Dendrochronology and Baseline Characterization of *Picea mariana*

in the Hudson Bay Lowlands

by
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A thesis submitted in partial fulfillment of the requirements for the Bachelor of Science in Biology

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Abstract

The Hudson Bay Lowlands are a vast region of subarctic peatlands that form the third largest wetland in the world. Peat mosses, lichens, ericaceous shrubs and a variety of vascular species including stunted trees characterize the vegetation of these peatlands. Only 5 percent of this region is well drained in the form of eskers, riparian banks and natural uplands. The De Beers Canada Victor Mine is situated in the Hudson Bay Lowlands, approximately 90 km west of Attawapiskat. This expansive open-pit mining project went into full production in the summer of 2008. This study characterizes the baseline population ecology and morphology of *Picea mariana* in the vicinity of the Victor Mine site using various forestry mensuration methods and dendrochronology. Nine populations, encompassing a variety of community types including minerotrophic fens, ombrotrophic bogs and bioherms were used in the characterization. Our analyses show that tree age cannot be predicted accurately by using morphological characteristics such as diameter and height. Dendrochronological analysis shows that growth in all populations was very slow with an average annual growth rate of 0.2 mm and did not vary over the last two centuries. However, an increased growth rate was apparent in 8 of the 9 sites over the last five years. The data of this study will assist De Beers Canada Inc. with management practices and the restoration of the Victor Mine site upon its closure.
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Introduction

Peat-forming ecosystems are an important component of northern landscapes covering approximately 14% of Canada’s landmass (Kettles & Tarnocai 1999; Gorham 1990). The difference between rates of decomposition of the sphagnum mosses and ericaceous shrubs which dominate the landscape and primary production is what sets peatlands apart from other wetland types (Keddy 2000). The formation of peat gradually isolates the surface of the peatland from the influences of the surrounding mineral soils and the peatland becomes increasingly dependent on precipitation for its nutrient and mineral requirements (Vitt et al. 1995). In fact, the supply of nutrients in a peatland often depends entirely on the content and flow rate of the water entering the peatland. Ombrotrophic peatlands (‘bogs’) receive moisture only in various forms of precipitation while minerotrophic peatlands (‘fens’) also receive surface runoff or groundwater with more minerals (Sjörs 1952). Because of this dependence on precipitation, bogs are normally highly deficient in mineral salts, low in pH and productivity (Smith & Smith 2001). Subsequently, the vegetation of ombrotrophic peatlands is highly specialized, acidophilous and poor in species richness, particularly of flowering plants (Sjörs 1959).

Two of the most important factors determining the type of wetland are water level fluctuations and mean water level. Fluctuating water levels allow for the decomposition of organic matter, which further reduces rates of organic matter accumulation leading to the development of different wetland types (Yabe & Numata 1994). Foster and Wright (1990) observed that there is a strong relationship between the stability of the water level and the
development of bogs and fens. The reason why the stable water level is necessary for the growth of *Sphagnum* is that there must be enough moisture for the prevention of desiccation and wind erosion.

Although a high water table is required for the growth of *Sphagnum* and other peat-forming species, this saturation often inhibits growth of vascular plants, including tree species. Water saturation limits soil aeration and access to nutrients (Macdonald & Yin 1999). As a result, trees grow slowly with a stunted growth form (Payette *et al.* 1994). The number of growing degree-days also significantly affects the growth and productivity of trees (Earle *et al.* 1994; Briffa *et al.* 1995)

Black spruce (*Picea mariana* (Mill.) B.S.P.) is one of the most common and widely distributed conifers in North America, ranging from the southern margin of the boreal forest to the arctic tree line (Viereck & Johnston 1990; Lavoie & Payette 1994). It is a hardy, cold-tolerant species able to withstand harsh climatic conditions under different growth forms and is the dominant tree species in the vegetation communities surrounding Hudson Bay (Pereg and Payette 1998). This evergreen tree typically holds its needles for 5-30 years and can grow in a range of infertile peatlands ranging from ombrotrophic bogs to minerotrophic forested fens (Montague & Givnish 1996).

Numerous studies concerning the distribution, growth forms and age structure of stands of black spruce have been conducted in Alberta (Woo-Jung *et al.* 2007; Macdonald & Yin 1999; Vitt *et al.* 1995; Dang & Lieffers 1989) and northwestern Quebec (Payette *et al.* 1994; Filion *et al.* 1986; Pereg & Payette 1998; Payette *et al.* 1994; Hofgaard *et al.* 1999) in peatland and upland
environments. Many of these studies use dendrochronological techniques to study tree growth and climate in these regions.

Dendrochronology is the systematic study of annual tree rings (Cook & Kairiukstis 1990). This science is based on the view that a tree is a stationary living entity that is capable of reacting to environmental factors (Schweingruber 1989). The aim of dendrochronological studies is primarily to determine the relationships among climate, site conditions, and tree growth in order to assess exogenous and endogenous factors that influence the growth of the stand of interest. Previous measurements of environmental conditions and their effects on neighbouring trees have demonstrated that a tree responds to changes almost immediately, which is generally reflected in the growth patterns of their annual rings (Schweingruber 1989). In addition to presenting the past in a historical context, dendrochronological studies also aim to better understand current environmental process and conditions with the intention of improving understanding of possible future environmental issues that may arise (Cook & Kairiukstis 1990; Brooks et al. 1998). Tree ring records are especially important data for remote areas where historical records of climate and forest dynamics are largely absent (Ise & Moorcroft 2008). For these reasons, dendrochronological studies of the dominant tree species in an area are often included in baseline environmental assessments and as part of the restoration process and closure plans for operations such as the De Beers Canada Victor Mine.

To date few dendrochronological studies have been conducted on the black spruce of the Hudson Bay Lowlands, with the exception of Scott & Stirling (2002) who studied black spruce growth in the vicinity of polar bear deans near Churchill, Manitoba at the north western edge of the lowland. The dendrochronology of white spruce (Picea glauca) has also been studied near
Churchill (Scott et al 1988). Many studies have however been conducted on the east coast of Hudson and James Bays in Québec (e.g., Payette et al. 1994; Filion et al 1986; Pereg & Payette 1998; Payette et al. 1994).

The Hudson Bay Lowlands is a vast region bordering southwestern Hudson Bay and western James Bay, covering approximately 373 700 km², or about 3.7% of Canada’s total landmass (Abraham & Keddy 2005). The lowlands contain a wide range of vegetation types that reflect local variations in climate, geological history, permafrost, fire, wildlife grazing and some human use. This region is characterized by relatively short, but warm summers (July mean temperature of 16.2°C) and experiences cold winters (January mean temperature of –20.4°C). Total annual precipitation in the lowlands is approximately 690 mm, the majority of which falls as rainfall. These climatic characteristics limit the growing season in the Hudson Bay lowlands and are responsible for the variation in productivity and morphology of the black spruce and other dominant vegetation species in the area.

In 2006, construction began on Ontario’s first diamond mine owned and operated by De Beers Canada Inc. situated in the Hudson Bay Lowlands. The De Beers Canada Victor Mine is located approximately 90 km west of the coastal community of Attawapiskat, situated on James Bay (Figure 1). The study site is located at approximately 52°N latitude and 83°W longitude in the Boreal Forest Proper region of Canada’s subarctic and is adjacent to the Attawapiskat River.

Development of the open-pit mine commenced in February 2006. The mine site itself consists of level uplands and roads created from limestone gravel and is surrounded completely by the peatlands of the Hudson Bay Lowlands. On-site infrastructure currently consists of housing for the over 300 permanent employees, on site recreation facilities, a mill and processing
plant and also on site wastewater and sewage treatment facilities. The site is accessible by air year-round and by winter road during a short period in the winter months.

![Figure 1. De Beers Canada Victor Mine site (red star).](image)

The aim of the present study is to characterize the age structure and morphology of the dominant conifer, black spruce, in the vicinity of the De Beers Canada Victor mine. The construction and development of this open-pit operation has afforded the valuable opportunity to perform a dendrochronological analysis of the trees on the western side of James Bay. As a result of this newly accessible location of study, several questions of interest arise. Here, we sample study sites in all three vegetation community types of the Hudson Bay Lowlands namely bogs, fens and small isolated uplands on limestone outcrops (bioherms). In this study we use tree ring analyses (Fritts 1976; Schweingruber 1989; Cook & Kairiukstis 1990) to (i) evaluate if there are differences in age structure and morphology between the lowland and upland areas, (ii) determine if morphological characteristics such as height and diameter at breast height (DBH)
can be used to estimate stand age, (iii) to evaluate how historical dendrochronological graphs can be used to predict future growth patterns in the study area and finally (iv) to observe how age distributions and growth rates may be affected by both physical and chemical characteristics.

**Materials and Methods**

*(i) Plot Selection*

Nine study sites were selected along a gradient of morphology of *Picea mariana* and vegetation community types. Sites were chosen to encompass different environmental gradients, which are reflected in the vegetation types, including bogs and fens as well as natural uplands on small limestone outcrops (bioherms).

At each site, a 10m by 10m plot was delineated. Two plots were situated on bioherms, while an additional two plots were situated in fen communities. The majority of study sites (five) were situated in true bog communities, in lowland areas (Figure 2 & Figure 3; Appendix A).

*(ii) Determination of pH and Conductivity*

Conductivity and pH were measured for each of the nine sample sites from the surface of the peat. Within each plot, three samples were randomly collected. In the peatland sites and one bioherm (Bioherm 3), peat samples were taken by hand from hollows within the plot. The pH was measured using an Accumet BASIC AB15 pH meter from Fisher Scientific while conductivity was measured using an Orion 4 star pH Conductivity Portable from Thermo Electron Corporation. Results were then recorded and averaged to represent each site.
Figure 2. Base map illustrating nine study sites (red circles) used in a dendrochronological study of black spruce at the De Beers Canada Victor Mine, 2008.
Figure 3. Digital photographs of nine study sites at the DeBeers Canada Victor Mine, Summer 2008.
(iii) Water Table Depth

Prior to the beginning of the field season, wells were constructed using 1-inch PVC piping. Holes 50 mm in diameter were drilled along the length of the pipes at approximately 2.5 cm intervals. A fine nylon mesh stocking was then placed over the holes, stretched and secured near the top of the well. This mesh allows only water to pass through into the well, and prevents peat from clogging the pipe. The bottom end was also secured and covered with duct tape so that the well could easily be placed into the peat without having peat entering the well.

During the month of June, the wells were installed. One well was randomly situated in a hollow within each of the nine study plots except at Bioherm 2 where no hollows had water in it. The wells were pushed manually into the peat until they could not be pushed in any further, either as a result of hitting bedrock or permafrost. Depths of the wells varied between approximately 30 to 150 cm. Measurements of water table depth were taken in both early July and mid August using a water level meter constructed from a measuring tape, a buzzer and batteries.

(iv) Mensuration of Morphological Characteristics

In June, all black spruce trees in each plot were measured for height, diameter at 30 cm above the soil surface and diameter at breast height (if possible). In the case where trees were abundantly coppiced as was often the case in the peatland sites, individual trees were selected based on dominance. Generally, the tallest stem from each coppiced black spruce was measured as the most dominant individual. Height of each tree was measured using either a measuring tape, or a Suunto clinometer for trees whose height exceeded 2 m. Both diameter measurements were taken using a DBH tape.
To determine forest canopy cover at each site, a spherical densiometer (Forest Densiometers) was used at a height of approximately 1 m above the ground. Measurements were taken from the centre of the plot, in each of the cardinal directions. Measurements were then averaged to obtain the crown cover for each of the nine study sites.

(v) Species Percent Cover

In order to characterize the sample sites by vegetation, percent cover of vascular plants, mosses and lichens was determined visually. Percent cover was determined for each vascular species separately, while moss species were grouped together as sphagnum and non-sphagnum mosses. Lichens were identified to species. As an oversight, no species percent cover data was collected for Bioherm 2.

(vi) Dendrochronology

At each of the nine sample sites, fifteen dominant trees were randomly selected for sample collection for dendrochronological analysis. Trees with a diameter of less than 8 cm were cut down using a handsaw. A disk from each tree was cut as near to the surface of the peat as possible. Cores were taken from trees with a diameter of more than 8 cm using a 30 cm long, 5.15 mm diameter Häglof increment borer. Cores were then stored in straws to ensure they were not broken while in the field.

In the lab, cores were treated with the standard dendrochronological procedures (Fritts 1976; Cook and Kairiukstis 1990) in which the cores were glued onto mounting wood using white glue and sanded with progressively finer sand papers down to a grit of 400. Sanding was used to enhance ring boundaries and to ensure that rings were fully exposed for analysis.
Processed samples were then scanned individually using a Canon CanoScan LiDE 90 scanner at a resolution of 2400 dpi. Each grayscale digital image was then imported into the WinDENDRO Mini version for analysis. Both the age of each sample and ring widths were measured using WinDENDRO, computer software developed by Regent Instruments (2006)

(vii) Data Analysis

Non-metric multidimensional scaling was performed using PRIMER 6 (PRIMER-E) in order to determine if there was similarities in cover type between study sites, using the species percent cover data. Numerous linear regressions were performed using SPSS version 15.0 in order to determine if the strength of relationships between tree age and diameter at 30cm above the peat surface and between tree age and height. For the same data sets, one-way ANOVAs were conducted using SPSS version 15.0 in order to determine the significance of the relationships between variables. Data collected for water table depth and dendrochronology were analyzed graphically through bar graphs and dendrochronological graphs respectively.

Results

pH ranged from 3.6 to 5.4 and conductivity ranged from 33.7 – 284.5 μS. Bioherm 2 was an outlier with a very low pH and high conductivity value. The highest pH (pH = 5.42) was measured at Bioherm 3, while the lowest pH (pH = 3.58) was measured at Bioherm 2. Additionally, Bioherm 2 was determined to have the highest conductivity (284.47 μS/cm). The lowest level of conductivity (33.67 μS/cm) was measured at the Trail site (Figure 4).
The water table across all sites was found to be within 0.5 m of the surface of the peat, clearly indicating waterlogged conditions except at Bioherm 2 where no water table was hit. The Cabin site was found to have the deepest water table both in July and August (Figure 5). The Kimberlite site had the shallowest water table in both months, in July the water table was measured to be at the surface. At Bioherm 2, permafrost was met before the water table (Figure 5).
NMDS was used as an index to sort sites on the basis of environmental variables of species assemblages (Figure 6). No data was collected for the site Bioherm 2 and was not included in this analysis. The NMDS was carried out with a low and acceptable degree of two-dimensional stress (stress = 0.07). The study sites appear to be equally dissimilar in terms of their species composition.

Both the Pools and Bioherm 3 sites had significant amounts of black spruce covering the plots (Appendix B). Additionally the Air Strip and Cabin sites both had significant amounts of *Cladina stellaris* and other lichens present. Bioherm 3 and the Fen sites are plotted far from the
Air Strip and Cabin sites due to their relatively low abundances of lichen species (Appendix A). The Quarry site had relatively low and even amounts of all species, except for black spruce, which has an estimated cover of 30% (Appendix A).

Figure 6. Non-metric multidimensional scaling ordination plot based on percent cover of vascular plants, bryophytes and lichens from study sites at the DeBeers Canada Victor Mine, 2008.
Heights of all sampled trees were between 0.4 and 10.5 m, while diameters ranged from 0.9 to 16.7 cm. The greatest amount of canopy cover by black spruce was observed on the two bioherm sites, with 49% canopy cover on Bioherm 3 and 54% canopy cover on Bioherm 2 (Table 1). Several of the sites that were situated in lowland areas have very little canopy cover. Quarry site had only 1% canopy cover by black spruce, while both the Cabin and Pools sites had a 2% cover (Table 1).

Table 1. Summary stand characteristics of sites situated at De Beers Canada Victor Mine, compiled from data collected in summer 2008.

<table>
<thead>
<tr>
<th>Site</th>
<th>Canopy Cover (%)</th>
<th>Total # of Black Spruce Trees</th>
<th>Age (Mean ± SE)</th>
<th>Height (Mean ± SE) (m)</th>
<th>Diameter at 30cm (Mean ± SE) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry (Q)</td>
<td>1</td>
<td>26</td>
<td>60 ± 12</td>
<td>1.00 ± 0.20</td>
<td>2.8 ± 0.5</td>
</tr>
<tr>
<td>Pools (P)</td>
<td>2</td>
<td>26</td>
<td>96 ± 19</td>
<td>2.32 ± 0.45</td>
<td>4.9 ± 1.0</td>
</tr>
<tr>
<td>Cabin (C)</td>
<td>2</td>
<td>20</td>
<td>107 ± 24</td>
<td>1.53 ± 0.34</td>
<td>3.3 ± 0.7</td>
</tr>
<tr>
<td>Air Strip (AS)</td>
<td>4</td>
<td>15</td>
<td>132 ± 34</td>
<td>1.81 ± 0.47</td>
<td>4.3 ± 1.1</td>
</tr>
<tr>
<td>Trail (T)</td>
<td>11</td>
<td>21</td>
<td>107 ± 23</td>
<td>2.00 ± 0.44</td>
<td>4.9 ± 0.9</td>
</tr>
<tr>
<td>Kimberlite (K)</td>
<td>13</td>
<td>23</td>
<td>109 ± 23</td>
<td>1.71 ± 0.36</td>
<td>3.6 ± 0.7</td>
</tr>
<tr>
<td>Fen (F)</td>
<td>24</td>
<td>28</td>
<td>72 ± 14</td>
<td>1.69 ± 0.32</td>
<td>3.3 ± 0.6</td>
</tr>
<tr>
<td>Bioherm 3 (BH3)</td>
<td>49</td>
<td>28</td>
<td>77 ± 15</td>
<td>4.17 ± 0.89</td>
<td>8.9 ± 1.7</td>
</tr>
<tr>
<td>Bioherm 2 (BH2)</td>
<td>54</td>
<td>39</td>
<td>158 ± 25</td>
<td>5.13 ± 0.82</td>
<td>9.3 ± 1.5</td>
</tr>
</tbody>
</table>
A significant relationship exists between age and height of trees sampled although the relationship was weak ($r^2 = 0.266$, $P < 0.001$) (Figure 7). A similar but weak relationship was also observed between the age and the diameter at 30 cm above the peat surface of each tree sampled ($r^2 = 0.196$, $P < 0.001$) (Figure 7).

Upon examining both height and diameter versus stand age data for individual sites, these same linear trends and levels of significance were not consistently observed. Seven of the nine study sites demonstrated significant associations between tree height and age, while only six of the nine sites demonstrated significant associations between diameter at 30 cm and age (Figure 8 & Figure 9). The Cabin site was found to demonstrate the second strongest relationships between both factors (Height: $r^2 = 0.482$, Diameter: $r^2 = 0.492$). The Air Strip site was determined not to have a significant relationship between age and height ($P = 0.113$, $r^2 = 0.182$) or between the diameters of each sample at 30 cm above the peat surface and stand age ($P = 0.416$, $r^2 = 0.052$) (Figures 8 & Figure 9). In examining the individual sites, in terms of recruitment and age, it is apparent that there was no initial recruitment event such as a fire, which occurred at any of the given sites (Figure 8 & Figure 9). Therefore, it is assumed that recruitment of new individuals occurred free from the influence of large scale events such as fires.
Figure 7. Relationship between (a) age and height and (b) age and diameter at 30 cm above the peat surface for black spruce sampled in 9 sites near the De Beers Canada Victor Mine in 2008.
Figure 8. Relationship between height (m) of *Picea mariana* trees from peat surface to crown and age per study site (n = 15), at the DeBeers Canada Victor Mine, 2008.
Figure 9. Relationship between diameter (cm) of *Picea mariana* trees at height of 30 cm from peat surface and age (years) per study site (n=15), at the DeBeers Canada Victor Mine, 2008.
The youngest stand was situated at Quarry with an average age of 60 ± 12 years (mean ± SE) while the oldest site was Bioherm 2 with an average age of 158 ± 25 years (mean ± SE) with a maximum age of 247 years (Table 1; Figure 10). Average annual ring width at the nine sites showed minimal variation over the long term (Figure 10) and demonstrate a flat trend except within the recent decade. Generally, the average growth rate remained steady at around 0.2 mm of radial growth per year at all sites, except at Bioherm 3. At this site the average growth rate was approximately 0.4 mm per year. If you consider the growth rate of individual trees at any site, it is actually quite variable (Figure 11), ranging from >0.1 mm/year to over 0.7 mm/year but the average growth of trees in a stand remains quite steady (Figure 10), except within the last decade. The apparent erratic behavior of the average growth rate growth in the early history of some stands (e.g., Cabin, Fen, Airstrip and Bioherm 2) is a function of the small number of trees in the sample for these early years.

The recent trends are best viewed if only the growth from 1980 on is graphed (Figure 12). Note that each of these graphs gives the average and standard deviation of growth based on 15 trees. One distinct anomaly was visible in this short-term data. At several sites, including the Trail, Airstrip, Pools, Kimberlite, Cabin and to a lesser extent the Quarry site, there was a increase in the mean growth rate beginning in 2005. The greatest average increase in growth rate was seen at the Air Strip site, with an increase in average growth rate since prior to 2005 of 0.47 mm (Figure 12). Bioherm 3 is the only site where growth rate is decreasing since 2005 (Figure 12). At the Fen site, this increase in average growth rate since 2005 is also present, but average ring width appears to have increased since the year 2000 at least. At Bioherm 2, an increase in average ring width has occurred since 2003.
Figure 10. Annual growth ring widths (mean +/- SD) per study site and number of samples (thin line)
Figure 11. Average annual ring widths per tree at the Trail Site.
Figure 12. Annual growth ring widths from 1980-2007 for Picea mariana samples (n = 15) collected at the De Beers Canada Victor Mine in 2008 (mean +/- SD).
This change in average annual growth rate can be quantified by comparing the average annual growth rate found in 2007 with the average annual growth rates averaged between 1980-2005. There was no relationship between this average change in annual growth rate of trees and the depth of the water table ($r^2 = 0.176$, $P = 0.262$; Figure 13). This change in average annual growth rate also shows no significant relationship with the distance of the sites to the open pit (Figure 14).

Figure 13. Change in average growth rate between 1980-2005 and 2007 in relation to water table depth measured in August, 2008 at nine study sites at the DeBeers Canada Victor Mine.
Discussion

Peat chemistry has been used in the past in supplementary descriptions of peatlands and more recently attempts have been made to use peat chemistry to characterize peatland types (Vitt & Wai-Lin 1990). Generally there is a linear relationship between peatland pH and conductivity. As the pH of a site increases, so does the conductivity (Vitt et al. 1995; Vitt & Wai-Lin 1990). Vitt et al (1995) measured both pH and conductivity at their study site in central Alberta. The bog was measured to have a pH of 3.9 and a conductivity of 37 µS/cm, while fen areas were determined to have a pH of between 5-6 and a conductivity value of 184 µS/cm (Vitt et al 1995). Values obtained for pH and conductivity at the De Beers Canada Victor Mine were within a
similar range to the aforementioned literature values with pH values between 3.5-5.4 and conductivity values ranging from 33.67 – 284.47 µS/cm. Conductivity and pH values measured in the present study did not form a linear trend as expected (Figure 4). The study site with the lowest measured pH, surprisingly had the highest conductivity (Bioherm 2). This was the only true upland site where the water table was not reached. The site had organic soils over permafrost, which may be responsible for the low pH. The high conductivity may in turn be a result of its upland nature on a limestone outcrop. More sampling of these upland limestone islands is warranted.

Upon examination of the historical dendrochronological graphs as well as the morphological data, it is evident that there is a difference in both age structure and morphology between the lowland sites and the two upland areas (Figure 8; Figure 9; Table 1). This is in contrast to the findings of Ise and Moorcroft (2008) who conducted a dendrochronological study of black spruce in northern Saskatchewan and determined that there was no difference between mean core ages among upland and lowland sites. Based on previous knowledge of the growing conditions within a bog compared to those of upland, well-drained areas, it was anticipated that the oldest study site would be situated on a limestone outcrop. An assumption can be made that because the bioherm is apparently not affected by changes in the water table or hindered by limited soil aeration and nutrient availability, trees growing on such sites would be able to grow older in age, uninhibited. On the Bioherm 2 site, there were trees that were well over 200 years old, and the discovery of such long-lived organisms at the site provides a unique opportunity to study the mechanisms of longevity in this species and potentially the historical climate in the area.
In addition to determining if there were differences in characteristic morphology and age structure between stands of lowland and upland origin, the present study also sought to determine if it was possible to estimate stand age using such morphological characteristics as height and diameter. Relationships between both height and age and diameter at 30cm above the surface of the peat and age were highly significant (P<0.001) which suggests that it is possible to approximate stand age using morphological characteristics. However, due to the low strength of the relationships (height: \( r^2 = 0.266 \), diameter: at 30cm \( r^2 = 0.196 \)) these estimates will be made with limited accuracy. The relationships between either diameter and age or height and age are stronger at some sites, but these relationships did not seem to be associated with the site type, although more extensive sampling across a wider gradient of site types may be required to assess this relationship.

Generally, with dendrochronological studies, it is possible to see trends in the long term graphs produced by analysis of annual tree rings and growth rates in a specific area (Dang & Lieffers 1989; Hofgaard et al. 1999; Ise & Moorcroft 2008; Filion et al. 1986). Although the present study demonstrated that the long-term trend across sites was flat with little variation, other studies have been able to correlate both increases and decreases in growth rate with variation in local climates (Hofgaard et al. 1999; Ise & Moorcroft 2008; Dang & Lieffers 1989). Due to the lack of long-term climatic data on site at the Victor Mine, it was not possible to construct historical graphs, which corresponded with variations in climate. The nearest long-term weather stations are situated at Attawapiskat, on the coast of James Bay and at Lansdowne House, approximately 200 km west of the De Beers Canada Victor Mine. Neither of these
climatic records would have been suitable for use in this study due to the variation in conditions on the coast of James Bay, as well as climatic variation further inland from the site itself.

Hofgaard et al. (1999) conducted a dendrochronological study along the border between Ontario and Quebec between 48°N and 50°N on black spruce. This study was able to correlate their chronologies with long-term data from weather stations nearby. It also determined that there was very little change in the growth rate of black spruce over the last 150-200 years in the region (Hofgaard et al. 1999) (Figure 15).

Figure 15. Adapted from Hofgaard et al. (1999). Chronologies demonstrate little change in growth rate over the last 150-200 years.
Growth of black spruce trees, commonly established in open forest stands, is extremely slow due to the high water table, poor soil aeration, cold substrate and low nutrient availability of these sites (Macdonald & Yin 1999). Causes for increase of average growth increment observed in the present study must therefore be related to improvements in one of these factors.

Drainage by pit dewatering is certainly an obvious hypothesis for the increase in radial growth observed in this study. In the summer of 2007 De Beers Canada began dewatering a large area surrounding the Victor Mine and pumping the water out of the water table and into the Attawapiskat River. In 2007, approximately 25 000 m$^3$ was being pumped daily. In 2008, this volume was increased to approximately 80 000 m$^3$ per day.

In natural peatlands, tree growth is strongly dependent on the depth of the water table (Jasieniuk & Johnson 1982; Lieffers & Rothwell 1987a). Significant increases in growth and changes in morphological characteristics have been observed elsewhere, as a result of the drainage of peatlands (Lieffers & Rothwell 1987; Macdonald & Yin 1999; Dang & Lieffers 1989; Hillman & Roberts 2006). Lieffers and Rothwell (1987a) determined that lowering the water table by as little as 50-60 cm over 2 years could have dramatic effects on tree growth. In a study conducted by Hillman and Roberts (2006) on the Wolf Creek peatland Alberta at similar latitudes to the present study, the mean annual increments for height, diameter, basal area and total volume determined for black spruce were compared to growth of similarly aged black spruce on a good, non-drained site. They determined that black spruce populations had increased in height by approximately 1.1m and increased in diameter at breast height by approximately 1.2cm within 6 years of drainage. Woo-jung et al (2007) also found that following drainage of
peatlands in central Alberta, ring width and basal area of black spruce was significantly increased (P < 0.001).

With the lowering of the water table, there is evidence to support that greater substrate aeration also contributes to apparent increases in growth (Campbell 1980; Hillman & Roberts 2006). In addition to these factors, the reduction in water content in drained peat also decreases the substrate heat capacity and thermal conductivity (Lieffers & Rothwell 1987a). In the spring, upon melting of the snow, surface layers of drained peatlands therefore warm more quickly than undrained peatlands, which may further facilitate improved growth.

Of interest, a study by Macdonald and Yin (1999), determined that post-drainage release growth in black spruce was inversely related to pre-drainage size. Generally, this inverse relationship between pre-drainage size and release growth may potentially lead to a reduction in size variability across sites. Larger trees were found to show initial growth reduction following drainage (Macdonald & Yin 1999). A probable cause is water stress, associated with the immediate, dramatic, lowering of the water table.

In addition to increased growth rates, previous studies determined that lowering the water table also resulted in deeper rooting depth of black spruce (Strong & LaRoi 1983). Traditionally the roots are shallow and spreading and occupy the unsaturated substrate above the water table (Lieffers & Rothwell 1987b). While there have been studies of rooting response of black spruce seedlings to different water level treatments (Lieffers & Rothwell 1986), there is little information regarding rooting of mature black spruce trees in relation to the depth of the water table. In a study conducted in Alberta, Lieffers and Rothwell (1987b) determined that the roots of black spruce penetrate deeper when the depth of the water table is greater.
If similar responses to drainage were to be observed over time at the Victor mine site they would be quite dramatic when considering that the average annual growth rate across nine sites we studied in the Hudson Bay Lowlands was approximately 0.2mm. Across most of the mine area, a thick layer of marine silts and clays which covers the limestone bedrock is expected to limit the water table changes in the overlying peat. Research is currently being conducted to determine the probable magnitude in decline in the surface water table (Jonathan Price, University of Waterloo, *pers. com*).

At our peatland study sites, the actual changes in water table elevation that may have been caused by pit dewatering are not known. At the time of these field studies, the water table in the uppermost aquifers across all sites at the Victor Mine did not fall below 50 cm in depth; however as the scale of the pumping increases, this depth is expected to increase, at least at sites at which the peat is not isolated from the underlying limestone aquifer which is being dewatered by the mine.

It is important to note that only one complete growing season (2007) had passed since pit dewatering began, yet increases in radial growth are evident at least since 2005. Although pit dewatering appears to have and will likely continue to increase tree growth, this lack of synchrony raises questions on other possible factors contributing to the increases in tree radial growth.

Placement of gravel pads for the roads, the camp and plant facilities and for the air strip may have changed local drainage patterns, although it is difficult to understand how this could have affected water tables. The excavation of the bioherm south of the airport may also have dropped water tables, prior to pit dewatering. Dust from the construction phase of the mining
operations may also have added nutrients or increased and ameliorated the pH of the study sites. Given the extensive peatlands which almost completely cover this landscape, background levels of nutrients are probably very low, so even modest increases may improve tree growth.

Another hypothesis which cannot be ruled out is the possibility that climate change caused by global warming is currently dropping water tables across the region and thereby draining peatlands and increasing tree radial growth. Climate change is expected to act on higher latitude regions and increase annual temperatures by 4-5 °C by 2040-2060 as compared to 1975-1995 (Natural Resources Canada 2003). If this were the case, changes in growth would also be expected to have occurred at considerable distance from the mine site. Further study is required to address this hypothesis.

Further studies would be required to track the progress of the black spruce communities. Further research could be conducted to see to what extent the dewatering affects the growth and morphology of individual trees at varying distances from the open pit itself. Periodic sampling will assist in compiling data to support that post-drainage release growth is occurring in the vicinity of the De Beers Canada Victor Mine site.

Results of a study conducted by Lachance and Lavoie (2004) suggests that even wetlands which are apparently resistant to disturbances, such as peatlands, can be severely affected by anthropogenic factors. Through the present study, it was determined that age structure and morphology differ between lowland sites and natural uplands. Additionally it was found morphological characteristics such as diameter at 30cm and height could be used to estimate stand age but with limited accuracy. Historical dendrochronological graphs did not demonstrate any long-term trends and therefore would be of limited use in predicting future growth patterns.
In recent years growth rates have increased and this may correlate to changes in the water table as the pit has been dewatered. These findings will aid De Beers in the proper management of black spruce populations surrounding the Victor Mine site as well as provide important information to be used in the reclamation process once the mine reaches the end of its lifespan.

**Literature Cited**


De Beers Canada Inc.


Appendices

Appendix A: Latitude and longitude coordinates of all nine sites used in this study.

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude</th>
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<td>083’55’04.0” W</td>
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<td>Trail</td>
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<td>083’55’37.0” W</td>
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**Appendix B:** Visually estimated vegetation cover (%) per site, for all sites except Bioherm 2

<table>
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<th>Species</th>
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<th>Fen</th>
<th>Airstrip</th>
<th>Bioherm 3</th>
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