# The changing disturbance regime of the boreal forest of the Canadian Prairie Provinces[1]

by K.P. Timoney[2]

The subhumid boreal forest of western Canada is different today from what it was 25 years ago. Before the 1950s, the main human impacts on this forest were agricultural expansion, escaped settlement fires, and high-grade logging. The latter half of the 20th Century saw increased human stresses placed on the ecosystems, against a background of insect outbreaks and high forest fire activity. In the Prairie provinces, current annual area burned is greater and more variable than it was in the 1970s. Over the past 25 years, the area disturbed by insects (primarily forest tent caterpillar) and disease has declined, but both the area and timber volume logged have risen. The boreal forest (particularly its southern half) is being converted to a fragmented landscape dominated by young aspen, shrub, grass, plantations, exotic species, industrial infrastructure, and agricultural fields. The current disturbance level has increased to the point that forest land and volume losses now exceed forest accruals in some regions; average forest age and biomass have been declining since about 1970. Relative to past decades, the present subhumid boreal forest region of Canada is warmer, and more fragmented and dissected; it supports less old growth, less old white spruce, and more young aspen and recently disturbed areas; it has simplified and truncated age-class structures; and it has a greater prevalence of non-native plants. Future stresses may include *in situ* tar sands development, groundwater depletion or degradation, and water diversions. Should present trends continue, declining forest productivity and predictability, and spread of exotic species are likely, as is replacement of coniferous forest by deciduous forest in some regions. Stressed aquatic systems may undergo major changes in biotic composition, productivity, and physical characteristics. Without a rapid decrease in the rate of disturbances, the establishment of a more complete protected areas network, and the adoption of ecosystem-centred management, the subhumid boreal ecosystem will continue to be degraded.

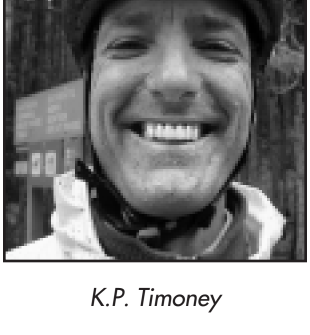
**Key words:** climate, defoliation, ecosystem, fire, logging, perturbation, petroleum, vegetation

La forêt boréale subhumide de l'Ouest canadien a changé depuis 25 ans. Avant les années 1950, les impacts d'origine humaine sur cette forêt étaient principalement causés par l'expansion agricole, les feux échappés liés à la colonisation et les coupes d'écrémage. La deuxième moitié du 20e siècle a vu s'accroître les stress imposés par les activités humaines sur les écosystèmes, dans un contexte d'importantes infestations d'insectes et de forte activité des feux de forêt. Dans les provinces des Prairies, la superficie brûlée annuellement est aujourd'hui plus importante et plus variable que dans les années 1970. Depuis 25 ans, la superficie perturbée par les insectes, livrée des forêts surtout, et par les maladies a diminué, mais l'exploitation forestière a augmenté tant en superficie qu'en volume de bois prélevé. La forêt boréale (dans sa partie sud en particulier) se transforme en un paysage fragmenté où dominent jeunes trembles, arbustes et arbrisseaux, graminées, plantations, espèces exotiques, infrastructure industrielle et champs agricoles. Le niveau de perturbation a augmenté au point que les pertes forestières en superficie et en volume dépassent aujourd'hui les gains dans certaines régions; depuis 1970 environ, la biomasse et l'âge moyens des forêts ne cessent de diminuer. Par rapport aux décennies passées, on constate que : la région de la forêt boréale subhumide du Canada est plus chaude, plus fragmentée et plus découpée; elle renferme moins de peuplements anciens, moins de vieilles épinettes blanches et plus de jeunes trembles ainsi que d'espaces perturbés récemment; elle affiche des structures de classes d'âges simplifiées et tronquées; elle contient plus de plantes non indigènes. D'autres agressions la menacent, notamment l'exploitation in situ des sables bitumineux, la diminution ou dégradation des eaux souterraines et les dérivations d'eau. Si les tendances actuelles se maintiennent, on peut s'attendre à une diminution de la productivité et de la prévisibilité des forêts, à l'invasion d'espèces exotiques, de même qu'au remplacement de la forêt coniférienne par une forêt feuillue dans certaines régions. Les systèmes aquatiques stressés pourraient également connaître d'importants changements de leur composition biologique, de leur productivité et de leurs caractéristiques physiques. En l'absence de réduction rapide des perturbations, d'amélioration du réseau d'aires protégées et d'approche d'aménagement écosystémique, l'écosystème subhumide boréal continuera de se dégrader.

**Mots clés :** climat, défoliation, écosystème, feu, exploitation forestière, perturbation, pétrole, végétation

## Introduction

In Canada, boreal ecosystems began to develop after deglaciation, roughly 10 000 years ago in the west and 4000–8000 years ago in the east (Payette 1992). Since that time, continual disturbance over a range of spatial and temporal scales has acted in concert with patterns of terrain to influence the type, age, size, and spatial distribution of communities. The Boreal Ecoclimatic Province (Ecoregions Working Group 1989) extends from northeastern British Columbia to the east coast (Fig. 1). There are three ecoregions in the subhumid boreal of western Canada: the High Boreal, Mid-Boreal, and Low Boreal. Although the subhumid boreal region extends outside Manitoba, Saskatchewan, and Alberta (the "Prairie Provinces"), this paper focuses on these provinces because the nature of the available data makes it difficult to extract data for portions of other jurisdictions (e.g.,



*K.P. Timoney*

[1]Paper presented at the "Old-growth Forests in Canada: A Science Perspective" Conference, October 14-19, 2001, Sault Ste. Marie, ON.

[2]Treeline Ecological Research, 21551 Twp. Rd. 520, Sherwood Park, Alberta T8E 1E3. E-mail: ktimoney@compusmart.ab.ca

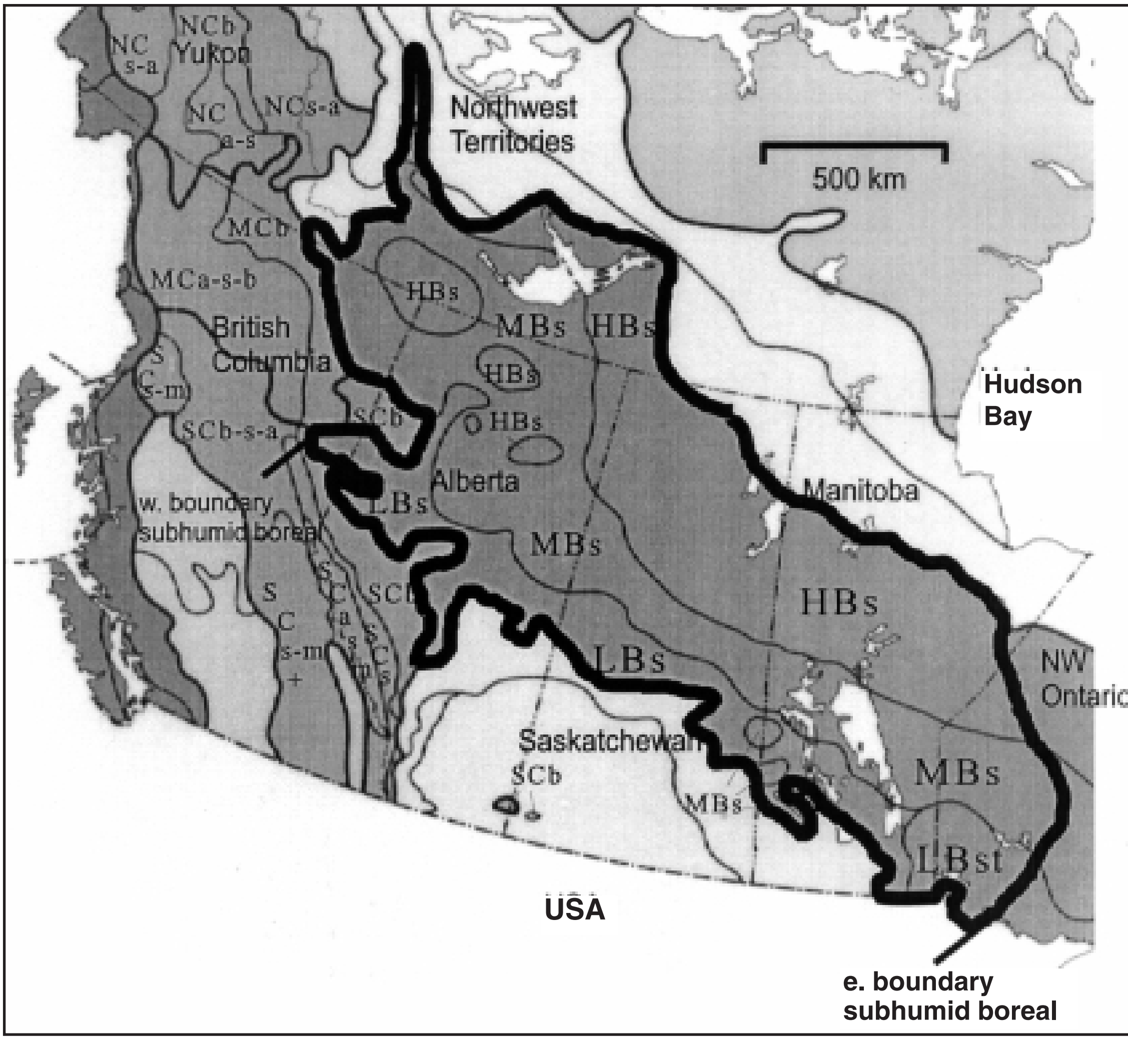



**Fig. 1.** Subhumid Boreal (bold line) ecoclimatic regions, after Ecoregions Working Group (1989). HBs = subhumid high boreal; MBs = subhumid mid-boreal, LBs = subhumid low boreal; LBst = subhumid transitional low boreal. Some Cordilleran ecoclimatic regions contain occurrences of subhumid boreal forest; SC= southern cordilleran, MC = Mid-cordilleran, and NC = northern cordilleran, with a (alpine), s (subalpine), b (boreal), m (montane), and + (moist) modifiers.

northeast British Columbia, the southern Northwest Territories, and the Mackenzie Valley).

A disturbance regime is a suite of processes that may span many orders of magnitude in time and space (Delcourt *et al.* 1983). Each type of disturbance is characterized by a set of attributes (extent, intensity/severity, frequency, and seasonality), which together modulate the structural and functional effects of the regime on the ecosystem. Disturbances interact and are influenced by terrain features, such as lakes and rivers, to create a complex, patchy, landscape mosaic, and change over time (White 1987, Campbell and Flannigan 2000). Most forests experience one or more changes in disturbance frequencies; thus, the search for a single natural disturbance interval is inappropriate (Johnson *et al.* 1995).

Disturbances and stressors may be "natural" in origin (such as windstorms), human-caused (such as seismic lines), or a complex of interacting natural and human influences. For example, annual area burned, although largely driven by climate, can be affected by landscape fragmentation, fire management, and vegetation (Flannigan *et al.* 1998). If disturbances are too great, frequent, or extensive, a new domain of attraction may be entered (Holling 1973, Paine *et al.* 1998). When this occurs, biological feedback and interactions may be altered, such that successional pathways change and the ecosystem does not respond as predicted from past observations (e.g., Perry *et al.* 1989). For example, response to forest cutting followed by prescribed burning and deep plowing, frequent wildfires, or exotic species introduction, may be inadequate or unpredictable, and may result in persistent community changes (e.g., White *et al.* 1993; Schindler 1998a, b). There may be delays between disturbance and detectable effects, such as species losses, termed an "extinction debt" (Tilman *et al*. 1994).

The history of agriculture and forestry on the Canadian Great Plains reveals a rapid change from stable to unstable ecosystems (Rowe and Coupland 1984). Before the mid-20$^{th}$ Century, the disturbance regime of western Canada's boreal forest was dominated by natural forces, with human influences playing local roles. In the past 50 years, western Canadian boreal disturbances have changed in type, frequency, severity, and areal extent. In this paper, I describe the boreal forest of the Prairie Provinces and its present and probable future disturbance regime.

Many plant and animal species are noted in this paper. For the sake of brevity, in the body of the paper, I have used common names where they exist. Common names of Alberta vascular and non-vascular plants follow Alberta Forestry, Lands and Wildlife (1990); for non-Alberta plants, nomenclature follows Scoggan (1978). Bird and mammal nomenclature follows Alberta Environment (2001); insect nomenclature follows Ives and Wong (1988).

## Climate

Mean annual temperature declines about 4°C from north to south across the zone, with values of +2°C in the south and –2°C in the north (Environment Canada 1982, 1993). Annual precipitation is moderate, ranging from 300–600 mm, with most precipitation falling in mid-summer; higher precipitation is found in the east and lower precipitation in the northwest; the frost-free period ranges from 60–120 days (Hare and Hay 1974, Ecoregions Working Group 1989). Mean temperature in January is about –15°C in the south and –25°C in the north. In July, the mean temperature is about 20°C in the south and 15°C in the north (Hare and Hay 1974). Although snow cover is persistent, it is generally concealed beneath the closed-crown conifer forests; thus, seasonal changes in albedo are modest, ranging from less than 0.4 in midwinter to 0.2 in midsummer, contributing to far higher net radiation in winter than in the subarctic (Hare and Ritchie 1972). Mean annual net radiation in the eastern portion of the region ranges from 40 kilolangleys (kly) in the Low Boreal ecoregion to 30 kly in the High Boreal ecoregion. In the west, mean annual net radiation is ~ 35 kly in the Low Boreal ecoregion and 25 kly in the High Boreal ecoregion (Hare and Ritchie 1972).

## Bedrock, Parent Materials, and Soils

Bedrock in eastern boreal Canada is predominantly Archean-age igneous, coarse-grained, acidic crystalline rocks, often metamorphosed, extending west and northwest to the Paleozoic and Mesozoic Sedimentary Basin marked by Lakes Winnipeg, Athabasca, and Great Slave (Geological Survey of Canada 1968). South and west of the Precambrian Shield, the bedrock in boreal western Canada is dominated by generally fine-grained, marine and freshwater sediments of Cretaceous and Devonian age. Parent materials overlying or derived from the bedrock are predominantly shallow (in the east) to deep (in the west) ground moraine, with glaciolacustrine plains best developed along the Shield/Paleozoic Basin interface (Geological Survey of Canada 1967). Rockland (bedrock lacking surficial materials) and eolian sand plains are locally important on the Shield and in the west, respectively. Soils (after Canada Soil Survey Committee 1978) are predominantly Podzols (east) and Brunisols (west) on modal, coarse-textured materials, typically under conifers. Luvisols, which increase in occurrence westward, are found under mixedwood and deciduous forests on medium and fine-textured deposits (often glaciolacustrine). Gleysolics are found in areas with high water tables and Organics and Organic Cryosols are found in peatlands. Regosols are found in areas with frequent deposition such as river valleys and Solonetzic soils are found in areas with alkaline or saline parent materials, often under graminoids.

## Vegetation

Under modal soil conditions, subhumid boreal ecosystems are dominated by closed-crown conifer, deciduous, and mixedwood forests in which white spruce and black spruce, balsam fir, aspen, balsam poplar, and white birch predominate. Under wet or peaty soil conditions, rain-fed, acidic bogs dominated by peat mosses and Ericaceae and groundwater-fed, basic to circumneutral fens dominated by *Drepanocladus, Scorpidium*, golden moss (*Tomenthypnum nitens*), and Cyperaceae are typical, along with transitional bog-fens. Some bogs may be ice-cored, occurring as dome-shaped palsas and extensive, flat peat plateaus. In boreal Canada, peatlands may be treeless (more common northward), or support black spruce on acidic sites or tamarack and/or white spruce on circumneutral and basic sites.

On dry sites, jack pine may dominate, or communities may be shrub-, lichen–moss-, or grass-dominated, with juniper, cherry, saskatoon, bearberry, blueberry, *Cladonia, Cladina, Stereocaulon, Cetraria,* hairy cap moss (*Polytrichum* spp.), wheatgrass (*Agropyron* spp.), reedgrass, hairy wildrye, fescue, ricegrass, needle grass, and bluegrass typical. Grasslands and marshes, typical of the Grassland Ecoclimatic Province (Ecoregions Working Group 1989), exist as azonal disjunct occurrences in boreal Canada. The former are often found on steep south-facing slopes and support such species as slender wheatgrass, western porcupine grass, and June grass (Raup 1935, Jeffrey 1961). With excessive surface water, particularly if the water contains salts or sulphates, various marshes and wet meadows may develop dominated by reedgrasses, sedges, foxtail barley, salt-meadow grass, spangletop, bulrush, cord grass, cattail, and forbs. Shrub communities (carrs) may persist in areas of excess soil moisture or frequent disturbance and are typically dominated by willows (*Salix* sp.), such as plane-leaved willow and pussy willow. Major marshes, wet meadows, and carrs are associated with rivers and lakes, a fine example of which is the Peace-Athabasca Delta west of Lake Athabasca (e.g., Dirschl *et al.* 1974).

At the boundaries of subhumid boreal ecoregions, there are distinct changes in forest types (see Canada Dept. Resources and Development 1950, Ecoregions Working Group 1989). To the east, in the subhumid transitional and moist boreal ecoregions of northwestern Ontario and southeastern Manitoba, balsam fir becomes a dominant forest tree. Many trees reach their native western or northwestern limits there, such as white pine, red pine, yellow birch, red maple, sugar maple, and eastern white-cedar (*Thuja occidentalis* L.). Black ash, along with green ash, and American elm, extend into the Low Boreal subhumid transitional ecoregion in the Lake of the Woods region. Bur oak extends farther west, reaching a western limit near the Saskatchewan border.

To the west, as the Cordilleran Ecoclimatic province is approached, foothills and mountains rise from the plain. Jack pine is replaced by lodgepole pine, a dominant forest type in dry foothills and lower subalpine sites, particularly after fire. Douglas fir and limber pine characterize dry montane valleys. Subalpine fir, Engelmann spruce, and, more abundantly at lower elevations, Engelmann hybrids with white spruce, become important. At higher elevations, whitebark pine and subalpine larch may be present.

## The Subhumid Boreal Forest: Structural Attributes and Types

In general, relative to older forests, young and mature boreal forests have lower canopy heights, higher canopy cover, fewer strata, less microtopography, fewer large snags and large logs, smaller diameter trees, and higher tree densities. Moss cover and basal area may be higher or lower (summary of old-growth forest attributes after Timoney 2001). Maximum canopy heights for boreal old-growth forests in Alberta range from about 10 m to more than 35 m. The age of onset of old-growth attributes varies by forest and site type, but in the boreal region, old-growth stand age ranges from about 80 to more than 300 years. The importance of gap dynamics varies with old-growth forest type. Pit and mound topography appears to be most characteristic of the taller spruce and spruce–mixedwood forests. Snags, which provide critical habitat structure, are important in all old-growth forests for which there are observations where reported densities range from about 30–200/ha (Lee *et al.* 1995, Stelfox 1995, Timoney and Robinson 1996). Logs are important in most old-growth community types, but there are few data available on densities and sizes of logs. Moss cover ranges from less than 2% in dry deciduous forests to more than 90% in wet coniferous forests. Site index (the height reached by the canopy at 50 years) ranges from less than 10 m to 20 m, depending on site conditions, with peak values of 18 m to 20 m observed in aspen and balsam poplar. Average tree diameter ranges from about 15 cm to 40 cm dbh. Tree density depends on site factors, stand history, and plot placement; characteristically, old-growth tree densities range from about 100–1000 stems/ha, with many observations in the 500–800 stems/ha range, and basal area/ha ranges from < 10 to 70 $m^2$ (usually 20–50 $m^2$) (Achuff and La Roi 1977, Peterson and Peterson 1992, Timoney *et al.* 1997). Typically, tree basal area is lower in old-growth than in mature forests. Canopy trees, soils, moisture regime, soil drainage, and dominant plants found in common western boreal forest types are reported in Table 1.

## Disturbance Regime: Past and Present

### Patterns and trends in the disturbance regime for the Prairie Provinces

Changes in disturbance regime, independent of human influences, are characteristic of northern ecosystems. Patterns and trends among wildfire, insect defoliation, and logging differ markedly (Fig. 2, Tables 2 and 3). Annual area burned (AAB) in the Prairie provinces from 1970–1999 showed no linear trend, despite record expenditures on fire suppression and increased fragmentation (Fig. 2, top; Tables 2, 3). This corroborates the view of Johnson *et al.* (1998) that there is little evidence of successful fire suppression in the western Canadian boreal forest. Over this latter period, annual area burned varied by a factor of 156 (maximum observed 156 times that of the minimum). From 1970–1999, the median AAB was 0.375 million ha (range 4.02 million ha). The largest fire year on record was 1989, in which 4 million ha burned (mostly in Manitoba). For Alberta, contemporary fire return interval (FRI) was in the 231- to 437-year range for the period 1918–1996, and in the 122- to 230-year range for the fire-prone 1980s (Timoney 1998). For the boreal mixedwood region of northeastern Alberta, Cumming (2000) calculated a return interval in the 244- to 476-year range over the period 1961–1996. For stocked timber-productive land in Manitoba, Saskatchewan, and Alberta, the FRI for the fire-prone 1980s was, respectively, 58, 213, and 119 years (raw data from Canadian Council of Forest Ministers 1993, Tables 1.1 and 3.1c).

Like fire, insect defoliation is highly variable in time and space. Annual area with moderate to severe defoliation by insects decreased from 1975–1999 (Fig. 2, middle; Table 3). The maximum observed over the 25 years was 263 times the minimum observed. A major peak occurred in 1976 and 1977 due to an outbreak of forest tent caterpillar in southern Manitoba (Government of Manitoba 2001). In 1979, the peak was due primarily to forest tent caterpillar in Saskatchewan (Hiratsuka *et al.* 1980); in 1980, due to forest tent caterpillar, large aspen tortrix, Bruce spanworm, and aspen leaf roller (Hiratsuka *et al.* 1981); in 1981, to forest tent caterpillar and large aspen tortrix (Hiratsuka *et al.* 1982); and in 1988, to forest tent caterpillar (Emond and Cerezke 1989).

The 25-year time series of Prairie Province defoliation (Fig. 2a) is dominated by aspen defoliators, that show a downward trend over the period, seldom cause mortality, and are often concentrated south of the boreal zone. Other important insects responsible for forest volume losses in Manitoba, Saskatchewan, and Alberta for the period 1982–1992 were spruce budworm, jack pine budworm, mountain pine beetle, and spruce beetle (Brandt and Amirault 1994, Canadian Council of Forest Ministers 1994). The severity and extent of jack pine budworm outbreaks may be increasing (Volney 1988), although there have been no major outbreaks in the 1990s (J. Volney, personal communication, CFS, Edmonton). Whether populations of spruce budworm are undergoing any long-term trends in the Prairie Provinces is uncertain, as a single outbreak may last more than a decade. Compared with the eastern boreal forest, spruce budworm outbreaks in western Canada tend to last longer but cause less mortality (J. Volney, personal communication 2001; J. Brandt, personal communication 2001). In the Prairie Provinces, outbreaks by spruce beetle tend to be rare and localized, and there are no clear trends in the region over recent decades (D. Langor, personal communication, CFS, Edmonton).

Defoliation is a major disturbance in terms of areal extent, with a median defoliation of 1.674 million ha/year (Table 2). However, defoliation figures should not be interpreted to mean the area has suffered mortality. Kurz and Apps (1999) (based primarily on J. Volney, personal communication) reported mortality factors of 5–15% to convert area damaged by spruce budworm, hemlock looper, jack pine budworm, and mountain pine beetle to area killed. For Alberta, Saskatchewan, and Manitoba (data from Brandt and Amirault 1994), over the period 1982–1987, the proportion of total volume losses due to insects and decay that resulted in mortality was 13.5%; annual volume loss (non-lethal and lethal) relative to the total standing volume of the forests was 0.09%/year. Relative to ecosystem merchantable volume, volume loss was small for the region and time period reported. The volume losses, however, may be conservative due to under-reporting in young stands, and non-reporting of species such as dwarf mistletoe (J. Brandt, personal communication, CFS, Edmonton). There is also concern that volume losses due to insects and decay are inadequately accounted for in calculating annual allowable cuts (Brandt and Amirault 1994). For Alberta, Saskatchewan, and Manitoba as a whole, recent forest losses (lethal and non-lethal) represented about 9% of the annual allowable cut (Brandt and Amirault 1994).

Table 1. Overview of Canadian subhumid boreal forest types (after Timoney 2001)

| Dominant Tree | Soil Orders | Ecological Moisture Regime | Drainage | Dominant Plant Species May Include[a] |
|---|---|---|---|---|
| Aspen | Luvisols, Gleysols | Submesic to Subhygric | Well to Mod-Well | *Picea glauca, Populus balsamifera; Amelanchier alnifolia, Corylus cornuta, Viburnum edule, Ribes oxyacanthoides, Rosa acicularis, Cornus stolonifera, C. canadensis, Aralia, Rubus pubescens, R. idaeus, Lathyrus ochroleucus, Linnaea borealis, Lonicera involucrata, Pyrola asarifolia, Calamagrostis canadensis* |
| Balsam Poplar | Luvisols, Gleysols, Regosols | Mesic to Hygric | Well to Poorly | *Picea glauca, Populus tremuloides; Alnus tenuifolia, Cornus stolonifera, Lonicera involucrata, Rosa acicularis, Rubus idaeus, Rubus pubescens, Viburnum edule, Aralia nudicaulis, Equisetum pratense, Mertensia paniculata, Calamagrostis canadensis* |
| White Spruce | Luvisols, Gleysols, Brunisols, Regosols (to Organic) | Subhygric to Hygric | Well to Poorly (to Very Poorly) | *Populus tremuloides, P. balsamifera, Betula papyrifera, B. neoalaskana, Abies balsamea; Alnus crispa, Alnus tenuifolia, Cornus stolonifera, Viburnum edule, Rosa acicularis, Aralia nudicaulis, Rubus pubescens, Cornus canadensis, Linnaea borealis, Mertensia paniculata, Mitella nuda, Calamagrostis canadensis, Fragaria virginiana, Maianthemum canadense; Equisetum arvense, E. pratense, Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis* |
| Jack Pine | Brunisols | Subxeric to Mesic | Rapidly to Well | *Picea glauca, Picea mariana, Populus tremuloides*; may be savannah or park-like; *Vaccinium vitis-idaea, V. myrtilloides, Alnus crispa, Arctostaphylos uva-ursi, Cornus canadensis, Saxifraga tricuspidata, Artemisia frigida, Cladina mitis, C. rangiferina, C. stellaris, Hylocomium splendens, Pleurozium schreberi* |
| Black Spruce (upland) | Luvisols, Brunisols, Podzols, Gleysols, Rockland, Organic (Folisol) | Mesic to Subhydric | Rapidly to Poorly | *Pinus banksiana, Populus tremuloides, Betula papyrifera; Vaccinium vitis-idaea, V. myrtilloides, Alnus crispa, Amelanchier alnifolia, Arctostaphylos uva-ursi, Empetrum nigrum, Cornus canadensis, Equisetum arvense, E. sylvaticum, Hylocomium splendens, Pleurozium schreberi, Ptilium crista-castrensis, Cladina mitis, C. rangiferina, C. stellaris, Cetraria nivalis* |
| Black Spruce Bog | Organic,Cryosols | Hygric to Hydric | Imperf. to Very Poorly | *Ledum groenlandicum, Rubus chamaemorus, Vaccinium vitis-idaea, Chamaedaphne calyculata, Hylocomium splendens, Pleurozium schreberi, Ptilium crista-castrensis, Sphagnum angustifolium, S. fuscum, S. magellanicum, Polytrichum strictum, Cladonia* spp. |
| Tamarack Fen | Organic, Cryosols, Gleysols | Hygric to Hydric | Imperf. to Very Poorly | *Picea mariana, Betula pumila, Carex* spp., *Salix* spp., *Aulacomnium* and *Drepanocladus* spp., *Pleurozium schreberi, Tomenthypnum nitens, Scorpidium scorpioides, Sphagnum angustifolium, S. fallax, S. jensenii, S. riparium, S. warnstorfii* |

[a]Nomenclature follows Alberta Forestry, Lands and Wildlife (1990).

The median Prairie province logging rate was 75 000 ha/year over the 1975–1999 period (Table 2). Annual variation was lower than in burn and defoliation regimes, with the maximum 2.2 times the minimum. Logging rates rose significantly over this period (Table 3, Fig. 2), although not exponentially as they have in Alberta (Timoney and Lee 2001). The irregular rise over time is noteworthy. An apparent decrease in area logged in the early 1980s was due primarily to reported declines in Manitoba and Saskatchewan (a time of major fire activity), and a major decline in the mid 1990s was due primarily to a reported decline in Alberta (National Forestry Database Program 2002). However, timber volume logged in Alberta rose 47% between 1990 and 1998. How can we account for the apparent discrepancy? Forests logged on Alberta Crown land under fire, insect, or disease salvage may go unrecorded (L. Kerkhoff, personal communication, 1999, Alberta Forestry, Edmonton, AB). Area logged in these situations may be extensive because post-disturbance volumes in such stands may be low. Honer and Bickerstaff (1985) estimated a volume yield of 30% for burn salvage and 60% for pest salvage. Timber logged from private land is similarly unrecorded as logged area. Timoney and Lee (2001) applied an empirical regression equation to calculate hectares logged from

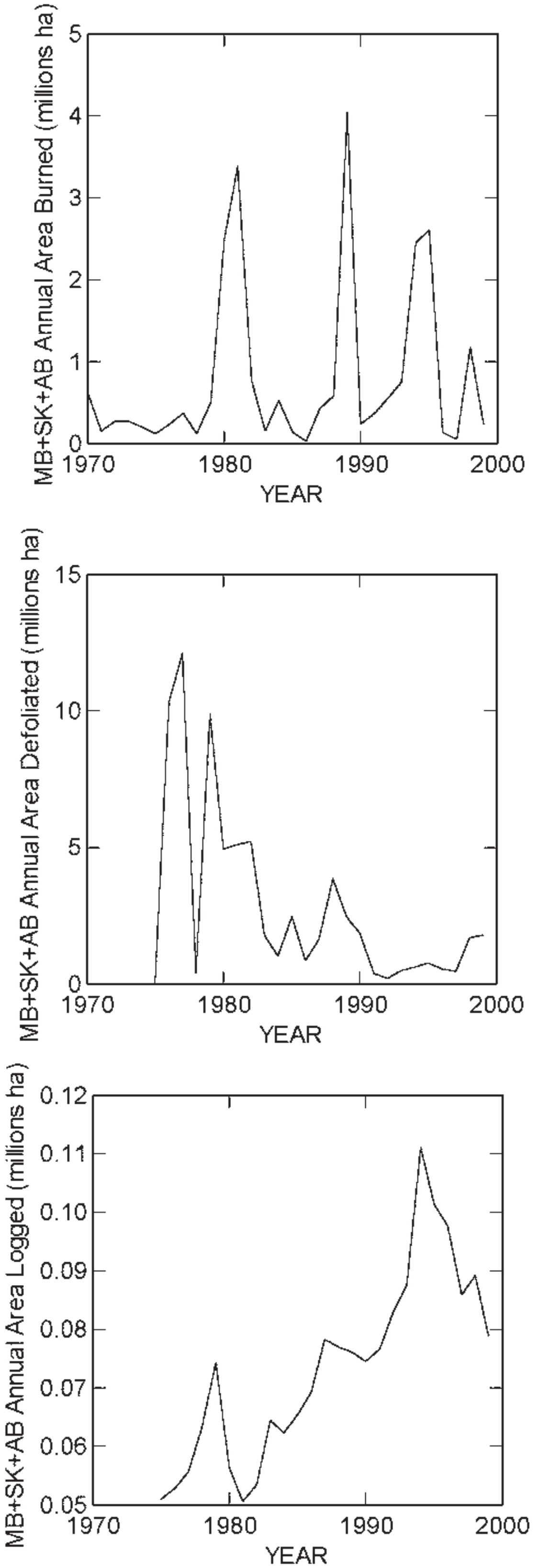



**Fig. 2.** Top: Manitoba, Saskatchewan, and Alberta: Annual area burned, 1970–99. Middle: Annual area of forests with moderate to severe defoliation, 1975–99. Bottom: Annual area logged, 1975–99. All data from Canada National Forestry Database, Tables 3.1, 4.1, and 6.1, downloaded from nfdp.ccfm.org.

**Table 2. Comparison of summary statistics for Prairie Province annual area burned (1970–1999), defoliated (1975–1999), and logged (1975–1999). Data from National Forestry Database Program, downloaded from http://nfdp.ccfm.org. "Moderate to severe defoliation" means 30% or more of the current foliage has been removed. Due to mapping on an insect by insect basis and the fact that a given area may support more than one insect defoliator, there is inevitable double and triple counting; thus, the hectares reported exaggerates the total area defoliated.**

| Statistic | Annual Area Burned (millions ha) | Annual Area Defoliated (millions ha) | Annual Area Logged (millions ha) |
|---|---|---|---|
| N of Years | 30 | 25 | 25 |
| Minimum | 0.026 | 0.046 | 0.051 |
| Maximum | 4.045 | 12.12 | 0.111 |
| Range | 4.019 | 12.07 | 0.061 |
| Total | 24.046 | 71.086 | 1.837 |
| Median | 0.375 | 1.674 | 0.075 |
| Mean | 0.802 | 2.843 | 0.073 |
| Std. Error | 0.194 | 0.676 | 0.003 |
| C.V. | 1.325 | 1.189 | 0.223 |

volume and estimated that area logged in Alberta exceeded the officially recorded area by 16 900 ha in 1996 and 14 631 ha in 1997. Due to "salvage," the area logged statistics of Table 2 and Fig. 2 are likely underestimates.

Although at first glance, the logging rates appear modest in relation to wildfire and insect/decay rates, there are three important considerations. (1) Wildfire, insect defoliation, and decay fungi are disturbances with which subhumid forest ecosystems have evolved and to which they are adapted. Defoliation and decay fungi seldom lead to stand replacement. (2) Wildfire does not select against old growth, but logging does (Timoney 1998). (3) All forests logged in the Prairie provinces are clearcut (National Forestry Database Program 2002), and a proportion of them are subjected to site preparation and scarification with attendant impacts on biological legacy and soils (e.g., Utzig and Walmsley 1988, Perry *et al.* 1989). Nationally, > 70% of burned lands undergo successful natural regeneration within 10 years, compared with only 30% successful natural regeneration on cutover lands (Honer and Bickerstaff 1985).

Few studies of changes in species composition in logged western boreal forests are available. Stelfox *et al.* (undated, Appendix Table 5.3) observed increases in dandelion, smooth brome, and Kentucky bluegrass, and decreases in mosses and lichens in cut and scarified cutblocks relative to undisturbed mature mixedwood forest. Boreal riparian forest plant species composition has been shown to differ between undisturbed and logged communities decades after logging (Timoney *et al.* 1997). Plant community composition has been observed to differ between post-harvest conditions and post-fire conditions up to 60 years after a disturbance (Crites 1999). Once logged, in boreal white spruce–*Hylocomium splendens* forests, bluejoint reedgrass and forb cover may increase greatly and prevent conifer establishment (Corns and Annas 1986). In boreal forests containing bluejoint reedgrass that are clearcut, Lieffers *et al.* (1993) noted that mechanical site preparation, a deep slash burn, herbicides, or grazing may be required to permit conifer re-establishment, with attendant impacts on soil, biota, and biodiversity caused by both the harvest and post-harvest treatments (Utzig and Walmsley 1988, Lee 1999). Decades-long differences in bird communities between post-fire and post-harvest western boreal forests have been demonstrated (Hobson and Schieck

**Table 3. Prairie Province trends in forest disturbance for annual area burned, defoliated, and logged. Data from National Forestry Database Program, data downloaded from http://nfdp.ccfm.org**

| Disturbance Type | Linear Regression Significant? (Year as independent variable) | Adjusted R2, F ratio, p) |
|---|---|---|
| Annual Area Burned, 1970–99 | No | 0.04, 1.11, 0.30 |
| Annual Area Defoliated, 1975–99 | Yes, decreasing | 0.34, 11.59, 0.00 |
| Annual Area Logged, 1975–99 | Yes, increasing | 0.71, 55.92, 0.00 |

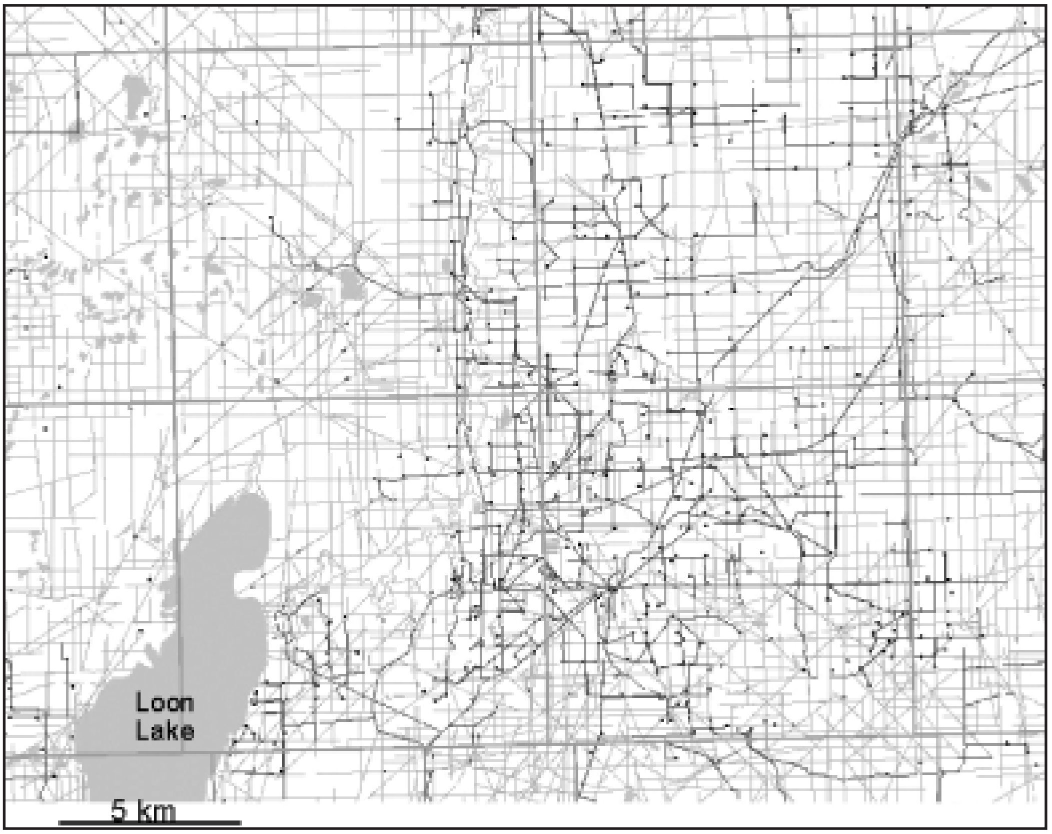



**Fig. 3.** Characteristic boreal landscape dissection and fragmentation in the Red Earth / Loon Lake area of north central Alberta. Black lines are roads and utility corridors; black dots are active and abandoned wells; narrow grey lines are seismic cutlines; thick grey lines mark township boundaries. Map centre at 56°17′30″N, 115°09′10″W, Townships 87 and 88, Ranges 8 and 9, W5.

1999). Fires lead to forests with different structure than those subjected to harvest, and this has important implications for sustainable forestry practices and for biodiversity conservation, e.g., of invertebrates (Spence *et al.* 1997). Long-term succession on seismic lines similarly raises concerns. Conversion to persistent shrubs (primarily willows and river alder), grasses, and exotics (such as smooth brome, timothy, and red fescue) is common (Timoney and Lee 2001). Tree regeneration and growth on seismic lines may be slow; seismic lines may be removed from forest production for up to one full logging rotation (Environment Council of Alberta 1979, Revel *et al.* 1984).

## Other disturbances

Wildfire, defoliation, and logging are not the only disturbances that are changing in the subhumid boreal forest of Canada. The trend towards clearing and farming the southern boreal began as early as the 1930s, when drought encouraged farmers to leave the dusty south (Rowe and Coupland 1984). Forest land in the mixedwood boreal region of Saskatchewan declined by 53% from 1953 to 1975 (Kabzems *et al.* 1976). Agriculture continues to expand in the southern portions of the boreal forest. Between 1981 and 1996, total farm area in Manitoba, Saskatchewan, and Alberta grew by 2.7 million ha (177 260 ha/year) (Statistics Canada 2001). Conversion of boreal forest to agriculture may be viewed as irreversible on a human time scale, especially if the lands are put into cereal production. The effects of Alberta agriculture on water quality were recently studied by CAESA (1998), which concluded that current agricultural practices in Alberta have resulted in serious declines in water quality. For example, nitrogen guidelines for protection of aquatic life in streams were exceeded in 32% of samples in low-intensity agricultural areas and in 87% of samples in high-intensity areas. Phosphorus in streams from livestock runoff and cropping exceeded guide-

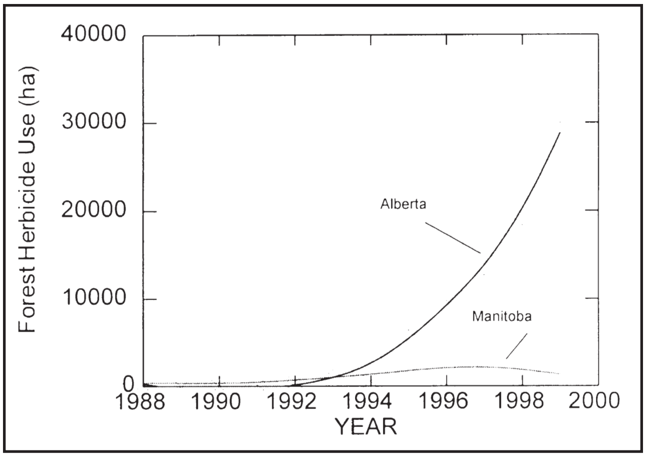



**Fig. 4.** Forest herbicide use on Crown land in Manitoba and Alberta, 1988–1999. Data from Canadian Senate (2002, rep09table5-e. htm), and NFDP (2002, table97e_11.htm).

lines in 89–99% of samples. Fecal coliform levels (due to livestock) exceeded human drinking standards in 90–100% of streams. Eutrophication and its impact on aquatic life were identified as serious concerns. Despite those findings, the Alberta Cabinet endorsed a doubling of livestock production (Alberta Agriculture 1999).

The expansion of seismic, oil, and gas activities is of great concern. The impacts of the oil and gas industry include loss and degradation of habitat; landscape fragmentation, dissection, and shrinkage; increased access to and disturbance of wildlife by humans and wolves; oil and saltwater spills; aquifer depletion and pollution; ecological effects of sour gas flaring; and greenhouse gas production. In 1998, there were an estimated 283 documented pipeline failures and more than 400 liquid releases (including water and oil) from pipelines, wells, and other oil and gas sources in boreal Alberta (Anielski and Wilson 2001). The Environment Council of Alberta (1979) found that about 70% of landscape disturbance for non-renewable resource extraction was due to seismic lines. In Alberta alone, Timoney and Lee (2001) gave a conservative estimate of a total of 1.5–1.8 million km of seismic lines, about four times the distance from the Earth to the Moon. The areal footprint of the petroleum industry and transportation network in Alberta was about 2.5–2.9 million ha as of the mid-1990s. If a 100-m buffer were placed around all wells, seismic lines, etc., to estimate edge effects, the affected area would cover 65–75% of the province. This affected area must be an overestimate, indicating that distances between seismic lines must often be < 200 m and, therefore, that interior habitat is disappearing in Alberta. Each year, the oil and gas industry in Alberta consumes about 63% of the land harvested by the forest industry (data from Anielski and Wilson 2001). Forest loss due to petroleum activities may soon surpass the loss due to logging in some parts of boreal Alberta (B. Stelfox, personal communication 1999, Forem Consulting, Bragg Creek, AB). Fig. 3 illustrates the characteristic network of seismic lines, roads, utility corridors, and wells found in a developed oil field. It is difficult to imagine disturbance-sensitive species such as Caribou, Grizzly Bear, and Wolverine (Horejsi 1995) surviving in such a dissected and fragmented landscape.

Commensurate with these industrial and agricultural activities are the networks of roads, processing plants, factories, settlements, and other infrastructure, peat mining, wetland drainage, persistent organic compounds, nutrient discharges, mercury contamination of Canadian Shield lakes after logging, hydroelectricity generation, transmission, water storage, mining, and pesticide and herbicide use. Forest herbicide use in Manitoba since 1988 shows no trend, but in Alberta, forest herbicide use is rising exponentially (Fig. 4). Saskatchewan does not apply forest herbicides (National Forestry Database Program 2002). Herbicides used are primarily glyphosate, with lesser amounts of hexazinone, triclopyr, 2,4-D, and others (Canadian Senate 2002). In summary, the boreal forest is being subjected to a panoply of disturbances, the cumulative effects of which lie beyond current scientific understanding.

## Discussion: The Future

Two central questions about the sustainability of western-Canadian boreal forests are (1) is the disturbance rate changing? and (2) is there evidence that forest losses are exceeding accruals? I address these questions in turn,

(1a) The area of undisturbed boreal "original" or "frontier" forest continues to decline because of logging, oil and gas exploitation, and agriculture (Anielski and Wilson 2001, Timoney and Lee 2001, Canadian Senate 2002). Fragmentation is increasing as a consequence of these activities, and is severe in boreal Alberta, whereas boreal Saskatchewan and Manitoba are far less fragmented (World Resources Institute 2000, Map 5). The total area disturbed by insects has apparently decreased in recent years, but the trend is dominated by aspen defoliators (primarily forest tent caterpillar). Because aspen defoliators disturb far more area than do spruce budworm, jack pine budworm, spruce beetle, etc., areal-disturbance trends for these latter insects, if they exist, tend to be masked.

(1b) Because fire is the dominant stand-replacing disturbance in the boreal forest, any change in disturbance would have major implications for the system. There is an apparent increase in national fire activity, dominated by fires in the Prairie Provinces, over the 20th Century (e.g., van Wagner 1988, Johnson *et al.* 1998, Weber and Stocks 1998). Flannigan *et al.* (2001) applied a predictive model and found that fire weather indices under twice current $CO_2$ and 6000 years-before-present analogue climates would rise in the western boreal forest region, likely resulting in more wildfire. For northeastern Alberta, over the period 1961–1996, Armstrong (1999) found no trend in annual area burned. Cumming (2000), however, tentatively concluded that, after correcting for fire suppression, fire activity may be increasing there. At Amisk Lake, in north-central Alberta, Campbell and Flannigan (2000) demonstrated a trend of increasing fire activity over the 20th Century, whereas at Opal Lake in central Saskatchewan, they found a decrease in fire activity.

(1c) For the Canadian boreal forest, from 1920–1969, the average total disturbance rate (primarily from wildfire and insects combined) was 1.7 million ha/year, and from 1970–1989, the average disturbance rate was 3.9 million ha/year (Kurz and Apps 1995). Both average forest age and forest biomass in Canada rose from 1920 to 1970, and have since declined (Kurz and Apps 1999). Since about 1980, Canada's forests have become a net carbon source rather than a sink (Kurz and Apps 1999).

(1d) How much of the apparent increase in fire activity is due to improvements in fire detection is debatable. One study (Kurz and Apps 1999) has examined the question of reliability of early disturbance data. They found an acceptable level of agreement between 1970 observed age-class structure, modelled age-class structure, and area disturbed by fire, insects, and logging between 1920–1969. For the sceptic who mistrusts pre-1970s fire data, it is important to realize that the total area burned in the Prairie provinces was 2.9 million ha in the 1970s compared with 12.6 million ha in the 1980s and 8.6 million ha in the 1990s. At the very least, it appears that burn rates have not decreased over the past 30 years; they may be increasing.

(2a) Forest accruals in area and in volume (due to growth) and losses (due to harvest, fire, and pests) were calculated by Honer and Bickerstaff (1985) for the period 1977–1981. They found a net loss in forest area for the Prairie Provinces of 145 000 ha/year, and a net loss in forest volume of 15.93 million $m^3$/year. At that time, the largest amount of non-satisfactorily regenerated (NSR) lands in Canada was in the Prairie Provinces; 26% of the national total for NSR lands was in Alberta (Honer and Bickerstaff 1985). Nationally, about 20% of areas logged, burned, or killed by insects or disease do not regenerate and go out of production (Honer and Bickerstaff 1985); they concluded that the forest land base is being eroded by regeneration failures and land withdrawals (a land withdrawal occurs when forest is converted to a non-forest use). Natural Resources Canada (2002) found that, nationally over the period 1975–1993, 10% of the area harvested since 1975 failed to regenerate successfully within 10 years, and, from 1979–1993, NSR lands increased in area by about 75 000 ha/year. Whether these negative trends are typical of the Prairie Provinces is questionable, as fire activity during the period was relatively high. Conversely, some recent years have had comparably high burn rates, logging rates have risen, and land losses due to the oil and gas industry and agriculture continue. The negative trend is corroborated by regional studies (see below).

(2b) In Alberta, logging and wildfire currently consume about 44 million $m^3$/year, twice what the Alberta government says can be sustainably removed. Such a consumption allows no organic matter to fuel forest function. The declines in the forest land area due to oil and gas activities and agricultural expansion exacerbate matters (Timoney and Lee 2001). By the late 1990s, the Pembina Institute (2001) calculated that Alberta had entered a timber sustainability deficit, with more timber being liquidated than is being replenished.

(2c) Annual allowable cut (AAC) in Alberta declined from 28.2 million $m^3$ in 1979 (Honer and Bickerstaff 1985) to 24.7 million $m^3$ in 1993 (Canadian Council of Forest Ministers 1994), and to 22.1 million $m^3$ by 1996 (Alberta Environment 2002), an apparent 22% decline in about 20 years. (Note AAC is not synonymous with annual harvest. The AAC is an estimate of how much volume a government feels can be removed; the harvest is the amount actually removed. An AAC may be adjusted to reflect changes to the forest land base or for political reasons.) In Manitoba, "despite there being less forest available to cut (i.e., merchantable volume decreases), the AAC increases due in part ... to assuming that industry will use much smaller trees and cut in extremely low volume stands and use logs with significant rot. This is not proven, even for L[ouisiana] P[acific],... and is unrealistic for other present industry (e.g., Tolko)" (Canadian Senate 2002).

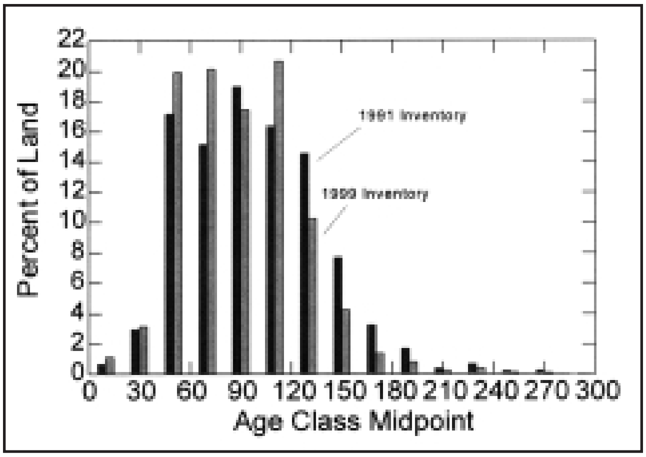



**Fig. 5.** Comparison of areal extent of forest age classes in Alberta, 1991 and 1999. Alberta Forest Service data provided courtesy of M. Anielski, Pembina Institute for Appropriate Development, Edmonton.

(2d) The rapidity of old-growth loss in Alberta is illustrated in Fig. 5. The 1991 inventory encompassed 20.08 million ha; the 1999 inventory encompassed 17.83 million ha. The deletion of about 2.25 million ha (11.2%) from the land base in eight years is alarming and demonstrates how disturbed lands may shift into NSR, unstocked, regeneration, or unclassified categories and, therefore, out of sight. However, using percent cover by class permits a comparison of the two inventories with the proviso that the difference in the 0- to 20-year age class is probably far larger than it appears in Fig. 5. Because such a treatment downplays recent disturbance, the data would lead to conservative interpretations. In spite of this, the proportion of land occupied by forests > 120 years old fell from 28.8% in 1991 to 17.6% in 1999, a relative decline of 38.9% in eight years. The decline is due to a variety of disturbances, not just harvesting. For example, between 1961 and 1999, about 1.32 million ha of forest were lost due to energy and agriculture (primarily due to seismic lines) and 1.31 million ha were logged (data from Anielski and Wilson 2001). The inescapable conclusion is that forests are disappearing rapidly, and much of the loss is old growth.

(2e) In Saskatchewan, Weyerhaeuser Canada is in the process of targeting old growth on its 3.3 million-ha forest management area (roughly 1/6 of the total forest area in Saskatchewan). Under its plan, 1–6% of the forests will be 100 years of age or older (Weyerhaeuser Canada 2000). "The average age declines in the first 70 years from about 120 years to about 65 years." The company has set a minimum retention level of 1% for age classes > 100 years, except for white spruce (> 120 years; target = 2%) (Weyerhaeuser Canada 1999). But the company notes that "large fires and other natural disturbances will continue to occur, making it impossible to guarantee... the minimum retention levels..." (Weyerhaeuser Canada 2000).

In summary, the evidence indicates that disturbance rates in boreal western Canada are increasing and that forest losses are exceeding accruals. The boreal forest is shrinking and becoming more fragmented under its current disturbance regime. Much of the human disturbance is directed at the old-growth forests.

How long will old-growth forests continue to exist in the Prairie Provinces? Firstly, both the inadequacy of age class by area inventories and the difficulty of obtaining government and industry data sets make calculations approximate. Secondly, assumptions are needed to arrive at an estimate of years to liquidation, such as constant logging and fire rates and insect and disease volume depletions, and no expansion in industrial or agricultural activities. In light of an expanding forest industry, intensification of oil and gas activities, and climate change, the assumption of a constant disturbance rate is optimistic and, therefore, the estimate of years to liquidation is optimistic. Thirdly, unless other disturbances remove them, there may be a small amount of old growth left on a harvested landscape. For example, Alberta-Pacific Industries choose cutblocks based not only on age, but also, for example, on patch volume, accessibility, haul distance, and road building costs. Old patches that are small, isolated, and difficult to deliver economically to mill tend to be left (R. Schneider, personal communication, Alberta Centre for Boreal Research, Edmonton). Assuming a continuation of 1999 cutting rates, average forest fire losses, insect mortality, and land-use depletions over the past 10 years; that younger trees grow incrementally, adding to the timber supply; and successful reforestation, Anielski and Wilson (2001) used a forest model that predicted that "overmature" forests (80 or more years old) would be exhausted in Alberta by 2042.

Regionally, for northeastern Alberta, B. Stelfox (cited in Anielski and Wilson 2001) applied a cumulative impacts model of fire and land use on the Alberta-Pacific Industries forest management area. He estimated that the overmature timber supply would be liquidated in 40 to 60 years (i.e., around 2040–2060). The 40-year estimate assumed no effective fire suppression and the 60-year estimate assumed full fire suppression and rapid recovery from oil and gas disturbances. In the Porcupine Mountains of Manitoba, Tolko plans to eliminate the mature and overmature white spruce forests within 20 years, likely within about 13 years (Soprovich 1998), i.e., by about 2010 to 2016.

For Manitoba, Saskatchewan, and Alberta as a whole, in 1991 there was an estimated 4.728 million ha of overmature forest area on non-reserve, stocked, timber-productive land (National Forestry Database Program 2002, Table 1.4). The "current" logging rate is roughly 94 266 ha/year (MB 15 544 ha/year in 1997, SK 17 500 ha/year in 1997, and AB 61 222 ha/year in 1998) (Natural Resources Canada 2000). If only overmature forests are being logged (a reasonable assumption based on "sustained yield" forestry policy), then the years-to-liquidation is roughly 4 728 000 ha/94 266 ha per year = 50.2 years from 1991, or 2041. If mature forests are also targeted, then the years-to-liquidation rises accordingly. Conversely, if disturbance rates rise, the years-to-liquidation decreases. Although such an estimate ignores recruitment into overmature status, it also assumes no mortality from wildfire, oil and gas, insects and disease, or agricultural expansion. Therefore, the estimate of years-to-liquidation may be conservative.

Land-base depletion from harvest, burn, and pests over the period 1977–1981 was 159 000 ha/year in Manitoba, 336 000 ha/year in Saskatchewan, and 327 000 ha/year in Alberta (Honer and Bickerstaff 1985). Nationally, at the 1981 rate of depletion from harvest, fire, and pests, they estimated that mature and overmature forests would be depleted in 20–80 years from 1981 (2001 to 2061).

That different methods and data sets should all indicate imminent old-growth depletion argues that the estimates are reasonable. The loss of Prairie Province old-growth forests within decades may seem an undesirable legacy. To sustained yield foresters, it means their desired outcome has been achieved (Anielski and Wilson 2001).

In Alberta, rare or declining boreal forest communities include (Allen 2001):

- riparian white spruce / river alder / meadow horsetail / *Hylocomium splendens*;
- sand hill white spruce */ Cetraria islandica*;
- riparian balsam poplar / river alder / red-osier dogwood / meadow horsetail;
- wet, nutrient-rich balsam poplar / alder-leaved buckthorn / common horsetail;
- moist, nutrient-rich balsam poplar / high-bush cranberry / ostrich fern;
- aspen / thimbleberry / wild sarsaparilla;
- and riparian aspen / Bebb's willow – beaked hazelnut / bluejoint reedgrass / ostrich fern.

At the population level, natural population fluctuations and the inadequacy of long-term data for all but a few "charismatic" species such as caribou and grizzly bear frustrate attempts to discern trends. Forest fragmentation is associated not only with a reduced number of forest bird species, but also with increased temporal variability in the number of species, both of which are associated with higher extinction and turnover rates (Boulinier *et al.* 1998). Pure habitat loss, rather than fragmentation, may better explain forest bird population decline and species loss in areas where forest harvesting is the dominant land use (Schmiegelow and Mönkkönen 2002). Some Alberta vertebrates that have declined, are at risk, or whose status is "sensitive" as a result of forest disturbances or landscape fragmentation include Barred Owl, Bay-Breasted Warbler, Blackburnian Warbler, Black-throated Green Warbler, Broad-winged Hawk, Canada Warbler, Cape May Warbler, Northern Pygmy Owl, Grizzly Bear, Northern Long-Eared Bat, Woodland Caribou, and Wolverine (Alberta Environment 2001). Although none of these species have been extirpated from the province, significant population declines are indicative of wholesale landscape changes.

In northeastern Alberta, the outlook is uncertain both for boreal ecosystems and for the forest industry. The Alberta government estimates a reserve of 1.7 trillion barrels of bitumen, most of which is overlain by a deep overburden. The bitumen will be extracted via a dense network of steam injection wells with vast volumes of fresh water extracted from the region's aquifers.

Without a reduction of disturbance rates, boreal forests and the forest industry may undergo catastrophic changes in some regions, with attendant social disruption and losses of ecological services. The same is true for Canadian boreal aquatic systems, Schindler (1998b) concluded: "Ecological sustainability of boreal waters would require that exploitation of all parts of the boreal landscape be much lower than it is at present." Pressure to extract more from a shrinking land base raises serious doubts about the viability of boreal ecosystems.

Recent climate change in boreal regions has been dramatic and raises questions about the sustainability of the existing boreal ecosystems. In northwestern Canada, spring temperatures have risen by 2.7°C over the period 1948–2000 (Environment Canada 2000). This is about three times the average rate of global warming. As the mean annual temperature varies by only 4°C north to south across the boreal ecoclimatic region (Environment Canada 1982, 1993), a 2.7°C spring warming is highly significant. Long-term observations on freeze-up and breakup dates for Northern Hemisphere lakes and rivers indicate that, over the past 150 years, the winter ice-on period has declined by about 18 days (Magnuson *et al.* 2000). For the Red River, southern Manitoba, these same authors found that the winter ice-on period has declined by about 30 days. Species present in forests reflect past disturbances. If climate change alters the disturbance regime, large impacts may be expected, especially for species and communities at their range limits (Dale *et al.* 2001), e.g., in southern boreal coniferous and mixedwood forests.

Under a twice current $CO_2$ climate, it is predicted that mean May–September temperature will rise over the Prairie provinces by 3–5°C (Flannigan *et al*. 2001), and that fire weather index and fire activity will increase over the core of the subhumid boreal (Flannigan *et al.* 1998, 2001). Modelling studies predict unprecedented increases in boreal temperature and fire activity, with a resulting greatly reduced extent of boreal forest and a corresponding increase in fragmentation (Weber and Flannigan 1997). The southern half of the western Canadian boreal forest would be exposed, under a twice current $CO_2$ climate, to conditions similar to those of present aspen parkland, where conifers are absent and aspen is restricted to groves; forest edges exposed to warm, dry conditions might suffer stresses leading to a decline in productivity (Hogg and Hurdle 1995). Increased fire activity may liberate increased amounts of sequestered carbon, resulting in a positive feedback with greenhouse gas-induced global warming (Weber and Stocks 1998).

Mild winters or drier and warmer summers in the boreal zone may mean increased fire activity and increased probability of insect outbreaks (Holling 1992). Warm, dry springs without frost favour forest tent caterpillar survival, and mild winters favour bark beetle survival (D. Williams, personal communication, CFS, Edmonton). Forest tent caterpillar outbreaks may become more severe as a result of forest fragmentation and climate warming (Fleming and Volney 1995, Roland *et al.* 1998).

## Conclusions

The degradation of the western boreal forest is not an isolated phenomenon. Forests throughout the world have been destroyed by wasteful and short-term forestry practices (Ludwig *et al.* 1993). The sustained-yield model assumes constant production from a homogeneous boreal landscape under human control. Traditional "sustained-yield" forest management leads to loss of landscape diversity, loss of old-growth forests, decline in productivity and stability, and increased risk of catastrophic changes (Christensen *et al.* 1996, Chapin *et al.* 1996, Chapin and Whiteman 1998).

Ecosystem instability is favoured by modern business practices that often have positive feedbacks between harvest intensity and resource abundance, such that decline in abundance drives up prices, raising harvest intensity (Chapin and Whiteman 1998). The attempt to extract a sustained high volume of wood from a shrinking land base in a naturally oscillating boreal system characterized by large-scale, catastrophic disturbances and climate change is unreasonable. Such an attempt is based on political and socio-economic expediency and not on ecosystem management. Short-term political–economic considerations can decouple disturbance rates from resource regeneration or accrual rates. In the face of over-exploitation, governments may subsidize the export of forest products in order to delay the unemployment that results when timber supplies become uneconomic (Repetto and Gillis 1988).

Despite alarming trends in many Canadian forest regions (World Resources Institute 2000), there is little political recognition that problems exist. The ministerial view (Natural Resources Canada 2000) regarding Canada's forests focuses on business: "... a growing world demand for forest products... The pulp and paper industry experienced record exports this year— an improvement experts confidently attribute to economic recovery in many of the Pacific Rim countries." The increasing demand for forest fibre is pushing the boreal forest on a course of dramatic change in which there will be little primeval forest left (Spence *et al.* 1997). It is critical to convey the sense of urgency felt by the scientific community that the boreal ecosystem is about to undergo fundamental change (Weber and Flannigan 1997).

The boreal forest of the Prairie Provinces has been radically changed over the past 25 years, and the rate of disturbance continues to increase. When the system is examined in detail, or we take a landscape or aerial perspective, we find sensitive species populations in regional decline (such as Woodland Caribou; Dzus 2001); we find old forests disappearing; we find movement of wildlife disrupted by fragmentation and dissection; we find high coliform counts in the streams, and fisheries in decline. All is not well. To pretend otherwise is fatuous.

There is a time-limited opportunity to protect the boreal ecosystem of western Canada from further degradation. Within the decade, disturbance rates must be lowered; an effective protected areas network must be established; and ecosystem-based management must become the basis for all land use. If we temporize, the opportunity will be lost.

## Acknowledgements

I thank Ian Thompson and anonymous reviewers for helpful criticism of the manuscript.

## References

**Achuff, P.L. and G.H. La Roi. 1977.** *Picea–Abies* forests in the highlands of northern Alberta. Vegetatio 33: 127–146.

**Alberta Agriculture. 1999.** Agriculture, food and rural development 1999–2002 business plan. Downloaded from www.treas.gov.ab.ca/comm/budget99/agric.html.

**Alberta Environment. 2001.** The general status of Alberta wild species, 2000. Alberta Environment, Edmonton, Alberta. Publ. No. I/023.

**Alberta Environment. 2002.** Timber Supply Status. Our forests today. Downloaded from http://www3.gov.ab.ca/srd/forests/fmd/timber/Timber.html. Document posted 16 March 2000, but report copyright Government of Alberta 1996.

**Alberta Forestry, Lands and Wildlife. 1990.** Alberta vegetation species list and species group checklists. Alberta Forestry, Lands and Wildlife, Edmonton. Publ. No. 56.

**Allen, L. 2001.** Alberta Natural Heritage Information Centre preliminary plant community tracking list. Alberta Natural Heritage Information Centre, Alberta Community Development, Edmonton, Alberta.

**Anielski, M. and S. Wilson. 2001.** The Alberta GPI accounts: forests. The Pembina Institute for Appropriate Development, Edmonton, Alberta.

**Armstrong, G.W. 1999.** A stochastic characterisation of the natural disturbance regime of the boreal mixedwood forest with implications for sustainable forest management. Canadian Journal of Forest Research 29: 424–433.

**Boulinier, T., J.D. Nichols, J.E. Hines, J.R. Sauer, C.H. Flather and K.H. Pollock. 1998.** Higher temporal variability of forest breeding bird communities in fragmented landscapes. Proceedings of the National Academy of Science 95: 7497–7501.

**Brandt, J.P. and P. Amirault. 1994.** Forest insect- and disease-caused depletions to forests of west-central Canada: 1982–1987. Natural Resources Canada, Canadian Forest Service - Northwest Region, Edmonton, Alberta. Info. Rep. NOR-X-333.

**CAESA (Canada-Alberta Environmentally Sustainable Agriculture Agreement). 1998.** Agricultural impacts on water quality in Alberta — an initial assessment. Alberta Agriculture Food and Rural Development, Edmonton, Alberta.

**Campbell, I.D. and M.D. Flannigan. 2000.** Long-term perspectives on fire-climate-vegetation relationships in the North American Boreal Forest. *In* E.S. Kasischke and B.J. Stocks (eds.). Fire, climate change, and carbon cycling in the boreal forest. pp. 151–172. Springer-Verlag, New York, NY.

**Canada Department of Resources and Development. 1950.** Native trees of Canada. Forestry Branch. Ottawa. Bulletin 61.

**Canada Soil Survey Committee. 1978.** The Canadian system of soil classification. Research Branch, Canada Dept. Agric., Hull. Publ. No. 1646.

**Canadian Council of Forest Ministers. 1993.** Compendium of Canadian Forestry Statistics 1992. National Forestry Database. Natural Resources Canada, Ottawa.

**Canadian Council of Forest Ministers. 1994.** Compendium of Canadian Forestry Statistics 1993. National Forestry Database. Natural Resources Canada, Ottawa.

**Canadian Senate. 2002.** Competing realities: the boreal forest at risk. Senate Subcommittee on the Boreal Forest. House of Commons, Ottawa. Downloaded from http://www.parl.gc.ca/36/1/parlbus/commbus/senate/com-e/bore-e/rep-e/rep09tablecontents1-e.htm.

**Chapin, F.S., M.S. Torn and M. Tateno. 1996.** Principles of ecosystem sustainability. American Naturalist 148: 1016–1037.

**Chapin, F.S. and G. Whiteman, G. 1998.** Sustainable development of the boreal forest: interaction of ecological, social, and business feedbacks. Conservation Ecology [online] 2, article 12. Downloaded from www.consecol.org/vol2/iss2/art12.

**Christensen, N.L., A.M. Bartuska, J.H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin, J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner and R.G. Woodmansee. 1996.** The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6: 665–691.

**Corns, I.G.W. and R.M. Annas. 1986.** Field guide to forest ecosystems of west-central Alberta. Northern Forestry Centre, Edmonton, Alberta.

**Crites, S. 1999.** A comparison of early successional understory plant communities following fire and harvesting. *In* Fire and Harvest Residual (FAHR) Project: the impact of wildfire and harvest residuals on forest structure and biodiversity in aspen-dominated boreal forests of Alberta. Final Report. pp. 116–139. Alberta Research Council, Edmonton, Alberta.

**Cumming, S. 2000.** A synopsis of fire research in the boreal mixedwood forest. Prepared for Alberta Pacific Forest Industries Inc. Available from Boreal Ecosystems Research Ltd., Edmonton, Alberta.

**Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001.** Climate change and forest disturbances. Bioscience 51: 723–734.

**Delcourt, H.R., P.A. Delcourt and T. Webb III. 1983.** Dynamic plant ecology: the spectrum of vegetational change in space and time. Quaternary Science Reviews 1: 153–175.

**Dirschl, H.J., D.L. Dabbs and G.C. Gentle. 1974.** Landscape classification and plant successional trends: Peace-Athabasca Delta. Canadian Wildlife Service, Ottawa. Report Series No. 30.

**Dzus, E. 2001.** Status of woodland caribou (*Rangifer tarandus caribou*) in Alberta. Alberta Environment, Edmonton. Alberta Wildlife Status Report No. 30.

**Ecoregions Working Group. 1989.** Ecoclimatic regions of Canada. Minister of Supply and Services, Ottawa. Ecological Land Classification Series No. 23.

**Emond, F.J. and H.F. Cerezke. 1989.** Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1988 and predictions for 1989. Forestry Canada - Northern Forestry Centre, Edmonton. NOR-X-303.

**Environment Canada. 1982.** Canadian climate normals, 1951–1980, Volume 2, Temperature. Minister of Supply and Services, Ottawa.

**Environment Canada. 1993.** Canadian climate normals, 1961–1990, Prairie Provinces. Minister of Supply and Services, Ottawa.

**Environment Canada. 2000.** Canadian regional spring temperature departures: trend and extremes, 1948– 2000. Downloaded from www.msc-smc.ec.gc.ca/ccrm/bulletin/ttabsumm.htm.

**Environment Council of Alberta. 1979.** Environmental effects of forestry operations in Alberta. Environment Council of Alberta, Edmonton, Alberta.

**Flannigan, M., M. Wotton, P. Richard, C. Carcaillet and Y. Bergeron. 1998.** Fire weather: past, present, and future. *In* Ninth symposium on global change studies and Namias Symposium on the status and prospects for climate prediction. pp. 305–309. American Meteorological Society, Boston.

**Flannigan, M., I. Campbell, M. Wotton, C. Carcaillet, P. Richard and Y. Bergeron. 2001.** Future fire in Canada's boreal forest: paleoecology results and general circulation model—regional climate model simulations. Canadian Journal of Forest Research 31: 854–864.

**Fleming, R.A. and W.J.A. Volney. 1995.** Effects of climate change on insect defoliator population processes in Canada's boreal forest: some plausible scenarios. Water, Air, & Soil Pollution 82: 445–454.

**Geological Survey of Canada. 1967.** Glacial Map of Canada. Ottawa. Map 1253A.

**Geological Survey of Canada. 1968.** Geological Map of Canada. Ottawa. Map 1250A.

**Government of Manitoba. 2001.** Pest alert: forest tent caterpillar. Forestry Branch, Insects and Disease. Downloaded from www.gov.mb.ca/natres/forestry/forest-health/fh-forestent.html.

**Hare, F.K. and J.E. Hay. 1974.** The climate of Canada and Alaska. *In* R.A. Bryson, and F.K. Hare (eds.). Climates of North America. Volume 11 of World Survey of Climatology. Elsevier Scientific Publishing Company, New York, NY.

**Hare, F.K. and J.C. Ritchie. 1972.** The boreal bioclimates. Geographical Review July: 333–365.

**Hiratsuka, Y., H.F. Cerezke and J. Petty. 1980.** Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1979 and predictions for 1980. Env. Can., Canadian Forestry Service – Northern Forestry Centre, Edmonton. NOR-X-225.

**Hiratsuka, Y., H.F. Cerezke, J. Petty and G.N. Still. 1981.** Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1980 and predictions for 1981. Env. Can., Canadian Forestry Service - Northern Forestry Centre, Edmonton. NOR-X-231.

**Hiratsuka, Y., H.F. Cerezke, B.H. Moody, J. Petty and G.N. Still. 1982.** Forest insect and disease conditions in Alberta, Saskatchewan, Manitoba, and the Northwest Territories in 1981 and predictions for 1982. Env. Can., Canadian Forestry Service – Northern Forestry Centre, Edmonton. NOR-X-239.

**Hobson, K.A. and J. Schieck. 1999.** Changes in bird communities within boreal mixedwood forest during the first thirty years: contrasting the effects of harvest and wildfire. *In* Fire and harvest residual (FAHR) project: the impact of wildfire and harvest residuals on forest structure and biodiversity in aspen-dominated boreal forests of Alberta. A Final Report. pp. 170–203. Alberta Research Council, Edmonton.

**Hogg, E.H. and P.A. Hurdle. 1995.** The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? Water, Air, & Soil Pollution 82: 391–400.

**Holling, C.S. 1973.** Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4: 1–23.

**Holling, C.S. 1992.** The role of forest insects in structuring the boreal landscape. *In* H.H. Shugart, R. Leemans and G.B. Bonan (eds.). A systems analysis of the Global Boreal Forest. pp. 170–191. Cambridge University Press, New York, NY.

**Honer, T.G. and A. Bickerstaff. 1985.** Canada's forest area and wood volume balance 1977–1981: an appraisal of change under present levels of management. Canadian Forestry Service. Pacific Forestry Centre, Victoria. BC-X-272.

**Horejsi, B.L. 1995.** Habitat fragmentation by the oil and gas industry in Alberta and British Columbia: its impact on wildlife. Western Wildlife Environments Consulting Ltd., Calgary, Alberta.

**Ives, W.G.H. and H.R. Wong. 1988.** Tree and shrub insects of the prairie provinces. Env. Can., Canadian Forestry Service – Northern Forestry Centre, Edmonton. NOR-X-292.

**Jeffrey, W.W. 1961.** A prairie to forest succession in Wood Buffalo Park, Alberta. Ecology 42: 442–444.

**Johnson, E.A., K. Miyanishi and J.M.H. Weir. 1995.** Old growth, disturbance, and ecosystem management. Canadian Journal of Botany 73: 918–926.

**Johnson, E.A., K. Miyanishi and J.M.H. Weir. 1998.** Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management. Journal of Vegetation Science 9: 603–610.

**Kabzems, A., A.L. Kosowan and W.C. Harris. 1976.** Mixedwood section in an ecological perspective. Saskatchewan Tourism and Renewable Resources, Regina, Sasketchewan. Tech. Bull. No. 8.

**Kurz, W.A. and M.J. Apps. 1995.** An analysis of future carbon budgets of Canadian boreal forests. Water, Air, & Soil Pollution 82: 321–331.

**Kurz, W.A. and M.J. Apps. 1999.** A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. Ecological Applications 9: 526–547.

**Lee, P. (project leader). 1999.** Fire and Harvest Residual (FAHR) Project: the impact of wildfire and harvest residuals on forest structure and biodiversity in aspen-dominated boreal forests of Alberta. A Final Report. Alberta Research Council, Edmonton.

**Lee, P.C., S. Crites, M. Nietfeld, H. Van Nguyen and J.B. Stelfox. 1995.** Changes in snags and down woody material characteristics in a chronosequence of aspen mixedwood forests in Alberta. *In* J.B. Stelfox (ed.). Relationships between stand age, stand structure, and biodiversity in aspen mixedwood forests in Alberta. pp. 49–61. Jointly published by Alberta Environmental Centre, Vegreville, AB, and Canadian Forest Service, Edmonton, Alberta.

**Lieffers, V.J., S.E. Macdonald and E.H. Hogg. 1993.** Ecology and control strategies for *Calamagrostis canadensis* in boreal forest sites. Canadian Journal of Forest Research 23: 2070–2077.

**Ludwig, D., R. Hillborn and C. Walters. 1993.** Uncertainty, resource exploitation, and conservation: lessons from history. Science 260: 17, 36.

**Magnuson, J.J., D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Stewart and V.S. Vuglinski. 2000.** Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289: 1743–1746.

**National Forestry Database Program. 2002.** Table 1.4, Area and volume of gross merchantable wood on stocked, timber-productive, nonreserved forest land by province/territory, 1991; Table 9.7, Application of forest herbicides by product, ownership, province/territory, 1992-2000; and Table 6.1, Silvicultural statistics by Province/Territory, 1975-1999. Downloaded from http://nfdp.ccfm.org/cp95/data_e/tab14e_1.htm; ... tab97e_1.htm, and ... tab61e_1.htm.

**Natural Resources Canada. 2000.** The State of Canada's Forests 1999–2000. Canadian Forest Service, Ottawa.

**Natural Resources Canada. 2002.** Criterion 2 Ecosystem Condition and Productivity. Downloaded from http://www.nrcan.gc.ca/cfs/proj/ppiab/ci/cr2p_e.html.

**Paine, R.T., M.J. Tegner and E.A. Johnson. 1998.** Compounded perturbations yield ecological surprises. Ecosystems 1: 535–545.

**Payette, S. 1992.** Fire as a controlling process in the North American boreal forest. *In* H.H. Shugart, R. Leemans and G.B. Bonan (eds.). A systems analysis of the global boreal forest. pp. 144–169. Cambridge University Press, New York, NY.

**Pembina Institute. 2001.** Timber sustainability. GPI Indicator # 39. The Pembina Institute for Appropriate Development, Edmonton, Alberta.

**Perry, D.A., M.P. Amaranthus, J.G. Borchers, S.L. Borchers and R.E. Brainerd. 1989.** Bootstrapping in ecosystems. Bioscience 39: 230–237.

**Peterson, E.B. and N.M. Peterson. 1992.** Ecology, management, and use of aspen and balsam poplar in the prairie provinces. Forestry Canada – Northern Forestry Centre, Edmonton, Alberta.

**Raup, H.M. 1935.** Botanical investigations in Wood Buffalo Park. Canada Department of Mines, National Museum of Canada. Ottawa. Bull. No. 74.

**Repetto, R. and M. Gillis (eds.). 1988.** Public policies and the misuse of forest resources. Cambridge University Press, Cambridge.

**Revel, R.D., T.D. Dougherty and D.J. Downing. 1984.** Forest growth and vegetation along seismic lines. University of Calgary Press, Calgary, Alberta.

**Roland, J., B.G. Mackey and B. Cooke. 1998.** Effects of climate and forest structure on duration of tent caterpillar outbreaks across central Ontario. The Canadian Entomologist 130: 703–714.

**Rowe, J.S. and R.T. Coupland. 1984.** Vegetation of the Canadian plains. Prairie Forum 9: 231–248.

**Schindler, D.W. 1998a.** A dim future for boreal waters and landscapes. Bioscience 48: 157–164.

**Schindler, D.W. 1998b.** Sustaining aquatic ecosystems in boreal regions. Conservation Ecology [online] 2, article 18. Downloaded from http://www.consecol.org/vol2/iss2/art18.

**Schmiegelow, F.K.A. and M. Mönkkönen. 2002.** Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. Ecological Applications 12: 375–389.

**Scoggan, H.J. 1978.** The flora of Canada. National Museum of Natural Sciences, Publications in Botany, No. 7. Ottawa, ON.

**Soprovich, D.W. 1998.** Forest management in Manitoba: annual allowable cuts compromise diversity. Eco-journal 8: 6–7.

**Spence, J.R., D.W. Langor, H.E.J. Hammond and G.R. Pohl. 1997.** Beetle abundance and diversity in a boreal mixed-wood forest. *In* A.D. Watt, N.E. Stork and M.D. Hunter (eds.). Forests and insects. pp. 287–301. Chapman and Hall, London.

**Statistics Canada. 2001.** Use of farmland, Canada and the provinces. Downloaded from www.statcan.ca/english/pgdb/land/geography/phys10.htm.

**Stelfox, J.B. (ed.). 1995.** Relationships between stand age, stand structure, and biodiversity in aspen mixedwood forests in Alberta. Jointly published by Alberta Environmental Centre, Vegreville, Alberta, and Canadian Forest Service, Edmonton, Alberta.

**Stelfox, J.G., J.B. Stelfox, W.C. Bessie and C.R. Clark. Undated.** Longterm (1956–1996) effects of clearcut logging and scarification on forest structure and biota in spruce, mixedwood, and pine communities of west-central Alberta. Unpublished report available from J.B. Stelfox, Forem Technologies, Box 805, Bragg Creek, Alberta.

**Tilman, D., R.M. May, C.L. Lehman and M.A. Nowak. 1994.** Habitat destruction and the extinction debt. Nature 371: 65–66.

**Timoney, K.P. 1998.** The old-growth forests of Alberta. Alberta Environmental Protection, Edmonton, Alberta.

**Timoney, K.P. 2001.** Types and attributes of old-growth forests in Alberta, Canada. Natural Areas Journal 21: 282–300.

**Timoney, K.P. and P. Lee. 2001.** Environmental management in resource-rich Alberta, Canada: first world jurisdiction, third world analogue? Journal of Environmental Management 63: 387–405.

**Timoney, K.P. and A.L. Robinson. 1996**. Old-growth white spruce and balsam poplar forests of the Peace River Lowlands, Wood Buffalo National Park, Canada: development, structure, and diversity. Forest Ecology and Management 81: 179–196.

**Timoney, K.P., G. Peterson and R. Wein. 1997.** Vegetation development of boreal riparian plant communities after flooding, fire, and logging, Peace River, Canada. Forest Ecology and Management 93: 101–120.

**Utzig, G.F. and W.E. Walmsley. 1988.** Evaluation of soil degradation as a factor affecting forest productivity in British Columbia, a problem analysis, Phase I. Canada – British Columbia Partnership Agreement on Forest Resources Development: FRDA II, Victoria. FRDA report 25.

**van Wagner, C.E. 1988.** The historical pattern of annual burned area in Canada. The Forestry Chronicle June: 182–185.

**Volney, W.J.A. 1988.** Analysis of historic jack pine budworm outbreaks in the Prairie Provinces of Canada. Canadian Journal of Forest Research 18: 1152–1158.

**Weber, M.G. and M.D. Flannigan. 1997.** Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes. Environmental Reviews 5: 145–166.

**Weber, M.G. and B.J. Stocks. 1998.** Forest fires in the boreal forests of Canada. *In* J.M. Moreno (ed.). Large forest fires. pp. 215–233. Backhuys Publishers, Leiden.

**Weyerhaeuser Canada. 1999.** Twenty-Year Forest Management Plan and Environmental Impact Statement. Weyerhaeuser Canada Saskatchewan Division, Prince Albert, Saskatchewan.

**Weyerhaeuser Canada. 2000.** Twenty-year Plan and EIA Web. The Plan. Downloaded from http://www.metla.fi/info/vlib/Forestry/Topic/Management/ (navigate to link Weyerhaeuser Canada Saskatchewan / A new 20-year forest management plan Web site). [Note this document has since been removed from the Web].

**White, D.J., E. Haber and C. Keddy. 1993.** Invasive plants of natural habitats in Canada. Environment Canada, Ottawa, Ontario.

**White, P.S. 1987.** Natural disturbance, patch dynamics, and landscape pattern in natural areas. Natural Areas Journal 7: 14–22.

**World Resources Institute. 2000.** Canada's forests at a crossroads: an assessment in the year 2000. World Resources Institute, Washington, DC, USA.

**Appendix 1. Common and scientific names of plant taxa appearing in the text. Nomenclature follows Scoggan (1978) and Alberta Forestry, Lands and Wildlife (1990).**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| alder-leaved buckthorn | *Rhamnus alnifolia* | June grass | *Koeleria macrantha* |
| American elm | *Ulmus americana* | juniper | *Juniperus* |
| aspen | *Populus tremuloides* | Kentucky bluegrass | *Poa pratensis* |
| awned sedge | *Carex atherodes* | larch | *Larix laricina* |
| balsam poplar | *Populus balsamifera* | lichen | *Cetraria* |
| balsam fir | *Abies balsamea* | lichen | *Stereocaulon* |
| bearberry | *Arctostaphylos uva-ursi* | limber pine | *Pinus flexilis* |
| Bebb's willow | *Salix bebbiana* | lodgepole pine | *Pinus contorta* |
| beaked hazelnut | *Corylus cornuta* | meadow horsetail | *Equisetum pratense* |
| black ash | *Fraxinus nigra* | needle grass | *Stipa* |
| black spruce | *Picea mariana* | ostrich fern | *Matteucia struthiopteris* |
| blueberry | *Vaccinium* | paper birch | *Betula papyrifera* |
| bluegrass | *Poa* | peat moss | *Sphagnum* |
| bluejoint reedgrass | *Calamagrostis canadensis* | plane-leaved willow | *Salix planifolia* |
| bulrush | *Scirpus* | pussy willow | *Salix discolor* |
| bur oak | *Quercus macrocarpa* | red fescue | *Festuca rubra* |
| cattail | *Typha latifolia* | red pine | *Pinus resinosa* |
| cherry | *Prunus* | red maple | *Acer rubrum* |
| common horsetail | *Equisetum arvense* | red-osier dogwood | *Cornus stolonifera* |
| common great bulrush | *Scirpus validus* | reedgrass | *Calamagrostis* |
| cord grass | *Spartina* | reindeer lichen | *Cladina* |
| dandelion | *Taraxacum officinale* | reindeer lichen | *Cladonia* |
| Douglas fir | *Pseudotsuga menziesii* | ricegrass | *Oryzopsis* |
| dwarf mistletoe | *Arcenthobium americanum* | river alder | *Alnus tenuifolia* |
| Engelmann spruce | *Picea engelmannii* | rocky mountain fescue | *Festuca saximontona* |
| fescue | *Festuca* | salt-meadow grass | *Puccinellia* |
| foxtail barley | *Hordeum jubatum sensu lato* | saskatoon | *Amelanchier alnifolia* |
| golden moss | *Tomenthypnum nitens* | sedge | *Carex* |
| green ash | *Fraxinus pennsylvanica* | smooth brome | *Bromus inermis* |
| hairy cap moss | *Polytrichum* | slender wheat grass | *Agropyron trachycaulum* |
| hairy wildrye | *Elymus innovatus* | spangletop | *Scolochloa festucacea* |
| high-bush cranberry | *Viburnum opulus* | stairstep moss | *Hylocomium splendens* |
| jack pine | *Pinus banksiana* | subalpine fir | *Abies lasiocarpa* |

**Appendix 1. Continued.**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| subalpine larch | *Larix lyallii* | white pine | *Pinus strobus* |
| sugar maple | *Acer saccharum* | white spruce | *Picea glauca* |
| thimbleberry | *Rubus parviflorus* | whitebark pine | *Pinus albicaulis* |
| timothy | *Phleum pratense* | wild sarsaparilla | *Aralia nudicaulis* |
| western porcupine grass | *Stipa curtiseta* | willow | *Salix* |
| white cedar | *Thuja occidentalis* | yellow birch | *Betula lutea* |