants along a forested transect (60 m) from the edge of a ski slope with only natural snow cover (0 m) to the edge of a ski slope subjected to artificial snow cover (60 m).

The results suggest that the chemical composition of artificial snow meltwaters does not play a major role *per se* in the germination of seeds of yellow birch and white spruce. However, the rate of growth subsequent to germination may be affected as the ground cover survey indicates that some plants prefer the edges of a ski slope with artificial snow to natural snow and vice versa.

The study is preliminary and conclusions from such a short-term study may be completely masked by the complex long-term interactions between ground cover, tree growth and environmental factors (Payette *et al.*, 1973). It will thus take more wide-ranging and intensive studies in the field to establish whether artificial snow does influence the growth and distribution of indigenous mountain flora over prolonged periods of artificial snow cover.
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REFERENCES


