GENERAL DISCUSSION

Levels of airborne pollutants

Additional to the aerially deposited trace element concentrations that were measured in plant tissue, sulphur dioxide (SO_2) is another potential pollutant originating from this electrical generating station that can adversely affect forest health. Sulphur was not chosen as a tracer element for pollution in this study as it is present in vegetation at fairly high concentrations as a component of plant proteins, so moderate increases resulting from SO_2 may be obscured (Applied Science Associates, 1978).

The maximum predicted ground-level concentration of SO_2 in the study area was 0.58 $\mu g/m^3$ annually (based on operation levels in 1998, which were historically the highest ever, but still only at a 42% capacity factor) (SENES, 2001). It has been suggested that a long-term concentration threshold of 100-150 $\mu g/m^3$ SO_2 will cause negative growth effects on forest trees, although some studies have demonstrated that annual average concentrations of 40-60 $\mu g/m^3$ SO_2 show adverse effects in conifers (Roberts, 1984). A critical level of 20 $\mu g/m^3$ SO_2 (annual mean) has been established in Europe for forest trees (Sanders et al., 1995). In comparison to these suggested thresholds, the levels of SO_2 in this study area were far below those of potential negative growth effects. Further, operations were historically less than 20% capacity on average, meaning that ambient concentrations in the past would have been even lower than the predicted annual concentration of 0.58 $\mu g/m^3$ SO_2.

It is unlikely that NO_X emissions from the generating station had any adverse effect on surrounding trees, as relatively high concentrations of NO_2 are required for visible symptoms to appear on plants, approximately 2 to 5 times the concentration of SO_2 under the same conditions (Taylor et al., 1986; Mulgrew and Williams, 2000).

Potential environmental impacts from coal-fired stations depend on the type of coal used, combustion conditions, station operating conditions and environmental characteristics (Van Voris et al., 1985). For example, there have been numerous studies on large coal-fired generating stations that use a high ash and sulphur content coal (Agrawal and Agrawal, 1989; Gupta et al., 1995). These authors studied the impacts on numerous tree species in India near 1550 MW and 3610 MW stations, which were operating with coals that had more than 30% ash content. The authors of both studies reported extensive visible injury symptoms (including necrosis and chlorosis) within 4-5 km from the generating station in almost all plant species, with injury gradually decreasing with increasing distance from the power plant. This widespread injury to vegetation was not present in the vicinity of the Selkirk station, which had less than one tenth the production capacity of these large-scale operations, and used a coal with less than 5% ash content.

Other studies that have focused on coal-fired generating stations have not demonstrated strong, negative pollution effects on surrounding forest stands. Muir and McCune (1988) studied foliar symptoms in sugar maple (*Acer saccharum* Marsh.), ash (*Fraxinus* spp.), yellow poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), and red oak (*Quercus rubra* L.) near a coal-fired station in southern Indiana. The authors found that year-to-year variations in oak growth at the site near the station were negatively correlated with SO_2 emissions from the station, but few differences were evident in terms of foliar symptoms between areas. Muir and McCune (1988) stressed that chlorosis and necrosis can indicate many different problems, including phytotoxic pollutant exposure, nutrient or water imbalances, presence of pests, and senescence. The lack of differences in foliar symptoms between the two areas was attributed to the fact that factors other than emissions from the power plant (previous history, microsites of individual trees, and climate) are more important in controlling tree growth.

According to Smith (1974), the response of vegetation to pollutants depends on the degree of pollutant loading. At low pollutant loads, vegetation can act as a sink for pollutants, and no or minimal physiological alteration occurs. The pollutants are shifted from the atmosphere to the organic or available nutrient section of the ecosystem. In a situation of intermediate pollutant load, reduced growth and reproduction may occur, as well as predisposition to disease and insect organisms. This may result in reduced productivity and biomass, and possibly altered species composition. Lastly, high air pollutant levels can lead to acute predisposition to environmental stresses and mortality. Based on the low predicted concentrations of airborne pollutants from the generating station in this study, vegetation likely acted as a sink for air pollution, transferring any accumulated pollutants to the organic or available nutrient portion of the ecosystem, as no consistent, adverse growth effects were observed in stands within the area of maximum predicted deposition. Additionally, the Selkirk station had switched from a low-sulphur lignite coal to a sub-bituminous coal in 1993, the latter with lower levels of trace elements, including many heavy metals (SENES, 2001). This fuel switching would have effectively reduced net emissions from the station following 1993.

It should be stressed however, that the Selkirk station did not possess either electrostatic precipitators or SO_2 scrubbers as pollution control devices, which can remove approximately 99% of particulate and gaseous pollutants from airborne emissions. Electrostatic precipitators are now the required pollution control devices on all new coal-fired generating stations. So, although the emissions from the Selkirk station were relatively low and discontinuous, they were comparatively “dirtier” than those from other large generating stations that are equipped with electrostatic precipitators. Almost all of the literature to date has focused on the adverse effects of emissions from generating stations with electrostatic precipitators and/or SO_2 scrubbers as pollution control devices, therefore it is difficult to compare results from this study directly to other studies looking at power plants that have these devices.

The station had operated at a very low level during the summer of 2001 when the forest health assessment was carried out, so any foliar symptoms that may have occurred during increased operation levels (e.g. in 1998, 2000) would not have been present at the time of assessment. The vigour index and the dieback index were used for this reason in the statistical analyses, as they are measures of forest health that would not fluctuate widely from year to year, as may be seen with measures of foliar chlorosis or necrosis. As the defoliation index was primarily a reflection of the level of forest tent caterpillar defoliation in plots in 2001, it was not selected for examining spatial patterns in relation to the generating station as defoliating insects do not tend to have mass outbreaks in forest trees exposed to air pollutants (Holopainen and Oksanen, 1995).

Measures of pollutant damage

Although the results of both the forest health assessment and the tree-ring analysis demonstrate that where tree decline was found it was not associated with airborne emissions from the Selkirk generating station, it may have been that macroscopic foliar symptoms and trace element analysis were not sensitive enough measures to detect any minor adverse effects on vegetation resulting from airborne emissions in plots closest to the station. A variety of studies have investigated methods of determining biochemical changes in plants exposed to increased SO_2 levels. Ricks and Williams (1975) found that enhanced levels of leaf sulphur leads to the preferential degradation of chlorophyll a over chlorophyll b, most likely from the increased acidic conditions within the leaf. Conversely, in naturally senescing leaves, they are broken down at comparable rates. Under field conditions where low SO_2 conditions exist, reduction in chlorophyll level could be a useful indicator of pollutant damage (Agrawal et al., 1991). Leaf-extract pH may also be a useful indicator as SO_2 entering the leaf is dissolved in inter-cellular water of mesophyll cells to form sulphurous acid (H_2SO_3), which depending on the pH of the medium dissociates into H^+ and HSO_3^- and SO_3^-, causing acidification of the cell (Puckett et al., 1973). A decrease in ascorbic acid, starch and protein contents following SO_2 exposure may also be related to the sensitivity of the plant (Agrawal et al., 1991).

If the forest health assessment carried out in the vicinity of the Selkirk generating station had occurred in 1998 or 2000, years of increased emissions, a comparison of one or more biochemical measures across plots could have been implemented. However, the low levels of production in the year of assessment prevented the use of such measures. Regardless, it remains that the focus of this research was on the observed macroscopic decline symptoms present within the study area, and there was no evidence indicating that crown dieback observed in bur oak stands south of the generating station was a result of airborne emissions from the station. Additionally, the station has now completely converted to natural gas operation, making any additional research on the coal-fired emissions impossible.

Conifers are considered to be more sensitive to air pollution than deciduous trees, and for this reason plots with white spruce were originally included in the forest health study. However, the only natural white spruce stands within the study area were in and near Birds Hill Provincial Park, in the far south end of the study area. There were no white spruce stands within the area of predicted maximum SPM deposition, so it would have been difficult to make any comparisons between stands based on potential pollution exposure. Additionally, control plots located between 42-85 km from the generating station were also initially included in the study for the purposes of the forest health assessment and trace element toxicology, however it was decided that focusing on plots near the generating station would be more useful when investigating causal factors for elemental concentrations and tree decline. Essentially, plots within the 16 km radius study area that were outside of the predicted area of average annual SPM deposition rate were able to serve as controls for the forest health assessment and trace element toxicology portions of the study.

Factors affecting tree health

It was determined in this study that climatic factors, including mean monthly temperature and total monthly precipitation, as well as soil conditions (e.g. nutrient levels and drainage regime) can have significant impacts on the health status of bur oak and trembling aspen trees in southeastern Manitoba. The microenvironment of individual stands, along with climatic factors, seemed to be more important in controlling tree health than were any adverse effects of airborne pollutants from the Selkirk coal-fired generating station. It is possible that in years of increased production (1976-77, 1987-88, 1998, 2000) there had been visible foliar effects and/or modifications of growth present, however there was no evidence of this in the summers of 2001 and 2002. Even if there was a small pollution effect from airborne emissions in the study area, it may have been embedded in large natural variations of tree health due to local site factors, including soil type and drainage regime.

Although tree mortality can be a useful bioindicator of forest condition, a main disadvantage is that there may be a significant time interval between the declining health of a tree and its death (Busing et al., 1996). For this reason, tree ring analysis was especially useful in determining the onset of decline in the declining bur oak stands south of the generating station. Linking the date of the onset of radial growth decline with the construction of the road adjacent to the declining bur oak sites enabled a plausible explanation for the observed decline.

When correlating forest health to causative factors, the most important question to address is whether the effects are most severe in areas of highest atmospheric pollution. It was clear from the contour maps of both the dieback and vigour indices that no spatial patterns relating to the Selkirk generating station were observable. Some considerations that need to be made in a diagnostic routine include the number of species being affected, the symptoms of injury and the part of the plant that is most affected, the distribution of affected plants (natural features including a high water table, a frost pocket or flat exposed areas can lead to localized stresses; symptoms in areas downwind from a pollution source may indicate pollutant damage), the presence of pest organisms, if similar symptoms have been seen previously (i.e. seasonality of symptoms), characteristics of the local terrain (soil, drainage), local management practices (application of fertilizers, pesticides), and local pollution sources (Taylor et al., 1986). Variation in soil type, competition, and tree age also need to be investigated (McLaughlin and Braker, 1985). In this study, variation in soil type and a high water table were clearly implicated as factors in the decline of bur oak, demonstrating the importance of investigating all natural stress factors.

Predisposition to decline is thought to arise either slowly due to microenvironment (e.g. impeded soil drainage, nutrient imbalance), or as growth shocks resulting from physical injury (e.g. frost injury, defoliation) or physiological stress such as drought (McClenahen, 1995). Within many oak species, oak decline is characterized by 1) progressive terminal branch dieback; 2) branch and bole sprout and staghead (dead branches in the outer crown) development; 3) sudden foliage wilt and browning, but no leaf drop; 4) fans and rhizomorphs of armillaria root rot often present beneath bark of roots and root collars on dying trees; 5) galleries and exit holes of the twolined chestnut borer often present in stems of dying or dead trees; 6) decline found throughout the range of oak; and 7) mortality related to site features, tree stress, and effects of insects and diseases (Wargo et al., 1983). One of the major causes of stress in trees is growing in locations to which they are not suited. Tree crowns most frequently begin to die back when the roots have been damaged or are diseased, because plants grow with a carefully balanced root/shoot ratio (Kozlowski and Pallardy, 1997). When a portion of the roots ceases to function, a portion of the crown usually dies as well. This can occur when already weakened trees are subjected to a particularly severe environmental stress (e.g. drought or waterlogging), resulting in an accelerated decline and then "sudden death"

(Hartman and Witt, 1991). Often, growth is reduced before the appearance of symptoms, and dieback symptoms can result from the effects of stress alone (i.e. even if a pest infestation does not occur following the reduced level of tree vigour). Stress, if sufficiently severe or prolonged, can result in tree mortality (Wargo et al., 1983).

The stands that exhibited oak dieback in this study had thin, sandy soils with low levels of plant-available nutrients, and poor site conditions like these are known to cause reduced growth in bur oak (Hosie, 1979). Further, the high water table, likely resulting from construction of a road adjacent to the plots just north of Birds Hill Park (plots 40 and 42), was an additional stress placed on already slow-growing trees. This added stress, although not evident by external symptoms until the late 1990's, had been suppressing radial growth since 1977. Soils that are waterlogged, compacted, or shallow have previously been implicated in oak decline (Wargo et al., 1983). It should also be mentioned that although there were no mature trembling aspen trees in either plot 40 or 42, there were some trembling aspen trees near these plots that were showing some crown dieback as well. These trees, like the declining bur oaks within the established study plots, were growing in very wet soil. Soil drainage is also important in the growth of aspen, with water tables shallower than 0.6 m or deeper than 2.5 m limiting the growth of aspen (Perala, 1990). Aspen roots have low tolerance for high soil moisture levels, and waterlogging of the soil can reduce the level of suckering (Peterson and Peterson, 1996). Additionally, aspen grows poorly on shallow soils over bedrock (Sims et al., 1990), so the combination of poor soil and a high water table was also having visible adverse growth effects on the aspen in these sites.

Other considerations

For the purposes of plot selection for the dendrochronological portion of this study in the summer of 2001, wind data were only available from the Winnipeg International Airport weather station (40 km south of the generating station), and not from weather stations closer to the source of emissions (see Appendix 4 for the wind rose diagram based on data from the Winnipeg International Airport). This initial wind rose showed that winds were predominantly from the south, and hence a subset of the forest health assessment plots were selected for sampling along a N-S transect, as well as along an E-W transect for purposes of directional comparison. However, after the dendrochronological sampling was completed, new wind data from a weather station near East Selkirk was made available, which demonstrated a SSE-NNW pattern of predominant wind direction (Figure 2.1a). This new, more accurate wind data showed a rotation of the previous wind rose approximately 22.5 degrees counter-clockwise, with an increased frequency from the NNW. Had this updated wind data been available prior to the dendrochronological sampling, selection of the plots would have reflected the new information. However, with the way sampling was carried out, plots E1 and E2 (indicated as plots 1 and 11 respectively, in the forest health assessment) were the only dendrochronological plots that were situated within the area of predicted average SPM deposition. Although this led to an unbalanced sampling regime, the results did show that trees in these two plots showed very similar radial growth trends to trees in other plots, regardless of direction or distance from the generating station.

Conclusions

Emissions from the coal-fired generating station do not appear to be linked to tree decline observed south of the Manitoba Hydro Selkirk generating station, as measured by radial growth, overall plot vigour, or degree of crown dieback. Rather, the bur oak decline was likely a result of poor soil conditions, confounded in two plots by restricted site drainage. Additionally, the spatial distribution of trace element concentrations in the leaf litter was not congruent with the area of predicted SPM deposition from the generating station, except for Ba, however concentrations of all elements were below those suggested for potential phytotoxicity. As the radial growth of both bur oak and trembling aspen in southern Manitoba was found to be significantly related to climate, it should be considered an important natural stress factor in future forest health studies in the area.

REFERENCES

Adriano, D. C., A. L. Page, A. A. Alseewi, A. C. Chang, and I. Straughan. 1980. Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems: a review. Journal of Environmental Quality 9: 333-344.

Agrawal, M., and S. B. Agrawal. 1989. Phytomonitoring of air pollution around a thermal power plant. Atmospheric Environment 23: 763-769.

Agrawal, M., S. K. Singh, J. Singh, and D. N. Rao. 1991. Biomonitoring of air pollution around urban and industrial sites. Journal of Environmental Biology 28: 211-222.

Alstad, D. N., G. F. J. Edmunds, and L. H. Weinstein. 1982. Effects of air pollutants on insect populations. Annual Review of Entomology 27: 369-384.

Applied Science Associates, Inc. 1978. Diagnosing Vegetation Injury Caused by Air Pollution. United States Environmental Protection Agency, Office of Air and Waste Management, Research Triangle Park, N.C.

Arp, P. A., and J. Manasc. 1988. Red spruce stands downwind from a coal-burning power generator: tree-ring analysis. Canadian Journal of Forest Research 18: 251-264.

Balsberg-Pahlsson, A. 1989. Effects of heavy-metal and SO_2 pollution on the concentrations of carbohydrates and nitrogen in tree leaves. Canadian Journal of Botany 67: 2106-2113.

Barghigiani, C., T. Ristori, and R. Bauleo. 1991. *Pinus* as an atmospheric Hg biomonitor. Environmental Technology 12: 1175-1181.

Beg, M. U., and M. Farooq. 1990. Performance of trees around a thermal power station. Environment & Ecology 8: 791-797.

Berry, W. L. and A. Wallace. 1974. Trace Elements in the Environment - Their Role and Potential Toxicity as Related to Fossil Fuels: A Preliminary Study. University of California, Los Angeles, CA.

Berthelsen, B. O., E. Steinnes, W. Solberg, and L. Jingsen. 1995. Heavy metal concentrations in plants in relation to atmospheric heavy metal deposition. Journal of Environmental Quality 24: 1018-1026.

Bourqe, C., and P. A. Arp. 1994. Sulfur dioxide plume dispersion and subsequent absorption by coniferous forests: field measurements and model calculations. Boundary-Layer Meteorology 71: 151-168.

Bowen, H. J. M. 1979. Environmental Chemistry of the Elements. Academic Press, London, England. 333 pp.

Breckle, S. W. and H. Kahle. 1992. Effects of toxic heavy metals (Cd, Pb) on growth and mineral nutrition of beech (*Fagus sylvatica* L.) Vegetatio 101: 43-53.

Busing, R. T., L. H. Liegel, and V. J. Labau. 1996. Overstory mortality as an indicator of forest health in California. Environmental Monitoring and Assessment 42: 285-295.

Bussotti, F., E. Cenni, A. Cozzi, and M. Ferretti. 1997. The impact of geothermal power plants on forest vegetation. A case study at Travale (Tuscany, central Italy). Environmental Monitoring and Assessment 45: 181-194.

Chevone, B. I., and S. N. Linzon. 1988. Tree decline in North America. Environmental Polllution 50: 87-99.

Cook, E. R., and J. L. Innes. 1989. Tree-ring Analysis as an Aid to Evaluating the Effects of Air Pollution on Tree Growth. National Academy Press, Washington, D.C.

Cook, E. R., A. H. Johnson, and T. J. Blasing. 1987. Forest decline: modeling the effect of climate in tree rings. Tree Physiology 3: 27-40.

Cox, R. M. 1988. The sensitivity of pollen from various coniferous and broad-leaved trees to combinations of acidity and trace metals. New Phytologist 109: 193-201.

Dahlsten, D. L., and D. L. Rowney. 1980. Influence of air pollution on population dynamics of forest insects and on tree mortality. In: P. R. Miller (Ed.), Proceedings of Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California. Pacific Soutwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, CA. pp. 125-130.

Davidson, A. W., D. Velissariou, J. D. Barnes, B. Gimeno, and R. Inclan. 1995. The use of Aleppo pine, *Pinus halepensis* Mill as a bioindicator of ozone stress in Greece and Spain. In: M. Munawar, O. Hanninen, S. Roy, N. Munawar, L. Karenlampi, and D. Brown (Eds.), Bioindicators of Envionmental Health. SPB Academic Publishing bv, Amsterdam, The Netherlands. pp. 63-72

Department of the Environment. 1993. Air Polllution & Tree Health in the United Kingdom. HMSO, London.

Djingova, R., I. Kuleff, and N. Andreev. 1993. Comparison of the ability of several vascular plants to reflect environmental pollution. Chemosphere 27: 1385-1396.

Eckstein, D., C. Krause, and J. Bauch. 1989. Dendroecological investigation of spruce trees (*Picea abies* (L.) Karst.) of different damage and canopy classes. Holzforschung 43: 411-417.

Efroymson, R. A., M. E. Will, G. W. I. Suter, and A. C. Wooten. 1997. Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision. United States Department of Energy.

Elseewi, A. A., F. T. Bingham, and A. L. Page. 1978. Availability of sulfur in fly ash to plants. Journal of Environmental Quality 7: 69-73.

Eversten, J. A., M. P. Mac Siurtain, and J. J. Gardiner. 1986. The effect of industrial emission on wood quality in Norway spruce (*Picea abies*). IAWA Bulletin 7: 399-404.

Fergusson, J. E. 1990. Heavy metals in plants. In: Fergusson, J. E. (Ed.), The Heavy Elements. Pergamon Press, Elmsford, NY, pp. 377-405.

Fox, C. A., W. B. Kincaid, T. H. I. Nash, D. L. Young, and H. C. Fritts. 1986. Tree-ring variation in western larch (*Larix occidentalis*) exposed to sulfur dioxide emissions. Canadian Journal of Forest Research 16: 283-292.

Grzywacz, A., and J. Wazny. 1973. The impact of industrial air pollutants on the occurrence of several important pathogenic fungi of forest trees in Poland. European Journal of Forest Pathology 3: 129-141.

Gupta, M. C., and A. K. M. Ghouse. 1987. Cuticular geography, pigment content and anatomical traits of *Ficus bengalensis* L. under the influence of coal-smoke pollutants. Journal of Tree Science 6: 106-110.

Gupta, B. N., A. J. Williams, and S. K. Banerjee. 1995. Impact of thermal power plant emissions on vegetation and soil. Proceedings of the Indian natns. Science Academy B61: 457-470.

Haapala, H., N. Goltsova, R. Seppala, S. Huttunen, J. Kouki, J. Lamppu, and B. Popovichev. 1996. Ecological condition of forests around the eastern part of the Gulf of Finland. Environmental Pollution 91: 253-265.

Hagemeyer, J., H. Kahle, S. W. Breckle, and Y. Waisel. 1985. Cadmium in interconnection with transpiration. Water, Air and Soil Pollution 29: 347-359.

Hall, J. P. 1995. Forest health monitoring in Canada: how healthy is the boreal forest? Water, Air and Soil Pollution 82: 77-85.

Hartman, J., and M. L. Witt. 1991. Shade Tree Decline and Related Problems. ID-50. Agricultural Communications Services, College of Agriculture, University of Kentucky, Lexington, KT.

Holopainen, J. K., and J. Oksanen. 1995. Arboreal insects as indicators of air pollution effects on woody plants. In: Munawar, M., O. Hanninen, S. Roy, N. Munawar, L. Karenlampi, and D. Brown (Eds.), Bioindicators of Environmental Health. SPB Acsdemic Publishing bv, Amsterdam, The Netherlands.

Hosie, R.C. 1979. Native Trees of Canada. 8th edition. Fitzhenry & Whiteside Ltd., Don Mills, Ontario.

Houston, D. B. 1974. Response of selected *Pinus strobus* L. clones to fumigations with sulfur dioxide and ozone. Canadian Journal of Forest Research 4: 65-68.

Huhn, G., H. Schulz, H. Stark, R. Tolle, and G. Schuurmann. 1995. Evaluation of regional heavy metal deposition by multivariate analysis of element contents in pine tree barks. Water, Air and Soil Pollution 84: 367-383.

Innes, J.L. 1993. Forest health: its assessment and status*.* C.A.B. International, Wallingford. 677 pp.

Johnson, A. H. 1989. Decline of red spruce in the Northern Appalachians: determining if air pollution is an important factor. In: Committee on Biologic Markers of Air-Pollution Damage in Trees, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council (Eds.), Biologic Markers of Air-Pollution Stress and Damage in Forests. National Academy Press, Washington, D.C. pp. 91-104.

Julchang, R., B. Freedman, C. Coles, B. Zwicker, J. Holzbecker, and A. Chatt. 1995. Vanadium contamination of lichens and tree foliage in the vicinity of three oil-fired power plants in eastern Canada. Air & Waste Management Association 45: 461-464.

Keller, T. 1980. The effect of a continuous springtime fumigation with SO_2 on CO_2 uptake and structure of the annual ring in spruce. Canadian Journal of Forest Research 10: 1-6.

Klein, D. H., and P. Russell. 1973. Heavy metals: fallout around a power plant. Environmental Science and Technology 7: 357-358.

Koricheva, J., and E. Haukioja. 1995. Variations in chemical composition of birch foliage under air pollution stress and their consequences for Eriocrania miners. Environmental Pollution 88: 41-50.

Kovacs, M. 1992. Biological Indicators in Environmental Protection. Ellis Horwood Limited, England.

Kozlowski, T. T. and S. G. Pallardy. 1997. Physiology of Woody Plants. Second Edition. Academic Press, Inc., San Diego, CA. 411 pp.

Larsson, S. 1989. Stressful times for the plant stress - insect performance hypothesis. OIKOS 56: 277-283.

Lawrey, J. D. 1979. Boron, strontium, and barium accumulation in selected plants and loss during leaf litter decomposition in areas influenced by coal strip mining. Canadian Journal of Botany 57: 933-940.

Lerman, S. L., and E. F. Darley. 1975. Particulates. In: J. B. Mudd and T. T. Kozlowski (Eds.), Responses of Plants to Air Pollution. Academic Press, New York, NY. pp. 141-158.

Long, R. P., and D. D. Davis. 1989. Growth variation of white oak subjected to historic levels of fluctuating air pollution. Environmental Pollution 106: 193-202.

Lorenz, M. 1995. International co-operative programme on assessment and monitoring of air pollution effects on forests - ICP forests. Water, Air and Soil Pollution 85: 1221-1226.

Maier-Maercher, U. 1999. Predisposition of trees to drought stress by ozone. Tree Physiology 19: 71-78.

Malhotra, S. S., and R. A. Blauel. 1980. Diagnosis of Air Pollutant and Natural Stress Symptoms on Forest Vegetation in Western Canada. Information Report NOR-X-228. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alberta.

Mankovska, B. 1994. Airborne sulphur and heavy metal polllution in the environment of a thermal power plant. Ekologia 13: 207-217.

Martel, J., and Y. Maufette. 1997. Lepidopteran communities in temperate deciduous affected by forest decline. OIKOS 78: 48-56.

McClenahen, J. R. 1983. The impact of an urban-industrial area on deciduous forest tree growth. Journal of Environmental Quality 12: 64-69.

McClenahen, J. R. 1995. Potential dendroecological approaches to understanding forest decline. In: Lewis, T. E. (Ed.), Tree Rings as Indicators of Ecosystem Health. CRC Press, Inc., Boca Raton, Florida, pp. 59-79.

McClenahen, J. R., and L. S. Dochinger. 1985. Tree ring response of white oak to climate and air pollution near the Ohio River Valley. Journal of Environmental Quality 14: 274-280.

McLaughlin, S. B., and O. U. Braker. 1985. Methods for evaluating and predicting forest growth responses to air pollution. Experientia 41: 310-319.

Mudd, J. B. 1975. Sulfur dioxide. In: Mudd, J. B. and T. T. Kozlowski (Eds.), Responses of Plants to Air Pollution. Academic Press, Inc., New York, pp. 9-22.

Muir, P. S., and B. McCune. 1988. Lichens, tree growth, and foliar symptoms of air pollution: are the stories consistent? Journal of Environmental Quality 17: 361-370.

Mulgrew, A. and P. Williams. 2000. Biomonitoring of Air Quality Using Plants: Air Hygiene Report no. 10. WHO Collaborating Centre for Air Quality Management and Air Pollution Control, Berlin.

Munch, D. 1993. Concentration profiles of arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, vanadium and polynuclear aromatic hydrocarbons (PAH) in forest soil beside an urban road. The Science of the Total Environment 138: 47-55.

Nash, T. H. I., H. C. Fritts, and M. A. Stokes. 1975. A technique for examining non-climatic variation in widths of annual tree rings with special reference to air pollution. Tree-Ring Bulletin 35: 15-24.

Oksanen, E., J. Sober, and D. F. Karnosky. 2001. Impacts of elevated CO_2 and/or O_3 on leaf ultrastructure of aspen (*Populus tremuloides*) and birch (*Betula papyrifera*) in the Aspen FACE experiment. Environmental Pollution 115: 437-446.

Perala, D. A. 1990. *Populus tremuoides* Michx. In: R. M. Burns and B. H. Honkala (eds.), Silvics of North America: 2. Hardwoods. Agricultural Handbook 654. USDA, Forest Service, Washington, D. C., pp. 555-569.

Peterson, E. B. and Peterson, N. M. 1996. Ecology and silviculture of trembling aspen. In: Corneau, P. G., G.J. Harper, M.E. Blache, J.O. Boateng, K.D. Thomas (Eds.),Ecology and Management of B.C. Hardwoods: Workshop Proceedings. December 1-2, 1993. Government of Canada, Province of British Columbia, Richmond, B.C., pp. 30-51.

Poikolainen, J. 1997. Sulphur and heavy metal concentrations in Scots pine bark in northern Finland and the Kola Peninsula. Water, Air, and Soil Pollution 93: 395-408.

Puckett, K. J., E. Nieboer, W. P. Flora, and D. H. S. Riachardson. 1973. Sulphur dioxide: its effects on photosynthetic (14C) fixation in lichens and suggested mechanisms of phytotoxicity. New Phytologist 72: 141-154.

Rachwal, L., L. O. De Temmerman, and J. R. Istas. 1992. Differences in the accumulation of heavy metals in poplar clones of various susceptibility to air pollution. Arboretum Kornickie 37: 101-111.

Rennenberg, H., and C. Herschbach. 1996. Responses of plants to atmospheric sulphur. In: M. Yunus and M. Iqbal (Eds.), Plant Response to Air Pollution. John Wiley and Sons Ltd., Chichester, England. pp. 285-293.

Rice, P. M., R. A. Boldi, C. E. Carlson, P. C. Tourangeau, and C. C. Gordon. 1983. Sensitivity of *Pinus ponderosa* foliage to airborne phytotoxins: use in biomonitoring. Canadian Journal of Forest Research 13: 1083-1091.

Ricks, G. R., and R. J. H. Williams. 1975. Effects of atmospheric pollution on deciduous woodland Part 3: effects on photosynthetic pigments of leaves of *Quercus petraea* (Mattuschka) Leibl. Environmental Pollution 8: 97-106.

Riemer, J., and J. B. Whittaker. 1989. Air pollution and insect herbivores: Observed interactions and possible mechanisms. In: E. A. Bernays (Ed.), Insect-plant Interactions. CRC Press, Boca Raton, USA. pp. 73-105.

Roberts, T. M. 1984. Effects of air pollution on agriculture and forestry. Atmospheric Environment 18: 629-640.

Rosenburg, C. R., R. J. Hutnik, and D. D. Davis. 1979. Forest composition at varying distances from a coal-burning power plant. Environmental Pollution: 307-317.

Ross, S. M. and K. J. Kaye. 1994. The meaning of metal toxicity in soil-plant systems. In: Ross, S. M. (Ed.), Toxic Metals in Soil-Plant Systems. John Wiley & Sons, Ltd., West Sussex, England, pp. 27-61.

Sanders, G. E., L. Skarby, M. R. Ashmore, and J. Fuhrer. 1995. Establishing critical levels for the effects of air pollution on vegetation. Water, Air and Soil Pollution 85: 189-200.

Saxe, H. 1996. Physiological and biochemical tools in diagnosis of forest decline and air pollution injury to plants. In: Yunus, M. and M. Iqbal (Eds.), Plant Response to Air Pollution. John Wiley & Sons Ltd., West Sussex, England, pp. 449-487.

Schutt, P. 1989. Symptoms as bioindicators of decline in European forests. In: Committee on Biologic Markers of Air-Pollution Damage in Trees, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council (Eds.), Biologic Markers of Air Pollution Stress and Damage in Forests. National Academy Press, Washington, D.C. pp. 119-124.

SENES Consultants Ltd. 2001. Environmental Impact Assessment 1993-2001 of the Selkirk Generating Station. SENES Consultants Limited, Vancouver, B.C.

Sims, R. A., H. M. Kershaw, and G. M. Wickware. 1990. The Autecology of Major Tree Species in the North Central Region of Ontario. Ontario Ministry of Natural Resources, Thunder Bay, Ontario.

Skarby, L., and G. Sellden. 1984. The effects of ozone on crops and forests. Ambio 13: 68-75.

Smith, W. H. 1974. Air pollution - effects on the structure and function of the temperate forest ecosystem. Environmental Pollution 6: 111-129.

Solberg, S. and K. Torseth. 1997. Crown condition of Norway spruce in relation to sulphur and nitrogen deposition and soil properties in southeast Norway. Environmental Pollution 96, 19-27.

Sutinen, S., and L. Koivisto. 1995. Microscopic structure of conifer needles as a diagnostic tool in the field. In: M. Munawar, O. Hanninen, S. Roy, N. Munawar, L. Karenlampi, and D. Brown (Eds.), Bioindicators of Environmental Health. SPB Academic Publishing bv, Amsterdam, The Netherlands. pp. 73-81.

Tamm, C. O., and E. B. Cowling. 1977. Acidic precipitation and forest vegetation. Water, Air and Soil Pollution 7: 503-511.

Taylor, O. C., C. R. Thompson, D. T. Tingey, and R. A. Reinert. 1975. Oxides of nitrogen. In: Mudd, J. B. and T. T. Kozlowski (Eds.), Responses of Plants to Air Pollution. Academic Press, New York, NY, pp. 121-139.

Taylor, H. J., M. R. Ashmore, and J. N. B. Bell. 1986. Air Pollution Injury to Vegetation. IEHO, Chadwick House, London.

Thompson, M. A. 1981. Tree rings and air pollution: a case study of *Pinus monophylla* growing in east-central Nevada. Environmental Pollution 26: 251-266.

Tichy, J. 1996. Impact of atmospheric deposition on the status of planted Norway spruce stands: a comparative study between sites in southern Sweden and the northeastern Czech Republic. Environmental Pollution 93: 303-312.

Tingey, D. T. 1989. Bioindicators in air pollution research - applications and constraints. In: Committee on Biologic Markers of Air-Pollution Damage in Trees, Board on Environmental Studies and Toxicology, Commission on Life Sciences, National Research Council (Eds.), Biologic Markers of Air-Pollution Stress and Damage in Forests. National Academy Press, Washington, D.C., pp. 73-80.

Treshow, M. 1980. Interactions of air pollutants and plant disease. In: Miller, P. R. (Ed.), Proceedings of Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, June 22-27, 1980, Riverside, California. Pacific Southwest Forest and Range Experimental Station, Forest Services, United States Department of Agriculture, Berkeley, CA, pp. 103-109.

Truby, P. 1995. Distribution patterns of heavy metals in forest trees on contaminated sites in Germany. Angew. Bot. 69: 135-139.

Turner, A. P. 1994. The response of plants to heavy metals. In: Ross, S. M. (Ed.), Toxic Metals in Soil-Plant Systems. John Wiley & Sons Ltd., West Sussex, England, pp. 153-187.

Tyler, G. 1978. Leaching rates of heavy metal ions in forest soils. Water, Air, and Soil Pollution 9: 137-148.

Ulrich, B. 1984. Effects of air pollution on forest ecosystems and waters - the principles demonstrated at a case study in central Europe. Atmospheric Environment 18: 621-628.

Ulrich, B., and Pankrath, J. (Eds.). 1983. Effects of air pollution in forest ecosystems. D. Reidel Publishing Co., Dordrecht, Holland.

Van Voris, P., T. L. Page, W. H. Rickard, J. G. Droppo, and B. E. Vaughan. 1985. Report for the Canadian Electic Association: Volume I. Environmental Implications of Trace Element Releases From Canadian Coal-fired Generating Stations. Battelle, Pacific Northwest Laboratories, Richland, Washington.180 pp.

Vaughan, B. E., K. H. Abel, D. A. Cataldo, J. M. Hales, C. E. Hane, L. A. Rancitelli, R. C. Routson, R. E. Wildung, and E. G. Wolf. 1975. Review of Potential Impact on Health and Environmental Quality from Metals Entering the Environment as a Result of Coal Utilization. Battelle Energy Program, Richland, Washington.

Wangen, L. E., and F. B. Turner. 1980. Trace elements in vegetation downwind of a coal-fired plant. Water, Air, and Soil Pollution 13: 99-108.

Wangen, L. E., and M. D. Williams. 1978. Elemental deposition downwind of a coal-fired plant. Water, Air, and Soil Pollution 10: 33-44.

Wargo, P. M., D. R. Houston, and L. A. LaMadeleine. 1983. Oak Decline. Forest Insect & Disease Leaflet 165. United States Department of Agriculture Forest Service.

Wolterbeek, H. T., and P. Bode. 1995. Strategies in sampling and sample handling in the context of large-scale plant biomonitoring surveys of trace element air polllution. The Science of the Total Environment 176: 33-43.

Wulff, A., and L. Karenlampi. 1993. The effect of the axclusion of dry and wet deposition on visible symptoms and accumulation of sulphur and flouride by *Picea abies* needles near point-sources. Scandanavian Journal of Forest Research 8: 498-509.

Yunus, M., and M. Iqbal. 1996. Plant Response to Air Pollution. John Wiley & Sons, West Sussex, England. 447 pp.

Zhang, L., D. Planas, and J. Qian. 1995. Mercury concentrations in black spruce (*Picea mariana* Mill. B.S.P.) and lichens in boreal Quebec, Canada. Water, Air, and Soil Pollution 81: 153-161.

APPENDIX 1

Soil characteristics of all stands, including soil classification and association, soil texture, % organic matter (OM), macro and micronutrients (ppm), pH,and salinity (electrical conductivity (EC) in dS/m) values.

Plot	OM	Nitrogen	Phosphorus	Potassium	Sulphur	Copper	Iron	Manganese	Zinc	Calcium	Magnesium
1	13.5	2	12	339	9	1.49	144	28.1	7.77	3640	766
2	19.9	1	59.1	572	17	2.32	398	30.5	16.9	3520	834
3	20.7	7	28	547	18	3.02	279	56.4	12.7	5400	1400
4	29.9	2	29	567	20	2.25	183	55.2	9.03	4570	1350
5	12.2	2	32	371	7	1.13	55	24.2	4.93	4820	966
6	22.4	1	45	381	9	0.75	43	27.2	6.84	6720	876
7	32.5	9	23	360	59	1.52	103	37	2.36	5990	1840
8	26.2	1	58.8	381	70	0.97	114	49.2	8.82	3630	1010
9	24.9	10	46	450	42	1.41	71	26.7	11.3	5670	1540
10	32.8	22	81	840	85	1.15	84	24.7	6	5070	1000
11	31.6	5	45	628	18	1.61	108	15.8	11.9	6920	1020
12	24.2	9	25	507	20	1.59	256	34.7	18.9	4140	1090
13	24.2	18	17	490	16	2.39	256	19.4	11.4	5150	1320
14	9	1	11	173	8	1.13	45	14.4	1.82	4040	683
15	19.5	11	27	498	7	1.18	66	18.8	2.93	5510	1180
16	17.7	2	13	249	18	0.97	122	38.5	1.31	4230	584
17	20.8	3	31	521	20	0.99	202	33.1	3.98	4470	753
18	16.8	4	27	331	16	1.14	48	17.1	2.98	6050	627
19	15.8	2	13	285	5	1.53	56	18.2	3.82	4180	960
20	21.5	2	23	446	8	1.15	116	36.3	2.3	4480	808
21	22.4	2	31	383	10	1.17	91	16.7	7.84	4370	1150
22	13.2	5	19	258	6	0.82	37	15.8	2.53	6340	728
23	19.9	2	18	465	14	1.66	107	24.8	6.17	5070	1250
24	32.9	5	15	320	17	1.43	271	11.7	10.7	3560	760
25	32.9	4	25	466	3	1.52	130	17.4	13.4	4660	1010
26	12.9	1	20	219	5	0.6	38	5	1.53	3020	663
27	9.5	13	20	138	4	0.25	37	7.1	2.21	2640	484
28	22.1	2	30	466	5	1.32	181	6.8	7.53	3260	703
29	23.7	2	24	378	14	1.37	251	6.8	8.85	3720	615
30	18.4	5	14	393	7	1.14	26	10.4	4.41	4570	1120
31	22.7	23	14	445	5	1.81	205	13.2	8.29	4760	1080
32	12.9	1	27	201	6	1.06	60	11.5	2.18	4800	777
33	34.2	5	24	387	2	1.27	113	14.7	11.1	4240	925
34	20.5	3	45	424	20	0.59	19	5.3	3.41	3730	941
35	14.2	1	43	337	7	0.93	46	20.6	5.41	6480	728
36	22.3	7	18	547	20	2.04	116	48.9	8.84	4820	1300
37	11	1	31	314	6	1.13	67	29.7	2.7	4470	911
38	19.6	5	62	404	6	2.31	119	18.3	12.1	6190	1200
39	28.7	10	24	600	20	1.37	85	15.4	16.6	5730	1070
40	10.2	1	5	155	4	0.65	29	8.8	2.48	4030	687
41	9.3	1	5	129	4	0.49	28	15.7	0.56	3640	751
42	12.9	1	9.6	198	6	0.35	26	9.1	1.51	3820	661

* Soil texture determined by % sand and % clay using a soil texture triangle (Canadian Soil Working Group, 1998).

APPENDIX 1 (contd.)

Plot	Sodium	Boron	pH	EC	Soil texture*	Soil classification	Soil association
1	33	1.41	6.8	0.35	Heavy Clay	Gleyed Rego Black Chernozem	Semple
2	28	1.35	6.3	0.33	Heavy Clay	Orthic Luvic Gleysol	Red River
3	80.3	1.76	6.7	0.95	Heavy Clay	Gleyed Black Chernozem	Red River
4	36	1.67	6.7	0.66	Heavy Clay	Gleyed Black Chernozem	Red River
5	9.3	1.38	7.2	0.76	Clay	Orthic Dk. Gray Chernozem	Garson
6	6	1.4	7.3	0.76	Clay	Orthic Dk. Gray Chernozem	Semple
7	7.4	1.67	7	0.84	Heavy Clay	Orthic Dk. Gray Chernozem	Semple
8	8.7	1.68	6.5	0.52	Clay Loam	Gleyed Gray Luvisol	Semple
9	9.1	2.31	7	0.84	Heavy Clay	Orthic Dk. Gray Chernozem	Semple
10	6.6	1.98	7.1	0.86	Clay	Eluviated Dk. Gray Chernozem	Semple
11	20	1.86	6.8	0.47	Heavy Clay	Gleyed Dk. Gray Chernozem	Semple
12	51	1.78	6.4	0.56	Clay	Orthic Dk. Gray Chernozem	Red River
13	19	1.78	6.5	0.49	Heavy Clay	Orthic Luvic Gleysol	Red River
14	8.5	0.68	7.4	0.45	Clay	Orthic Dk. Gray Chernozem	Garson
15	6	2.07	7.2	0.62	Heavy Clay	Rego Black Chernozem	Semple
16	13	1.1	6.7	0.31	Silty Clay	Orthic Melanic Brunisol	Semple
17	11	1.65	6.6	0.37	Clay	Orthic Black Chernozem	Semple
18	7.9	1	7.5	0.58	Clay	Orthic Regosol	Semple
19	7.6	0.93	7.2	0.41	Clay	Gleyed Eluv. Dk. Gray Chernozem	Garson
20	8	1.52	6.8	0.35	Heavy Clay	Orthic Dk. Gray Chernozem	Semple
21	9.4	1.75	7.1	0.41	Heavy Clay	Orthic Dk. Gray Chernozem	Red River
22	25	1	7.5	0.6	Clay Loam	Rego Dk. Gray Chernozem	Semple
23	6.6	1.73	7	0.41	Heavy Clay	Gleyed Dk. Gray Chernozem	Red River
24	13	1.57	6.8	0.29	Clay	Orthic Luvic Gleysol	Red River
25	13	1.9	6.7	0.39	Heavy Clay	Gleyed Rego Black Chernozem	Red River
26	7.7	1.1	7.6	0.21	Clay Loam	Gleyed Dk. Gray Chernozem	Zora
27	6	1.2	7.2	0.29	Sandy Loam	Eutric Brunisol	Pine Ridge
28	7	1.1	6.9	0.23	Heavy Clay	Gleyed Black Chernozem	Red River
29	7.4	1.23	6.8	0.27	Clay	Gleyed Rego Black Chernozem	Red River
30	6.3	1.59	7.5	0.58	Clay	Gleyed Dk. Gray Chernozem	Red River
31	16	1.99	7	0.47	Clay	Gleyed Black Chernozem	Red River
32	16	0.83	7.6	0.45	Clay Loam	Rego Black Chernozem	Garson
33	10	1.63	7.1	0.41	Heavy Clay	Gleyed Black Chernozem	Red River
34	19	1.27	7.8	0.47	Heavy Clay	Orthic Dk. Gray Chernozem	Semple
35	15	1.36	7.5	0.64	Silty Clay	Orthic Dk. Gray Chernozem	Garson
36	19	1.67	7	0.31	Heavy clay	Gleyed Orthic Dk. Gray	Riverdale
37	14	1.28	7.3	0.45	Clay	Orthic Dk. Gray Chernozem	Peguis
38	19	1.45	7.5	0.64	Clay	Gleyed Orthic Dk. Gray	Peguis
39	17	2.34	7.2	0.52	Heavy Clay	Gleyed Rego Black Chernozem	Red River
40	21	0.81	7.7	0.39	Loam	Orthic Dk. Gray Chernozem	Garson
41	13	0.62	7.8	0.31	Clay Loam	Orthic Dk. Gray Chernozem	Garson
42	10	0.8	7.8	0.29	Clay Loam	Orthic Dk. Gray Chernozem	Pine Ridge

* Soil texture determined by % sand and % clay using a soil texture triangle (Canadian Soil Working Group, 1998).

APPENDIX 2

Elemental concentrations (ppm) of arsenic (As), barium (Ba), strontium (Sr), and vanadium (V) in the leaf litter, trembling aspen woody tissue, and bur oak woody tissue.

	Leaf litter				**Bur oak woody tissue**				**Trembling aspen woody tissue**			
Plot	As	Ba	Sr	V	As	Ba	Sr	V	As	Ba	Sr	V
1	1.3	145	55.3	10.7	0.6	57.3	31.6	0.06	0.5	58.6	59.1	0.05
2	0.5	84	76.9		0.6	57	58.9	0.08	0.5	41.1	64.8	0.05
3	1	131	72.1	3.87	0.5	78.9	49.1	0.06				
4	0.6	50.6	85.7	4.15					0.6	26.9	86.1	0.06
5	0.6	94.2	24.2	4.03	0.6	53.6	14.7	0.08				
6	0.6	55.8	26.6	2.52	0.6	45.4	12.4	0.06	0.6	24.6	20.4	0.06
7	0.5	56.4	47.9	2.14					0.5	20.1	30.6	0.05
8	0.6	40.8	58.7	1.45	0.6	34.4	35.4	0.06	0.5	23.5	48	0.05
9	0.6	92.6	45	3.26	0.5	47	26.7	0.05	0.6	20.6	37.2	0.06
10	0.5	51.1	35.2	2.41	0.6	35.2	16.2	0.06	0.5	23.7	21.3	0.05
11	0.6	77.6	63.6	1.61					0.6	59.4	62	0.06
12	0.6	115	51.8	3.99	0.6	89.8	43.9	0.06				
13	0.7	91.2	64.8	7.69	0.5	44.8	31.2	0.05				
14	0.6	51.8	13.6	2.19	0.6	24	10.2	0.06				
15	0.5	60	53	1.71					0.6	31.8	31.6	0.06
16	0.5	56.4	19.7	1.52	0.6	48.3	7.72	0.06	0.6	21.6	11.8	0.06
17	0.5	93.9	29.5	2.86	0.5	88.6	18.9	0.05	0.6	29.3	24	0.06
18	0.6	55.9	24.3	2.5	0.5	34.1	12.3	0.11	0.6	14.6	13.7	0.06
19	0.5	40.7	24.3	1.27	0.6	55.2	19.2	0.06	0.6	17.4	18	0.06
20	0.6	82	23.6	3.24	0.6	77.6	13.8	0.06	0.6	29.8	16.1	0.06
21	0.6	56.9	51.7	1.86	0.6	58.9	31.2	0.06	0.6	30.1	43.7	0.06
22	1.6	67	18.8	14.1	0.5	58.2	16.2	0.05	0.6	15.7	14.4	0.06
23	0.6	83	26.3	1.84	0.6	56.8	19.1	0.06				
24	0.5	79.5	55.2	2.75	0.6	34.7	25	0.06	0.5	32.5	43.2	0.05
25	0.6	87.5	60.1	3.38	0.6	88.6	43.6	0.06	0.6	41.1	51.8	0.06
26	0.6	36.7	43.1	1.97					0.6	15.4	22.5	0.06
27	0.6	45.8	17.9	1.82	0.6	50.9	11.4	0.06	0.6	16.7	12.2	0.06
28	0.7	65.7	53	4.09	0.6	36.5	26.8	0.06	0.5	31.4	40.2	0.05
29	0.6	80.2	46.4	3.3	0.5	36.9	19.7	0.05	0.5	26.1	26.7	0.05
30	0.6	46.5	39.7	0.91	0.6	54.3	22.5	0.06	0.5	30.6	34.5	0.05
31	0.8	75.1	42.3	5.36	0.6	65	28.3	0.06	0.6	32	38.8	0.06
32	1.3	87.7	21.1	12.6	0.6	34.8	17.2	0.09				
33	0.7	98.8	42.4	4.74	0.5	52.1	30	0.06				
34	0.6	66.7	31.7	5.01	0.5	40.1	23.4	0.05	0.6	14.9	18.6	0.06
35	0.6	78.8	25.5	4.12	0.6	33.3	19.7	0.07				
36	1	77.9	56.6	11.8					0.5	25.7	23	0.05
37	0.9	84.9	22.2	10	0.6	57.9	15.6	0.07	0.5	23	12.6	0.05
38	1.7	85.9	38.6	18.6					0.5	21.6	28.5	0.05
39	2	115	36.9	19.2	0.5	86.3	39.6	0.05	0.6	35.2	36.7	0.06
40	0.6	33.3	16	3.04	0.6	11.5	8.9	0.11	0.5	7.25	9.14	0.05
41	0.7	36.7	16.9	5.6					0.5	11.7	10.9	0.05
42	0.6	38.1	16.9	2.24	0.6	18.7	11.4	0.06				

Blank values indicate no data for that plot

APPENDIX 3

Forest health assessment categories and values for all bur oak and trembling aspen stands surveyed. Values are expressed as a percentage of trees per plot exhibiting the presence of a given descriptor, unless otherwise indicated.

Plot	Vigour 1	Vigour 2	Vigour 3	Vigour Index*	Defoliation 1	Defoliation 2	Defoliation 3	Defoliation 4	Defoliation Index*
1	5.00	10.00	70.00	78.33	75.00	10.00	0.00	0.00	23.75
2	6.25	40.63	46.88	76.04	93.94	0.00	0.00	0.00	23.48
3	0.00	40.00	60.00	86.67	80.00	13.33	0.00	0.00	26.67
4	11.11	16.67	50.00	64.81	72.22	0.00	0.00	0.00	18.06
5	9.09	21.21	54.55	71.72	78.79	0.00	0.00	0.00	19.70
6	13.64	27.27	45.45	68.18	31.82	0.00	0.00	0.00	7.95
7	8.33	20.83	54.17	70.83	0.00	0.00	0.00	0.00	0.00
8	2.17	21.74	58.70	73.91	0.00	52.17	26.09	0.00	45.65
9	4.76	19.05	71.43	85.71	4.76	19.05	71.43	0.00	64.29
10	2.94	14.71	68.63	79.41	78.43	0.00	0.00	0.00	19.61
11	20.00	10.00	66.67	80.00	73.33	13.33	0.00	0.00	25.00
12	8.00	40.00	32.00	61.33	80.00	0.00	0.00	0.00	20.00
13	8.33	16.67	58.33	72.22	79.17	0.00	0.00	0.00	19.79
14	10.00	90.00	0.00	63.33	100.00	0.00	0.00	0.00	25.00
15	7.89	39.47	50.00	78.95	47.37	7.89	0.00	0.00	15.79
16	3.03	3.03	81.82	84.85	60.61	0.00	0.00	0.00	15.15
17	6.58	10.53	68.42	77.63	63.64	0.00	0.00	0.00	15.91
18	11.43	60.00	25.71	69.52	11.43	25.71	2.86	0.00	17.86
19	8.11	18.92	70.27	85.59	18.92	32.43	16.22	0.00	33.11
20	11.11	14.81	59.26	72.84	25.93	25.93	22.22	0.00	36.11
21	0.00	29.63	48.15	67.90	77.78	0.00	0.00	0.00	19.44
22	25.00	8.33	58.33	72.22	83.33	8.33	0.00	0.00	25.00
23	5.56	22.22	55.56	72.22	58.33	16.67	0.00	0.00	22.92
24	3.03	48.48	42.42	75.76	78.79	3.03	0.00	0.00	21.21
25	3.92	19.61	74.51	88.89	41.18	3.92	0.00	0.00	12.25
26	5.00	30.00	47.50	69.17	42.50	32.50	0.00	0.00	26.88
27	0.00	15.79	84.21	94.74	21.05	57.89	0.00	0.00	34.21
28	3.28	31.15	63.93	85.79	95.08	0.00	0.00	0.00	23.77
29	6.67	35.56	53.33	79.26	91.11	2.22	2.22	0.00	25.56
30	6.67	10.00	56.67	65.56	60.00	13.33	0.00	0.00	21.67
31	4.00	38.00	42.00	68.67	32.00	32.00	16.00	0.00	36.00
32	18.18	54.55	18.18	60.61	0.00	0.00	0.00	90.91	90.91
33	17.65	8.82	61.76	73.53	58.82	0.00	0.00	0.00	14.71
34	9.52	57.14	23.81	65.08	14.29	47.62	19.05	0.00	41.67
35	4.76	19.05	61.90	76.19	85.71	0.00	0.00	0.00	21.43
36	16.13	38.71	35.48	66.67	45.16	32.26	9.68	0.00	34.68
37	23.08	7.69	61.54	74.36	15.38	38.46	0.00	0.00	23.08
38	4.26	6.38	82.98	88.65	91.49	2.13	0.00	0.00	23.94
39	9.09	30.30	57.58	80.81	78.79	9.09	0.00	0.00	24.24
40	38.89	11.11	27.78	18.01	50.00	5.56	16.67	0.00	27.78
41	0.00	38.89	55.56	81.48	83.33	11.11	0.00	0.00	26.39
42	80.00	0.00	0.00	26.67	86.67	0.00	0.00	0.00	21.67

* Indices range from 0-100

APPENDIX 3 (contd.)

Plot	Dieback 1	Dieback 2	Dieback 3	Dieback Index*	Chlorosis	Necrosis	Wilt	Gall-forming Insects	Defoliating Insects
1	10.00	5.00	0.00	6.67	0.00	0.00	10.00	0.00	70.00
2	21.21	21.21	0.00	21.21	0.00	0.00	24.24	0.00	75.76
3	20.00	0.00	0.00	6.67	0.00	0.00	26.67	0.00	13.33
4	5.56	0.00	5.56	7.41	0.00	0.00	0.00	0.00	0.00
5	18.18	3.03	0.00	8.08	0.00	44.13	0.00	0.00	78.79
6	9.09	13.64	0.00	12.12	0.00	0.00	0.00	0.00	4.55
7	0.00	4.17	0.00	2.78	0.00	0.00	0.00	0.00	0.00
8	8.70	2.17	0.00	4.35	0.00	0.00	0.00	0.00	78.26
9	14.29	0.00	4.76	9.52	12.60	17.98	0.00	0.00	95.24
10	3.92	0.98	0.00	1.96	0.00	14.04	0.98	6.86	75.49
11	13.33	0.00	3.33	7.78	0.00	0.00	13.33	3.33	83.33
12	32.00	8.00	8.00	24.00	0.00	39.23	0.00	0.00	76.00
13	8.33	4.17	4.17	9.72	0.00	18.83	2.08	4.17	66.67
14	80.00	10.00	10.00	43.33	0.00	56.79	0.00	0.00	100.00
15	7.89	0.00	0.00	2.63	0.00	0.00	0.00	0.00	55.26
16	0.00	0.00	3.03	3.03	0.00	17.55	0.00	0.00	33.33
17	5.19	1.30	0.00	2.60	0.00	13.17	0.00	0.00	23.38
18	17.14	0.00	5.71	11.43	0.00	22.21	0.00	0.00	40.00
19	0.00	0.00	2.70	2.70	0.00	21.57	0.00	5.41	64.86
20	3.70	7.41	0.00	6.17	0.00	0.00	0.00	0.00	77.78
21	3.70	0.00	0.00	1.23	0.00	28.13	0.00	11.11	77.78
22	0.00	16.67	0.00	11.11	0.00	0.00	0.00	8.33	91.67
23	5.56	2.78	0.00	3.70	0.00	33.56	0.00	0.00	75.00
24	21.21	6.06	0.00	11.11	0.00	27.42	0.00	15.15	78.79
25	1.96	0.00	1.96	2.61	0.00	30.32	0.00	1.96	45.10
26	2.50	2.50	0.00	2.50	0.00	40.69	0.00	0.00	75.00
27	0.00	0.00	0.00	0.00	0.00	23.41	0.00	15.79	78.95
28	6.56	0.00	1.64	3.83	0.00	32.90	0.00	9.84	93.44
29	4.44	0.00	0.00	1.48	0.00	24.94	0.00	11.36	93.33
30	3.33	0.00	0.00	1.11	0.00	14.96	0.00	6.67	73.33
31	12.00	2.00	0.00	5.33	0.00	31.95	0.00	44.00	84.00
32	45.45	18.18	0.00	27.27	0.00	0.00	0.00	0.00	90.91
33	8.82	0.00	2.94	5.88	0.00	22.55	0.00	32.35	58.82
34	38.10	14.29	4.76	26.98	0.00	29.21	0.00	38.10	80.95
35	57.14	14.29	0.00	28.57	0.00	0.00	0.00	0.00	100.00
36	6.45	16.13	0.00	12.90	10.35	10.35	0.00	0.00	87.10
37	15.38	7.69	7.69	17.95	0.00	0.00	0.00	0.00	53.85
38	6.38	2.13	0.00	3.55	0.00	0.00	6.38	0.00	91.49
39	24.24	12.12	9.09	25.25	0.00	0.00	6.06	0.00	87.88
40	15.00	7.70	31.00	41.13	13.63	31.81	0.00	33.33	77.78
41	5.56	0.00	0.00	1.85	0.00	0.00	0.00	11.11	94.44
42	0.00	53.33	33.33	68.89	0.00	0.00	0.00	33.33	86.67

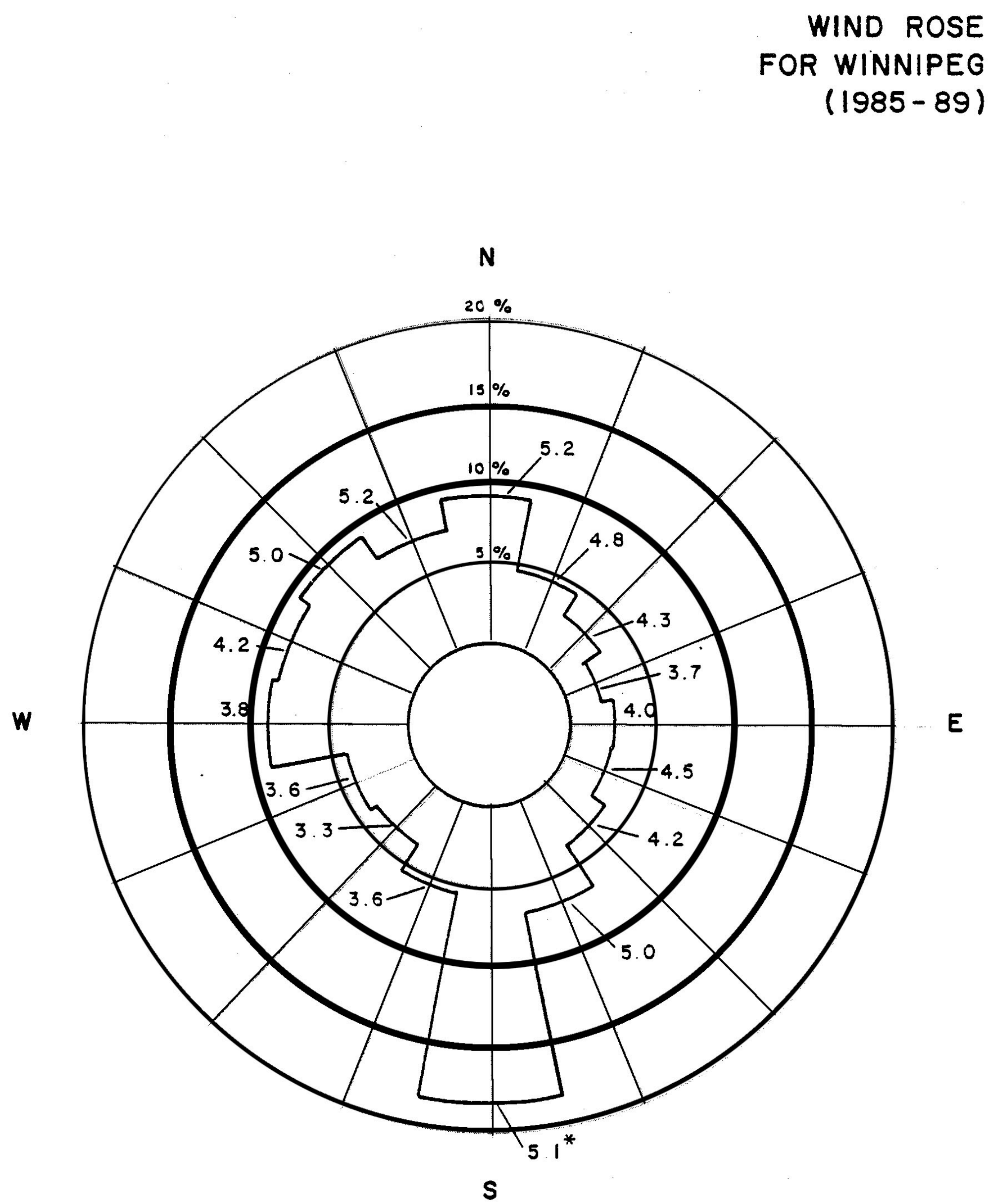
* Indices range from 0-100

APPENDIX 3 (contd.)

Plot	Leaf mining Insects	Skeletonizing Insects	Sucking Insects	Leaf spot	Leaf rust	Cankers	Conks
1	0.00	0.00	25.00	0.00	0.00	20.00	5.00
2	0.00	87.88	0.00	0.00	0.00	27.27	0.00
3	0.00	66.67	93.33	0.00	0.00	0.00	0.00
4	0.00	72.22	0.00	11.11	0.00	27.78	16.67
5	0.00	81.82	81.82	0.00	0.00	0.00	0.00
6	0.00	31.82	0.00	4.55	0.00	4.55	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	71.74	2.17	0.00	0.00	2.17	8.70
9	0.00	19.05	76.19	0.00	0.00	0.00	0.00
10	61.76	69.61	3.92	0.00	0.00	12.75	0.98
11	0.00	83.33	0.00	0.00	0.00	33.33	0.00
12	0.00	80.00	80.00	0.00	0.00	4.00	0.00
13	10.42	25.00	54.17	0.00	0.00	2.08	2.08
14	0.00	100.00	100.00	0.00	0.00	0.00	0.00
15	7.89	50.00	0.00	18.42	0.00	10.53	5.26
16	21.21	21.21	21.21	0.00	0.00	3.03	3.03
17	10.39	38.96	0.00	0.00	0.00	10.39	0.00
18	8.57	31.43	14.29	2.86	0.00	2.86	0.00
19	21.62	37.84	5.41	2.70	0.00	0.00	0.00
20	0.00	77.78	7.41	0.00	0.00	18.52	3.70
21	0.00	77.78	62.96	14.81	0.00	11.11	0.00
22	0.00	91.67	0.00	0.00	0.00	0.00	16.67
23	72.22	75.00	75.00	0.00	0.00	5.56	0.00
24	21.21	57.58	66.67	3.03	0.00	3.03	0.00
25	33.33	45.10	37.25	0.00	0.00	1.96	1.96
26	35.00	40.00	0.00	22.50	0.00	5.00	0.00
27	0.00	78.95	0.00	0.00	0.00	0.00	5.26
28	81.97	91.80	14.75	4.92	21.31	3.28	1.64
29	48.89	93.33	28.89	40.00	0.00	4.44	4.44
30	30.00	73.33	13.33	3.33	0.00	16.67	0.00
31	80.00	84.00	20.00	2.00	0.00	0.00	2.00
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	50.00	58.82	50.00	0.00	0.00	2.94	0.00
34	80.95	80.95	9.52	4.76	0.00	9.52	4.76
35	0.00	85.71	0.00	0.00	0.00	9.52	0.00
36	0.00	87.10	0.00	0.00	0.00	0.00	3.23
37	0.00	53.85	0.00	0.00	0.00	0.00	7.69
38	0.00	36.17	0.00	0.00	0.00	2.13	27.66
39	0.00	87.88	0.00	6.06	0.00	0.00	0.00
40	50.00	72.22	33.33	5.56	22.22	16.67	0.00
41	83.33	94.44	11.11	0.00	0.00	0.00	22.22
42	0.00	86.67	86.67	0.00	0.00	0.00	6.67

APPENDIX 4

Wind rose diagram generated from the Winnipeg International Airport weather station, over a four-year period (1985-1989). Source: SENES Consultants Ltd.



NOTE:

1. WIND SPEED INDICATED AS m/s*

APPENDIX 5

Designations for plots used in the forest health assessment, trace element toxicology, and dendrochronological portions of the study.

Forest Helath and Trace Element Toxicology Plots	Tree-ring Plots	Owner*
1	E1O, A	G. VanAert
2		A. Gavel
3		n/a
4		n/a
5	S1O	E. Dalebozik
	S2A	W. Pervank
6		n/a
7		n/a
8		n/a
9		n/a
10		D. Hygard
11	E2A	C. Wazny
12		n/a
13	W3O	n/a
14		n/a
15		n/a
16		n/a
17		n/a
18		n/a
19		Government of Manitoba
20		n/a
21		L. Pearson
22	E3O, A	n/a
23		n/a
24		Lower Fort Garry Nursery
25		n/a
26	S5A	Bazan
27	S4O, A	D. McGuire
28		Danbo
29		Denz
30		n/a
31	W1O	n/a
32	E4O	n/a
33	W2O	n/a
34		n/a
35	N1O	n/a
36	N3A	L. Waznylyk
37	N2O, A	n/a
38	N4A	J. Rolls
39		L. Hoppe
40	S3O	R. Northwood
41		J. Tye
42		J. Tye
	C1A	Reid
	C2O	n/a

n/a = Owners did not provide his/her last name.