National circumstances in the international circumboreal community

by Michael A. Wulder[1], Celina Campbell[2], Joanne C. White[1], Mike Flannigan[3] and Ian D. Campbell[4]

ABSTRACT

Boreal forest nations are often thought to have similar environmental, social, and economic contexts. In this communication we show that boreal forest nations are a disparate grouping, with some similarities and many differences. Highlighting these differing national contexts provides insights into how a given nation utilizes the boreal forests over which it holds stewardship responsibilities. Current national contexts are related to each nation's physiography, climate, history, legacy of past forest management, the timing of transition from natural to plantation forests, population density and distribution, and access to resources and markets. Boreal forests are dominated by pioneer species that are resilient to disturbance and have a demonstrated ability to adapt to past climate changes. National responses to natural disturbances are linked to forest area, ownership, and management intensity. Boreal forests in large nations (e.g., Canada, Russian Federation) are typically publicly owned, and disturbances such as fire are allowed to progress naturally over remote areas. In smaller nations, where there is often a greater proportion of private ownership and a focus on production forestry, natural disturbances are more aggressively controlled (e.g., Sweden, Finland). Large nations with low boreal human population densities have a greater proportion of natural boreal forest, with relatively higher levels of biodiversity when compared to the fully managed forests of some smaller boreal nations. In smaller nations, the combination of limited forest area and private ownership has facilitated the dominance of intensive sustainable forestry management practices (e.g., Finland). Conversely, in nations with more spatially extensive forest assets that are publicly owned and managed to meet multiple objectives, extensive sustainable forest management practices dominate (e.g., Canada, Russian Federation).

Key words: boreal forest, global, national circumstances, environmental, social, economic, forestry practices, Canada

RÉSUMÉ

Les pays forestiers nordiques sont souvent perçus comme ayant un contexte environnemental, social et économique semblable. Dans cet article, nous démontrons que les pays forestiers constituent un groupe disparate ayant quelques similitudes et plusieurs différences. La mise en évidence de ces contextes nationaux différents permet une vision intrinsèque de l'utilisation faite par un pays donné des forêts boréales pour lesquelles il détient des responsabilités d'intendance. Les contextes nationaux actuels sont décrits selon la géographie physique, le climat, l'histoire, l'héritage de l'aménagement forestier antérieur, l'époque de la transition des forêts naturelles vers les plantations, la densité et la distribution de la population, ainsi que l'accès à la ressource et aux marchés de chaque pays. Les forêts boréales sont dominées par des espèces pionnières qui sont résilientes suite à une perturbation et ont une capacité démontrée de s'être adaptées aux changements climatiques du passé. Les réactions à l'échelle nationale face aux perturbations sont liées à la superficie forestière, au type de tenure et à l'intensité de l'aménagement. Les forêts boréales des grands pays (par ex., le Canada. la Russie) sont typiquement sous une gestion publique et les perturbations comme les feux de forêt peuvent progresser de façon naturelle dans les régions éloignées. Dans le cas des plus petits pays, où l'on retrouve souvent une plus forte proportion de terrains privés et un accent mis sur la production forestière, les perturbations naturelles sont contrôlées plus énergiquement (par ex., la Suède, la Finlande). Les grands pays ayant une faible densité de population nordique démontrent une proportion plus importante de forêts boréales naturelles qui expriment des niveaux plus élevés de biodiversité par rapport aux forêts totalement aménagées de certains pays nordiques plus petits. Dans le cas des plus petits pays, la combinaison des superficies forestières réduites et du type de tenure privée a facilité la dominance des pratiques intensives d'aménagement forestier durable (par ex., la Norvège, le Danemark). Inversement, dans les pays ayant des ressources forestières s'étendant sur de plus grandes superficies et qui sont de propriété publique et aménagées pour répondre à de multiples objectifs, les pratiques extensives d'aménagement forestier dominent (par ex, le Canada, la Russie).

Mots clés : forêt boréale, mondial, états nationaux, environnemental, social, économique, pratiques forestières, Canada

[1]Canadian Forest Service (Natural Resources Canada), Pacific Forestry Centre, Victoria, British Columbia. Corresponding author. E-mail: mike.wulder@nrcan.gc.ca

[2]Earth Science Sector, Geological Survey of Canada (Natural Resources Canada), Northern Environment Subdivision, Ottawa, Ontario, Canada.

[3]Canadian Forest Service (Natural Resources Canada), Great Lakes Forestry Centre, Sault Ste. Marie, Ontario.

[4]Policy Research Initiative (Human Resources and Social Development Canada), Ottawa, Ontario.

Introduction

"Each country is unique in terms of the quantity, quality, characteristics, and descriptions of its forests. Countries also differ in terms of forest conditions relative to national population, such as the amount of forest per capita, the amount reforested annually per capita, or the annual forest growth per capita. National circumstances further differ with respect to stages of economic development, land ownership patterns, population patterns, forms of social and political organization, and expectations of how forests should contribute or relate to society" (Heiner 1995).

The circumboreal community is an international community of nations, sectors, people, and unique physical environments. The boreal biome occurs in many industrialised nations, providing them with environmental, social, and economic capital. Understanding and respecting the differences between national and regional circumstances is a prerequisite for effective development of sound boreal research priorities (e.g., Kellomäki 2000, Spence 2001) and policies (e.g., McDonald and Lane 2004) that collectively will help ensure circumboreal sustainability (Shvidenko and Apps 2006).

In this communication, similarities and differences in national environmental, social, and economic boreal forest contexts are presented and compared. It should be noted that data availability, quality, and comparability are variable; thus, all numbers should be considered indicative only of general trends. Most national level statistics are not calculated by biome or ecozone, and as a result, the available data often include non-boreal areas, and are therefore (to varying degrees) considered a proxy for national trends in the boreal. Given the percentage of the forest that is boreal, the breakdown is a reasonable surrogate for boreal forest conditions in the Russian Federation, Canada, Sweden, Finland, Norway, Iceland, and St. Pierre and Miquelon (an overseas collective of France), but not the United States, China, Kazakhstan, or the United Kingdom.

Environmental Context

The circumpolar boreal biome (Fig. 1) is located between the tundra and the temperate mixed and deciduous forests or savannah/prairie (approximately 45º and 70º north latitude; Larsen 1980, Foote and Krogman 2006) and covers approximately 1640 million hectares (ha) of which about 60% to 80% is forested (Dixon *et al.* 1994, Iremonger *et al.* 1997). Boreal forests represent approximately 27% of the world's forest cover (FAO 2001, 2005) and contain some of the largest tracts of primary forest (no clearly visible signs of human activities and the ecological processes are not significantly disturbed) in the world (FAO 2006).

A biome is a large ecological region, classified according to the prevailing climate and dominant vegetation types. While there is no universally accepted definition, the boreal forest biome is typically characterized by long, severe winters and short summers (Strahler and Strahler 1997), and is dominated by a variety of cold-tolerant, slow-growing, generally short-lived coniferous (e.g., spruce, fir, and pine) and deciduous (e.g., larch, alder, birch, and aspen) tree species (e.g., Strahler and Strahler 1997, Kimball *et al.* 2004, Hytteborn *et al.* 2006). The boreal biome contains many different environments. The borel forest is the forested part of the boreal biome. About three quarters of the boreal forest is closed forest (canopy relative stocking > 40%) and the remainder is open forest (relative stocking between 10% and 40%) (Shvidenko and Apps 2006). Soils are typically Podzols and Cryosols with an abundance of organic soils (e.g., peatlands). The world's largest reservoir of peat, containing approximately 455 Gt of carbon (C) (Gorham 1991), occurs in the boreal. The global value for peatlands is approximately 500 to 860 Gt C (Markov *et al.* 1988, Bohn 1976). Permafrost underlies approximately 60% of the boreal forest biome (Shvidenko and Apps 2006).

Trees of the boreal forest are generally of a small size relative to their age. Coniferous boreal forests tend have lower net primary production (NPP) and net ecosystem production (NEP) when compared to temperate and tropical forests (Jarvis and Linder 2000, Watson *et al.* 2000). NPP in the boreal biome is estimated at 280 g m^{-2} yr^{-1} (Saugier and Mooney 2001) and NEP at 12 g C m^{-2} yr^{-1} (Bonan *et al.* 2003). These low annual growth rates and NEP values are expected, as both are a function of the length of the growing season (time between spring thaw and autumn freeze) (Jarvis and Linder 2000).

The boreal biome is characterized as having low taxonomic diversity, low functional redundancy in ecosystem properties, and low productivity (Hobbie *et al.* 1994, Pastor *et al.* 1998). Boreal biodiversity is low relative to the level of biodiversity in many other forested biomes (Millennium Ecosystem Assessment 2005). While few boreal species are at risk of extinction, some species or populations are at risk: in marginal areas (transitional ecotones) where the species primary habitat is not within the boreal; where migratory species are subject to risk factors occuring outside the boreal forest biome (e.g., southern winter habitats); and, in areas where there is a high prevalence of private ownership and a long history of land use (e.g. Mayer and Tikka 2006). As natural disturbances (e.g., fire, insects, storms) are the primary agent of boreal forest stand rejuvenation (e.g., Apps *et al.* 1995, Korpilahti *et al.* 1995, Shvidenko and Apps 2006), boreal forests are well adapted to disturbances, demonstrating high resilience (Lassig and Mocalov 2000, Chapin *et al.* 2004b, Shvidenko and Apps 2006). Further, as much of the North American boreal forest biome was covered with ice until approximately 18 000 to 6000 ^{14}C years ago (Dyke 2004), most North American boreal species are well adapted to rapid dispersal over poorly developed soils—making endemism relatively rare. Non-forested areas are distinguished by barren land, meadows, bare rock, and in some areas, water bodies (e.g., lakes, swamps, marshes). Globally, the boreal biome is increasingly becoming an important source of natural resources and associated revenues (e.g., energy, hydroelectric development, minerals and metals, timber and non-timber forest products) (e.g., National Roundtable on the Environment and the Economy 2005).

Boreal forest area

The lack of a universally accepted definition of boreal forest is accompanied by the absence of a standardized methodology for defining its spatial extent. A variety of methods have been used to assess and characterize the area of boreal forest, including field surveys, aerial photographs, and satellite remotely sensed data (e.g., Spribille and Chytry 2002, Gamon

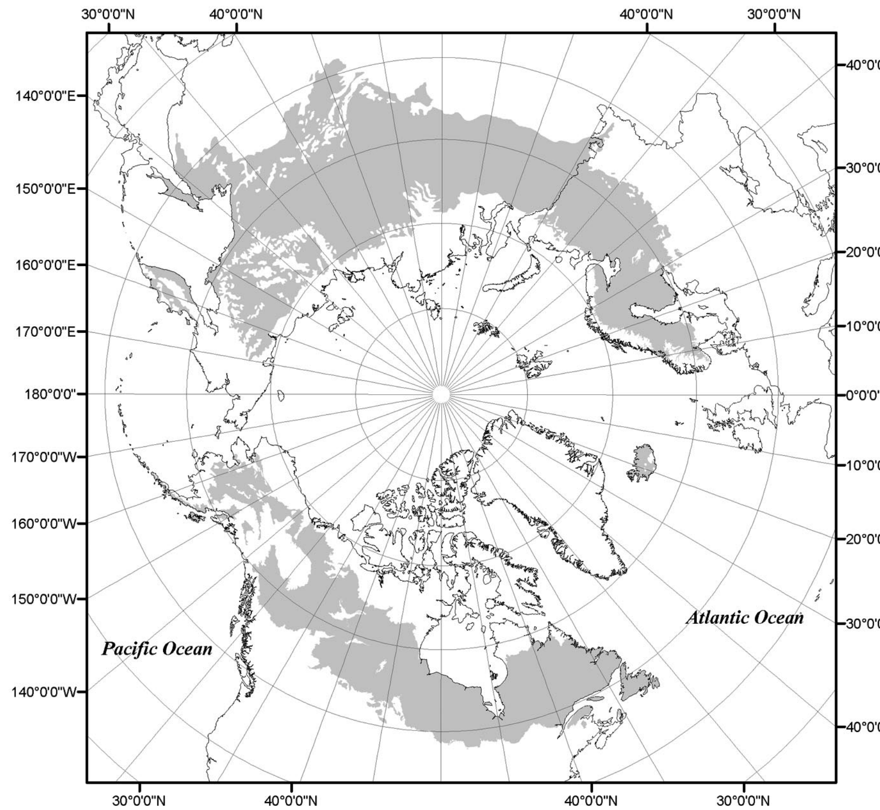

Fig. 1. Map of the circumpolar boreal forests.

et al. 2004, Mather 2005). Different methods result in the measurement of different variables, at differing scales, and the resulting areal estimates are thus not directly comparable. Assessing the status of the boreal forest is therefore challenging, as changes in the areal extent through time and space may result from changes in the type of source data used and/or from changes in definitions and methodological issues associated with measurement, as well as from genuine accretions and depletions of forest area (Mather 2005, Gold *et al.* 2006). Notwithstanding these caveats, Table 1 summarizes the distribution of circumpolar boreal forest by nation (FAO 2001, 2006). The estimate of total boreal forest area of 1105 million ha presented in Table 1 is a similar order of magnitude to the 1250 million ha in Apps *et al.* (1993), the 1370 million ha in Dixon *et al.* (1994), the 1046 million ha in Iremonger *et al.* (1997), 1005 million ha in FAO (2001), and the 1160 million ha in Shvidenko and Apps (2006). It is noteworthy that the Russian Federation and Canada together have approximately 90% of the global boreal forest, whereas the Nordic (i.e., Finland, Iceland, Norway, and Sweden) countries collectively have approximately 5% (FAO 2001, 2005).

The total area of boreal forest does not appear to be declining (FAO 2006, Shvidenko and Apps 2006). Considering only the countries where the forest is dominantly boreal (Russian Federation, Canada, Sweden, Finland, Norway, Iceland, and St. Pierre and Miquelon) there has been a slight increase in boreal forest area from 1990 to 2005 (FAO 2006). In Canada and the Nordic countries the combined losses in area are less than or equal to the total gains per year leading to a net gain; in the Russian Federation the losses are greater than the gains (FAO 2006). It is not clear to what degree these changes are real, and to what degree they are artefacts of improved measurement or changed definitions. Although, in Canada, forest area is increasing as marginal farmlands are left to return to forest cover (White and Kurz 2005), suggesting that at least a portion of the apparent gain is indeed real.

Boreal ecological zones

The range of edaphic (i.e., chemical, physical, and biological characteristics of the soil which affect an ecosystem) and climatic (e.g., moisture, temperature) conditions found in the boreal have resulted in a number of different forest communities. These communities have unique characteristics such as natural disturbance regimes, biogeochemical cycles, and productivity, with each responding uniquely to external drivers such as climate change, anthropogenic disturbances, and

Table 1. Area of circumboreal forests

Nation[a]	Percent of Country's Total Forest Area That Is Boreal Forest (Source: Table 14, FRA 2000[b])	Total Area of Forest and Other Wooded Land (1000 ha) (Source: Table 3, FRA 2005[c])	Boreal Forest Area (1000 ha)	% of Total Global Boreal Forest Area
Russian Federation	86	882975	759359	68.69
Canada	73	402085	224000[d]	20.26
United States	13	303089	39402	3.56
Finland	98	23300	22834	2.07
Sweden	72	30785	22165	2.01
China	8	284905	22792	2.06
Norway	93	12000	11160	1.01
Kazakhstan	17	18959	3223	0.29
United Kingdom	14	2865	401	0.04
Iceland	100	150	150	0.0146
St. Pierre and Miquelon	100	3	3	0.0003
TOTAL		**1961116**	**1105489**	**100**

[a]Some countries, such as Mongolia, Japan, Estonia, Latvia and Lithuania claim to have boreal forest in some documents; however, as areas are not given in the FAO FRA 2000 and 2005 reports they have not been included in this list.
[b](FAO 2001)
[c](FAO 2006)
[d]CanFI 2001 (CFS 2007) data used rather than FAO data.

ecosystem disruptions. Each boreal country has developed its own typology(ies) for boreal forests that recognize the range and variation present in that country. There is no standardized international methodology or classification system to describe these boreal communities, making international comparisons difficult.

The North American boreal forest is dominated by boreal moist and wet forest, the Russian Federation by boreal moist forest, and the European boreal is dominated by boreal wet forest (Iremonger *et al.* 1997, Peinado *et al.* 1998). Unique boreal environments include areas of boreal rain forest in Canada and the Far East, boreal dry bush in the Russian Federation and the Far East, and boreal desert in North America (Iremonger *et al.* 1997). The global boreal can be broadly classified as coniferous (58%), forest tundra (33%), and mountain boreal (10%). In Canada, 40% of the total boreal forest area is found within the coniferous forest dominated ecozones, compared to 50% in the Russian Federation, 95% in Finland, and 67% in Sweden (Table 2).

Table 2. Distribution of total forest area by ecological zone and % boreal coverage (Source: Table 14, FRA 2000[a])

Area	% of Total Forest Area: Coniferous Forest[b]	Tundra[c]	Mountain[d]
Russian Federation	50	3	33
Canada	40	24	9
United States	0	5	8
Finland	95	0	3
Sweden	67	0	5
China	8	0	n.s.
Norway	46	n.s	47
Kazakhstan	0	0	17
United Kingdom	10	0	4
Iceland	87	0	13
St. Pierre and Miquelon	100	0	0
Global Boreal Forest	58	10	33

[a] (FAO 2001)
[b] Boreal Coniferous Forest is defined by vegetation physiognomy: coniferous dense forest dominant.
[c] Boreal Tundra Woodland is defined by vegetation physiognomy: woodland and sparse forest dominant.
[d] Boreal Mountain Systems are defined by altitude (> 600 m).
Source for definitions: Table 47-2 Ecological zone breakdown used in FRA 2000, page 326 of FRA 2000 report

Boreal forest age-class dynamics

Generally, boreal forest stands are susceptible to disturbance and as a result, are short-lived in comparison to temperate forest stands (e.g., CFS 2001). Forest age-class demographics are important determinants of both market (e.g., timber and non-timber forest products) and non-market ecosystem goods and services (e.g., biodiversity, clean air, and water).

Fig. 2 summarizes three examples of age class distributions from Finland, Sweden, and Canada, and illustrates the impact of different national circumstances on forest age class structures. Sweden's forest has the youngest age-class structure reflecting intensive forest management practices. Finland's forest has a baby-boom-like demographic wave reflecting the impact of the Second World War on its forest industry (Andersson and Östlund 2004). In Canada, there was a high rate of natural disturbances in the late 1800s due to the Little Ice Age that altered species ranges and disturbances regimes, and restructured ecosystems (Campbell and McAndrews 1993, Bergeron *et al.* 2004). There was also a high rate of accidental anthropogenic forest fire associated with the construction of the cross-continental railway in the late 1800s (e.g., Johnson *et al.* 1990). These disturbances resulted in the establishment of large cohorts of young forest stands in the early

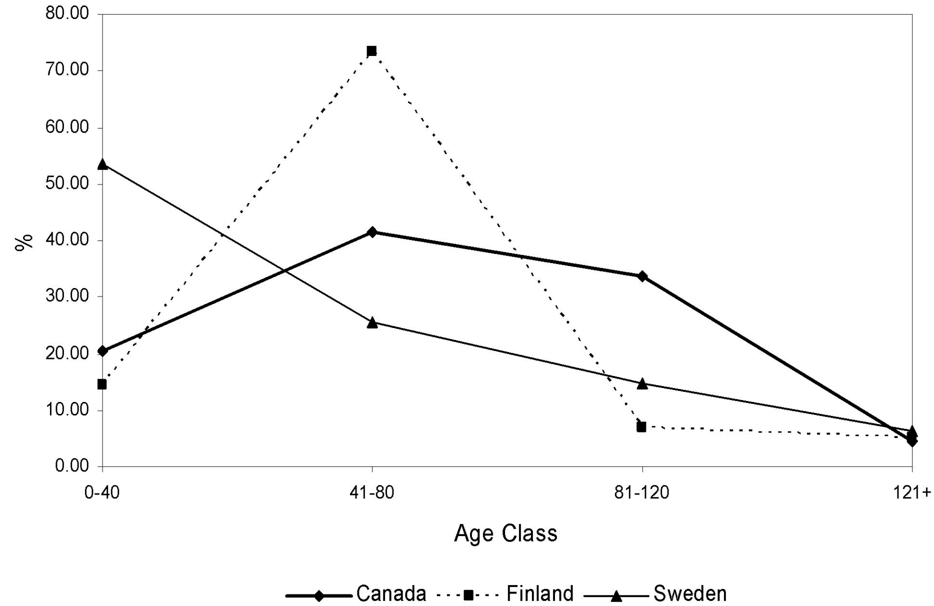

Fig. 2. Boreal forest age class distribution as a percentage of forest area (Source: MCPFE 2003, CFS 2007).

1900s. From 1920 to 1970 the disturbance regime was relatively stable, and as a result, by 1970 the national forest base was dominated by mature trees. From around 1970 to the present, there has been a dramatic increase in natural disturbances, where older, fire-prone and insect and disease-prone stands are being replaced by new young stands (Kurz and Apps 1999). This current rejuvenation process may be due to a combination of both natural disturbance cycles and natural/anthropogenic climate change (e.g., Royama 1984, Yu *et al.* 2003, Campbell *et al.* 2004, Gray and MacKinnon 2006, Soja *et al.* 2007).

Boreal forest disturbances

Boreal environments are characterized by both natural (e.g., fire, insects, storms [ice, wind, rain], and wildlife) and anthropogenic disturbances (e.g., land use, land use change, natural resource use management, pollution). Natural and anthropogenic disturbances may differ substantially in their ecological effects (Niemelä 1999). Table 3 summarizes the relative importance of these different disturbances in boreal forest nations. While the North American boreal is dominated by crown fire (fire located primarily in tree crowns, often causing stand mortality and replacement), the Russian Federation forest is dominated by ground fire (fire located primarily in understorey and surface litter, often clearing underbrush but not leading to stand mortality and replacement). Disturbance in Nordic countries results mainly from storms and herbivory (as described below). This largely reflects the higher moisture levels in the Nordic boreal, which reduces the risk of fire ignition and spread.

The rate and magnitude of boreal forest disturbances vary significantly through time and space. These differences are a function of a large number of natural and anthropogenic variables. Disturbances are agents of intentional or unintentional landscape transformation. Different edaphic, climatic, and vegetation variables, the size of the boreal asset, human infrastructure investment, forest ownership structure, and forest management functions (e.g., objectives and strategies) can significantly impact how natural and anthropogenic disturbances are managed (e.g., risk assessment and disturbance management strategies). Not surprisingly, in countries that have a small landbase and little forest land, and where forest stands are dominantly privately owned and managed for fibre, intensive sustainable forest management practices dominate (e.g., Nordic countries) (Löfman and Kouki 2003, Mielikäinen and Hynynen 2003); whereas, in nations with large forest assets, in which forest stands are dominantly publicly owned and managed for multiple purposes, extensive sustainable forest management practices dominate (e.g., Canada) (Siry *et al.* 2005).

These two very different types of management practices have evolved as a function of different national circumstances and are thus difficult to compare. For example, in areas where the forest asset is dominantly publicly owned and where extensive sustainable forest management practices prevail (e.g., Canada), forest fire suppression mainly focuses on reducing risk to human infrastructure and, where possible, the protection of forest resources. This strategy attempts to maintain the integrity of the forest ecosystem including its natural disturbance cycles and natural stand structures. Conversely, in areas where intensive sustainable forest management practices dominate (e.g., Nordic countries), disturbances are almost always mitigated in order to reduce loss of fibre and non-wood forest products. Sustainable forest management, whether it is extensive or intensive, involves trade-offs. For example, areas that are being intensively managed for fibre may lose some of their non-market natural capital. This is illustrated in the Nordic countries, which over the last 150

Table 3. Primary, secondary, and tertiary agents of natural disturbances

Nation/Area	Primary	Secondary	Tertiary	Reference
Russian Federation	Fire (surface)	Storm	Insect/Disease	MCPFE 2003
Canada	Fire (crown)	Insect/Disease	Unknown	CFS 2007
United States	Fire (crown)	Insect/Disease	Unknown	USDA *et al.* 2005
Finland	Storm	Insect/Disease	Unknown	MCPFE 2003
Sweden	Wildlife	Storm	Insect/Disease	MCPFE 2003
Norway	Storm	Wildlife	Insect/Disease	MCPFE 2003
Iceland	Wildlife	Insect/Disease	Storm	MCPFE 2003

years have managed their forests almost exclusively for sustained fibre yield, in the process reducing inter alia biodiversity, the number of large trees, the amount of standing dead trees, the quantity of forest floor litter and peat stocks (Schilstra 2001, Kuuluvainen and Laiho 2005, Hytteborn *et al.* 2006, Mayer *et al.* 2006). Finally, the sheer size and low density of human habitation in the boreal forest in the Russian Federation and Canada make natural disturbances much more difficult to manage than in smaller countries such as the Nordic countries.

Natural disturbances

In the Siberian and North American boreal, fire is the most important agent of disturbance (Table 3). In the absence of significant fire in much of the European boreal, animal herbivory and storms are considered the most significant natural disturbances. In Canada and Alaska, animal herbivory and storm disturbances have not been measured at the biome level, although they do occur. In Canada, herbivory may have been significant at a regional scale in the past, as there is evidence that the southern margin of the boreal forest in western Canada was prehistorically controlled in part by large animal herbivory (Campbell *et al.* 1994, Campbell and Campbell 2000). In the Russian Federation, Canada, and Alaska, annual reductions in standing biomass due to natural disturbances are significantly greater than reductions due to harvesting (Conard *et al.* 2002, MCPFE 2003, USDA *et al.* 2005, FAO 2006). In the smaller boreal nations (e.g., Nordic countries) reductions due to harvesting outweigh reductions due to natural disturbances (Kasischke and Stocks 2000, Väätäinen 2001, MCPFE 2003, FAO 2006).

Fire ecology is a function of edaphic, climatic and vegetation characteristics. At a high level, boreal forests can be divided into three main ecological groupings based on fire ecology (Campbell and Flannigan 2000, MCPFE 2003, USDA *et al.* 2005, Hytteborn *et al.* 2006):

1. regions where fire is rare (e.g., European boreal forest in the Russian Federation, Sweden, Finland, Norway, United Kingdom, Iceland, eastern Canada);
2. regions dominated by significant levels of stand-destroying crown fires (e.g. western Canada); and,
3. regions dominated by significant levels of non-stand destroying surface fires (e.g., Siberian boreal, Alaska).

While it is widely believed that in the intensively managed, small, privately owned boreal Nordic forests, fires are largely under the control of forest managers (Shvidenko and Apps 2006), the high level of humidity in the region also likely reduces the magnitude and frequency of fire as it does in eastern Canada (Campbell and Flannigan 2000). Furthermore, given the relatively high population density in the European boreal, landscape fragmentation (e.g., conversion to agricultural land) may also have contributed to the low fire rates (Flannigan *et al.* 1998, Paatalo 1998). In addition, there has been a boreal-wide shift in the dominant cause of fire ignitions from lighting to human-induced fire. For example in the Russian Federation between 2002 and 2005, 87% of fires were started by people (Mollicone *et al.* 2006). In the Russian Federation this human impact on fire has been attributed to a lack of fire suppression and ineffectual fire-management policies, new socioeconomic conditions in the region, and the revitalization of the oil industry (Dienes 2004, Karpachevskiy 2004, Achard *et al.* 2005). In Canada human-caused fires accounted for approximately 65% of fire ignitions, but only 35% of the area burned (Stocks *et al.* 2002). Other research has indicated that changes in human influence have resulted in changes in fire regimes. The results of a study by Wallenius *et al.* (2005) revealed the non-random spatial and temporal nature of forest fires in an unmanaged area of Fennoscandia and northwest Russia, suggesting that much of the historical fire activity in this area was human-caused, and that a change in human behaviour had resulted in a change in fire regime in this area (in contrast to other theories that climate change or a change in fire suppression activity were causal agents of changes in fire regimes).

Insect disturbances can also have a large impact on forests; insect-induced mortality in Canada during the period 1920 to 1995, impacted 76 million ha (Kurz *et al.* 1995), with the annual rate of disturbance attributed to insects tripling after 1970 (Kurz and Apps 1999). In 2004, the total area of forest defoliated by insects or killed by beetles in Canada was estimated at 13.1 million ha. Similar trends have been obtained for Russian Federation forests, where recent insect damage and disease mortality have affected as much as four million hectares annually. Some of this increase in damage may be attributable to an increase in the spatial extent of monitoring activities. In Siberian and Canadian forests, insect damage is estimated to be of the same magnitude as fire loss (IPCC 2001b). Like fire, some types of insect disturbances can be stand-destroying (e.g., bark beetles) whereas other types (defoliators) may not be; however, defoliators often result in long-term losses in volume (e.g., Hall 1995, Parsons *et al.* 2003, Mayfield *et al.* 2005, Soja *et al.* 2007). Also like fire, insect disturbances vary through time and space in response to stand conditions, weather, and other factors. For example, a mountain pine beetle outbreak in British Columbia, Canada, has increased from 164 000 ha in 1999 to 8.5 million ha in 2005 (Westfall 2006). The cumulative pine mortality for this period is estimated to be approximately 450 million m^3, representing

Table 4. Characteristics of forest in countries/areas that contain boreal forest (Table 8, FRA 2005[a], p. 225)

	Percent Forest				
Country/Area	Primary[b]	Modified Natural[c]	Semi-Natural[d]	Productive Plantation[e]	Protective Plantation[f]
Russian Federation	32	66	–	1	1
Canada	53	47	–	–	–
United States	34	58	2	6	–
Finland	6	0	94	0	0
Sweden	17	–	80	2	0
China	6	58	20	14	1
Norway	2.7	–	94.5	2.8	–
Kazakhstan	0	72.8	0	0	27.2
United Kingdom	0	50	50	0	0
Iceland	0	37	0	37	26.1
St. Pierre and Miquelon	-	100	–	–	–
Global Boreal Forest	32.2	57.8	5.8	3.6	0.5

[a](FAO 2006)

Forest/other wooded land of:

[b]native species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.

[c]naturally regenerated native species where there are clearly visible indications of human activities.

[d]native or introduced species, established through planting or seeding mainly for provision of services.

[e]introduced species and in some cases native species, established through planting or seeding mainly for production of wood or non wood goods.

[f]native or introduced species, established through planting or seeding mainly for production of wood or non wood goods.

one third of the total provincial pine volume (1.35 billion m^3). By 2013, it is projected that 80% of British Columbia's pine volume may be killed by the outbreak of mountain pine beetle (Eng *et al.* 2006). The mountain pine beetle has expanded into areas that have no previous record of infestation and poses a significant threat to Canada's boreal forests (Logan and Powell 2001, Carroll *et al.* 2004, Carroll 2005).

Anthropogenic disturbances

Like natural disturbances, anthropogenic disturbances and thus their consequences differ significantly between nations. At a global level, direct anthropogenic disturbance in much of the boreal is generally of less importance than in temperate or tropical regions (Malhi *et al.* 1999). Much of the European boreal has a very large anthropogenic footprint (i.e., area under human influence), whereas much of the Canadian, Siberian, and Alaskan boreal forests have a smaller anthropogenic footprint (Table 4; Sanderson *et al.* 2002, USDA *et al.* 2005, FAO 2006, Mayer *et al.* 2006). The key reason for these differences include: different temporal and spatial settlement histories, land ownership structure, geography, climate, forest types, forest disturbance regimes, forest age class composition, size of boreal asset and forest management practices.

Canada, for example, is a young and very large country, with a relatively small population concentrated along its southern border. As a result, there is no current or planned access to, or management of, a very substantial portion of the total forest. Most of Canada's forest is publicly owned. Due to logistics and the demands of ecological sustainability, forests tend to be natural and extensively managed (FAO 2006). In contrast, Finland has been settled for much longer than Canada, has a much greater population density, a well-developed transportation and service infrastructure, and thus greater access to the boreal forest. Finnish forests are mostly privately owned, intensively managed and semi-natural (FAO 2006).

There are distinct differences between forest characteristics in the countries that have boreal forest. For example, the Russian Federation and Canada have 78% of the globe's primary forest and 68% of the globe's modified natural forest; whereas, the Nordic countries have 1% and 0% respectively. Conversely, the Nordic countries have 51% of the globe's semi-natural forest, whereas the Russian Federation and Canada have 0% (Table 4). The proportions of natural/modified, natural, semi-natural and plantation forests change through time. However, given the economic pressure to move towards high productivity (but lower biodiversity) plantations and the development of new access roads and other infrastructure, the trend is for change to be unidirectional, away from natural forest and towards plantations. In those countries with mature infrastructure and long histories of commercial forest exploitation, such as the Nordic countries, this means that the forest has already been largely converted and is no longer changing rapidly; in those regions such as northern Canada and Siberia where commercial exploitation/development has only recently begun and there is still, therefore, a large area of natural forest, the rate of conversion is inevitably higher (e.g., Achard *et al.* 2006). For example, in Canada's western boreal forest area, key agents of anthropogenic change have been identified as commercial forestry, fossil fuel, mining, agriculture, climate change, and hydrologic alterations (Foote and Krogman 2006). Although these change agents are presented in relation to impacts upon wetlands, the findings of Foote and Krogman (2006) inform upon the nature, type, and intensity of anthropogenic activity in the western boreal and indicate within nation differences.

In the small Nordic boreal, forests are intensively managed, with a limited area protected (UNEP 2005). This has been attributed to high private ownership and land use history (Mayer *et al.* 2006). Furthermore, not all of the protected

Nordic boreal forests are considered typical of natural forests that would have existed in the region at the beginning of the 20th century (Uotila *et al.* 2002). Alternatively, much of Canada's boreal forest is extensively managed with vast protected areas (approximately 16.4 million ha of boreal forest are protected under national or provincial programs, with approximately 12.9 million hectares of this total area protected from any form of commercial activity [Canadian Council of Forest Ministers 2005]), covering an area larger than several boreal forest nations (Table 1). Throughout the circumboreal forest, many protected areas occur in national parks, areas that are difficult to access, areas underlain by permafrost, and areas with lower than commonly available commercial value (e.g., Nilsson and Götmark 1992, Scott *et al.* 2001, Mayer *et al.* 2006). In 2000, the FAO reported that only 5.0% of boreal forest was found in protected areas, compared to 15.2% for tropical forests, 11.3% for subtropical forests, and 16.3% for temperate forests (FAO 2001). Not surprisingly, protection of boreal forests is much more difficult to achieve in boreal nations with a greater proportion of private ownership (Parviainen and Frank 2003, Mayer and Tikka 2006).

Pollution

Boreal forest ecosystems have been described as *reservoirs* of pollution: places where pollution and related precursors are stored (e.g., mercury, radionuclides) (Johansen *et al.* 2003, Nordin *et al.* 2005, Su and Wania 2005, Turetsky *et al.* 2006, Yoschenko *et al.* 2006). These forest ecosystems hold large pollution *stocks* (the amount of pollution in the reservoir at a given time) in their trees, soil, peat, and water. A forest in which pollution stocks are increasing is called a pollution *sink*; one in which pollution stocks are decreasing, a pollution *source*. Whether a forest is a pollution sink or source can and does change over time. Forest management (e.g., disturbance management) can impact a forest's pollution sink–source status. When the forest is disturbed by fire, insects, harvesting or other factors, some of the pollution is released to the air, soil, or water and the forest becomes a pollution source. When the forest grows again, it absorbs pollution from the air, soil, and water and stores it in the plant tissue, forest floor litter, soil, and peat, and the forest becomes a pollution sink.

The construction of hydroelectric dams, and the associated reservoirs that ensue, are a significant source of mercury and greenhouse gas emissions; not only is the vegetation in the area flooded and thus no longer available as an assimilator of greenhouse gases, but as the vegetation and surficial organic matter decomposes, mercury is released into the water and carbon dioxide and methane are released into the atmosphere. This elevated level of greenhouse gas emissions is thought to diminish over time (Tremblay *et al.* 2004). Rosenberg *et al.* (1987) estimated that approximately 20 000 km^2 of Canada's boreal forest had been lost to hydroelectric reservoirs, with an additional 11 000 km^2 slated for hydroelectric development.

Wood smoke contains many substances that are considered harmful to human health (Stolhywo and Sikorski 2005, New Hampshire Department of Environmental Services 2006, Pope and Dockery 2006). Smoke from forest fires is a major source of smog and particulate pollution and has been implicated in asthma and other respiratory illnesses, cardiopulmonary morbidity and mortality, and increased health care costs (Cheng *et al.* 1998, Guenther *et al.* 2000, Chung 2003, Zhang *et al.* 2003, Lee *et al.* 2005, Mott *et al.* 2005). Smoke from forest fires can travel long distances. For example, smoke from a forest fire in the Northwest Territories, Canada, is thought to have caused a pollution event in Atlanta, Georgia (Wotowa and Trainer 2000), particulate matter from forest fires in Quebec was transported to Baltimore (Sapkota *et al.* 2005), and smoke from the Russian Federation negatively impacted air quality in Korea (Lee *et al.* 2005). Boreal forest fires have also been linked to increased remobilization of stored toxics such as mercury and methylmercury (St. Louis *et al.* 2001, Sigler *et al.* 2003, Turetsky *et al.* 2006) and radionuclides (Johansen *et al.* 2003, Yoschenko *et al.* 2006) contributing to exacerbating toxicities for northern food chains. Fine black particulate matter from boreal forest fires has also been linked to global warming through its effect on albedo (Hansen *et al.* 2000, Menon *et al.* 2002, Kim *et al.* 2005, Highwood and Kinnersley 2006).

At the biome level, boreal ecosystems have not been significantly impacted by pollution; however, there are pollution hot spots, such as oil and gas development, smelters, open pit mineral and energy extraction, and nuclear accidents and test explosions (e.g., Rigina *et al.* 1999, Aamlid *et al.* 2000, Reimann *et al.* 2001, Hytteborn *et al.* 2006). Due to high levels of air pollution, significant tracts of the Siberian and European boreal forests are being, or are at risk of being, damaged (Rigina *et al.* 1999, Lorenz *et al.* 2002). For example, Shvidenko and Nilsson (1994) indicate that an area of 6.5 million ha in Siberia has been negatively affected by industrial pollution.

In developed countries, the major impacts of air pollution on forest services are likely to be on recreation and non-wood products (Nilsson *et al.* 1992). For example, in much of the European boreal forest, there is still radioactive ^{137}Cs in forests and other natural and semi-natural ecosystems since the 1986 accident at the Chernobyl nuclear power plant, which contaminated both wood and non-timber products, including food (e.g., Avery 1996, Tveten *et al.* 1998, STUK 2003) For example in 2006, sheep in Norway were found to be contaminated with unusually high levels of radioactivity from the Chernobyl disaster; levels of ^{137}Cs in the sheep reached 7000 becquerels per kilogram (bq/kg), largely from eating ^{137}Cs-contaminated mushrooms. In Norway the level of radioactivity in food deemed safe for human consumption is 600 bq/kg (New Scientist 2006).

Acid deposition (rain, fog, snow) can lead to nutrient imbalances and toxicity in trees, which in turn can increase sensitivities to other stresses such as insect infestations and cold sensitivity (Ulrich 1984, Sverdrup *et al.* 1994, Cronan and Grigal 1995, Binkley and Hoberg 1997, Adams *et al.* 2000). Some boreal forest areas (e.g., European) receive more acid deposition than others (e.g., Canada). Effects are most significant in watersheds and lakes in regions where the soils are poorly buffered. In these conditions, lake acidification, reduction in biological activity, and changes in species composition can occur (e.g., Huser and Rydin 2005). Research into the impacts of acid deposition on boreal forests has produced varying results. Some studies have quantified impacts on forest growth (DeHayes *et al.* 1999; Ouimet *et al.* 2001), while the results of other studies suggest acid deposition is not currently damaging the growth of boreal forests (e.g., Hall 1995, Binkley and Högberg 1997, Solberg *et al.* 2004) and is less serious than originally believed (Menz and Seip 2004).

Tropospheric ozone has been shown to impact the structure and productivity of forest ecosystems in industrialized countries and is likely to increase in extent, with further industrial development and agriculture management (Percy and Ferretti 2004). Nitrogen deposition, which is higher in northern Europe than elsewhere (Nordin *et al.* 2005), has been implicated in productivity increases or decreases (depending on species and conditions) over large regions. Boreal forests, which historically have been nitrogen-limited, appear to be most affected (Federal Research Centre for Forestry and Forest Products 2006).

Impacts of human physical infrastructure

Our understanding of the cumulative impacts of disturbances on the landscape is increasing with greater emphasis on integrated landscape management (e.g., Schneider *et al.* 2003, Bayne *et al.* 2005). Human physical infrastructure affects landscapes both directly and indirectly. For example, linear features such as roads, cut-lines, seismic lines, and pipelines can create new edge habitats, alter hydrological dynamics, disrupt ecological processes, increase mortality in animals, lead to a degradation, loss and isolation of wildlife habitat, provide access for hunting and other uses, and can cause landscape fragmentation and soil compaction (e.g., Vaisanen *et al.* 1986, Roland 1993, Hobson and Bayne 2000, Kuri *et al.* 2000, Patriquin and Barclay 2003). It has been shown that linear features can act as wildlife corridors, thereby altering predator-prey dynamics (including hunting) and impacting species composition by facilitating the introduction of invasive alien species (e.g., Lambert and Hannon 2000, Fleming and Schmiegelow 2003, Oberg *et al.* 2003, James *et al.* 2004, Bayne *et al.* 2005, Hannon and Drapeau 2005, Merrill *et al.* 2005). Despite their many potential negative consequences, roads facilitate improved control of natural disturbances such as forest fire by acting as firebreaks and providing access for suppression crews. In parts of the circumboreal where there is significant human presence (e.g., European boreal), there is little forest area left that is not directly impacted by human infrastructure. However, there are still significant areas of the boreal in the Russian Federation and Canada that have not yet been impacted by human infrastructure (Sanderson *et al.* 2002).

Impacts of climate change

It is anticipated that climate change will result in shifts in species distributions (Malcolm *et al.* 2002, Walther *et al.* 2002) and that the boreal forest will experience a net increase in species diversity, accompanied by increased competitive interactions amongst species (Thuiller *et al.* 2005). The boreal has been characterized by significant climate changes through time. The paleoecological evidence shows that the boreal forest biome has changed dramatically through time (Adams *et al.* 1990, Campbell and McAndrews 1993, QEN 1995, Adams and Faure 1997), and that the boreal is dominated by species that would elsewhere be considered pioneer species, capable of rapid migration into barren lands when the climate or environmental conditions allow (e.g., aspen). Most boreal species survived glacial episodes and associated climatic extremes, suggesting these species may be capable of adapting to climate warming.

While "the ability of trees to track anthropogenic warming may be more limited than previously thought" (Anderson *et al.* 2006), assessing impacts of global change is complicated by the problems associated with translating models and data across spatial and temporal scales (Peterson 2000). Further, the impacts of climate change are expected to be spatially uneven, with greater relative warming expected in the continental interiors. The large continental interiors of the Canadian and Russian Federation forests can be expected to be impacted by changes in climate that would lead to potential changes in length of growing season, hydrological regimes, disturbance regimes, species suitability, and productivity. The possible manifestations of these changes and the rate at which they will occur are the subject of intensive research and debate (e.g., Flannigan *et al.* 1998; Walther *et al.* 2002; Chapin *et al.* 2004a, b; Anderson *et al.* 2006).

The Intergovernmental Panel on Climate Change (IPCC 2001a) has found that the boreal forest biome will experience a relatively greater increase in temperatures than will lower latitude regions. Temperature changes over the past 100 years have been greater in the boreal, with increases of 2°C to 3°C (Stocks *et al.* 1998). The areas most likely to be impacted are the ecological transition zones (e.g., boreal margins). Models indicate that future environmental boreal dynamics will evolve with the changing conditions. As has occurred in the past, future changes will likely result in a reorganization of plant and animal assemblages. Depending on the magnitude and rate of climate change (and other associated changes in global biogeochemical cycles and anthropogenic activities) the species associations apparent today may change in both spatial distributions and composition (IPCC 2001b), and thus dynamics.

The boreal forest biome contains 30% to 35% of global terrestrial C storage and is thus an important variable in the global climate system (Apps *et al.* 1993, McGuire *et al.* 1995, Zoltai and Martikainen 1996, Alexeyev and Birdsey 1998). The boreal ecosystem contains approximately 64 mg/ha C in vegetation and 343 mg/ha in soil (including organic soils/peatlands). The total boreal C-stock is approximately 88 Pg C in vegetation and 471 Pg C in soil. Boreal soils have more C than those of any other biome. Much of the C is contained in organic soils (10–40%) and much of it is labile and can easily oxidise (Neff and Hooper 2002) through fire or decomposition, both of which are expected to increase in the near future due to climate change (Yu *et al.* 2003, Turetsky *et al.* 2006). This would, in turn, release more C into the atmosphere and further exacerbate the affect of climate change. In addition anthropogenic activities that affect forest C storage (i.e., fire suppression, peat/wetland drainage, land use, land use change, forestry) can also impact global change (Watson *et al.* 2000).

Scientific evidence is mounting that climate change in Canada, the Russian Federation and Alaska is already resulting in rapid non-linear change. These changes include changes in tree-line elevation, decreased forest health, increased insect infestations and large fires (Soja *et al.* 2007), shrub thickening at the northern boundaries (Strum *et al.* 2001), and increased permafrost melting and associated greenhouse gas emissions (Gillett *et al.* 2004, Zimov *et al.* 2006, Lavorel *et al.* 2007). Despite these changes, field observations suggest that, for the moment, the spatial extent of boreal forest extents remain basically stable. This may reflect inherent lags between forest response and climate change, or competitive pressures between tree stands and surrounding

Table 5. Boreal nation demographics (Source: CIA World Factbook 2006[a])

Country	Population (July 2006)	Age Structure (%) 0–14 Years	15–64 Years	65+ Age	Median Age	Population Growth Rate (%)	Life Expectancy at Birth	Fertility Rate (born/woman)
Russian Federation	142893540	14.2	71.3	14.4	38.4	-0.37	67.08	1.28
Canada	33098932	17.6	69	13.3	38.9	0.88	80.22	1.61
United States	298444215	20.4	67.2	12.5	36.5	0.91	77.85	2.09
Finland	5231372	17.1	66.7	16.2	41.3	0.14	78.5	1.73
Sweden	9016596	16.7	65.7	17.6	40.9	0.16	80.51	1.66
China	1313973713	20.8	71.4	7.7	32.7	0.59	72.58	1.73
Norway	4610820	19.3	65.9	14.8	38.4	0.38	79.54	1.78
Kazakhstan	15233244	23	68.8	8.2	28.8	0.33	66.89	1.89
United Kingdom	60609153	17.5	66.8	15.8	39.3	0.28	78.54	1.66
Iceland	299388	21.7	66.5	11.7	34.2	0.87	80.31	1.92
St. Pierre and Miquelon	7026	23.5	65.7	10.8	34.1	0.17	78.61	2.01
Tropical comparison								
Brazil	188078227	25.8	68.1	6.1	28.2	1.06	71.69	1.93
India	1095351995	30.8	64.3	4.9	24.9	1.38	64.71	2.73
Indonesia	245452739	28.8	65.8	5.4	26.8	1.41	69.87	2.4

[a](CIA 2006)

tundra and herbaceous vegetation (Masek 2001). However, at least once in the past, a climatic warming led to a very rapid transformation of the forest tundra to forest (MacDonald *et al.* 1993). It has been suggested that forest stands, once established, do not much respond to small changes in climate, and that the bulk of the response to climate change may come in the form of regeneration failures or stand type changes following disturbances (Hogg 1997, Hogg and Schwarz 1997, Hogg and Bernier 2005). Poor regeneration of forest following fire has been observed along the southern boreal/grassland boundary (Hogg 1997) and in climatically dry areas of the southwestern Yukon (Hogg and Wein 2005).

Social Circumstances

Boreal demographics

Most boreal nations have an aging population (median age 36.4 years) and a low population growth rate (mean 0.4% per year) (Table 5). This is in marked contrast to tropical regions where the population is dominated by a young and rapidly growing population (for example the median age in Brazil, India and Indonesia is 26.3 years and the population growth rate is high, at 1.3% per year). The demographic differences between boreal and tropical nations will likely have significant impacts on future forests and forestry.

At a national level, the total available boreal area necessary to produce forest market (timber and non-timber forest products) and non-market (e.g., clean air and water) goods and services per capita vary widely between boreal nations. Canada has the smallest population per ha of boreal forest, and the United Kingdom the largest (Table 6).

The GDP real growth rate and GDP per capita within boreal nations is highly variable—ranging form $6800 (China) to $42 800 (Norway) (Table 7). Kauppi *et al* (2006) found that the growing stock of forests increased between 1990 and 2005 for all nations with a GDP greater than $4600 per capita. They conclude that the propensity for nations to strive towards a higher GDP, and the policies often associated with raising the GDP, do not necessarily always result in a reduction of the forest growing stock. This provides a source of optimism regarding the future state of forests, with many nations moving towards a forest transition from a net reduction, to a net increase, in total forest area.

Table 6. Population distribution in boreal nations (Source: FRA 2005[a] and CIA World Factbook 2006[b])

Country/Area	Boreal Forest Area (1000 ha)	Population National Total	Total Population Boreal Forest Area (Per ha)
Russian Federation	759 359	145 000 000	0.2
Canada	224 000	32 434 732	0.1
United States	39 402	295 734 134	7.5
Finland	22 834	5 223 442	0.2
Sweden	22 165	9 001 774	0.4
China	22 792	1 306 313 812	57.3
Norway	11 160	4 593 041	0.4
Kazakhstan	3 223	15 185 844	4.7
United Kingdom	401	60 441 457	150.7
Iceland	150	296 737	2.0
St. Pierre and Miquelon	3	7 012	2.3

[a](FAO 2006)
[b](CIA 2006)

Ownership and forest management

In the circumboreal countries, 86% of the forest land is publicly owned and 14% is privately owned (Table 8). In the Russian Federation, Canada, China, Kazakhstan, and St. Pierre and Miquelon, the majority of forests are publicly owned. In the United States, Finland, Sweden, Norway, United Kingdom and Iceland, the majority of forests are privately held.

Table 7. Economic indicators for boreal nations (Source: CIA World Fact Book 2006[a])

	GDP (purchasing power parity)	GDP (real growth rate %)	GDP per capita	Unemployment (%)
Russian Federation	$1.584 trillion	6.4%	$11 000	7.6
Canada	$1.111 trillion	2.9%	$33 900	6.8
United States	$12.31 trillion	3.2%	$41 600	5.1
Finland	$161.9 billion	3%	$31 000	8.4
Sweden	$268.3 billion	2.7%	$29 800	5.8
China	$8.883 trillion	10.2%	$6 800	9[b]
Norway	$196.4 billion	4%	$42 800	4.6
Kazakhstan	$125.3 billion	9.5%	$8 300	8.1
United Kingdom	$1.818 trillion	1.9%	$30 100	4.7
Iceland	$10.59 billion	5.6%	$35 700	2.1
St. Pierre and Miquelon	$48.3 million	n.s.	$7 000	10.3

[a](CIA 2006)
[b]Official registered unemployment in urban areas in 2004; substantial unemployment and underemployment in rural areas; an official Chinese journal estimated overall unemployment (including rural areas) for 2003 at 20% (2005 est.)

Table 8. Forest ownership in countries/areas that contain boreal forest (Source: FRA 2005[a], Table 5, p. 202)

	% Forest Ownership 2000		
Country/Area	Public	Private	Other
Russian Federation	100	0	0
Canada	92.1	7.9	n.s.
United States	42.4	57.6	–
China	100	–	–
Finland	32.1	67.8	0.1
Sweden	19.7	80.3	0
Kazakhstan	100	–	–
United Kingdom	36.2	63.8	0
Iceland	46.6	53.2	0.8
St. Pierre and Miquelon	86.7	13.3	–

[a](FRA 2006)

In the Russian Federation, China, Sweden, Finland, and Norway the majority of forest is managed for forest production (Table 9). In Canada, the United States, Kazakhstan, the United Kingdom, Iceland and St. Pierre and Miquelon, the majority of the forest land is managed for multiple purposes. In the Nordic countries where forests are dominantly privately owned (Sweden, Finland, and Norway) forest production is the primary function of the forest.

Management practices and descriptive terminology differ substantially across the circumboreal. For example, in some cases (e.g., steep mountainous slopes with thin soil) clearcutting can cause soil erosion and significantly reduce the probability of successful stand regeneration. Clearcutting stands with significant amounts of *Calamagrostis canadensis* can lead to rapid expansion of the grass, which can seriously hinder regeneration (largely a western Canadian boreal problem). Also, watering-up (rise in water table) after clearcutting (due to loss of leaf area and a consequent reduction in interception and evapotranspiration) is an issue at wetter sites (Dubé *et al.* 1995). Alternatively, in other areas where fire is the major stand-renewing process (as is the case for most of the western Canadian boreal where stands therefore tend to be even-aged, mono-specific or, aspen–spruce mixedwoods) clearcutting is used to emulate natural processes (Perera *et al.* 2004). Clearcutting is also sometimes used to describe the high grading of mature trees in a stand and leaving the younger trees intact for regeneration, which is elsewhere called selective harvesting. The lack of standardized forest management terminology reduces the meaningfulness of international comparisons, hampers international assessments, and obscures the suitability of different silvicultural practices to locations.

Economic Context

Harvesting

It is unknown exactly how much industrial roundwood is extracted from the boreal forest; it has been estimated that the boreal contributes approximately three quarters of the global supply of industrial coniferous wood (Shvidenko and Apps 2006), an increase from approximately 40% of the global supply in 1992. This share is forecast to remain the same in 2010 and 2020 (Nilsson 1996). The export value of circumboreal forest products has been valued at approximately 47% of the total global forest exports, providing 5% of gross export earnings in the Russian Federation, 13% in Canada and 9% to 34% in the Nordic countries (Nilsson 2000).

Boreal countries are not removing wood proportional to their share of boreal forest. For example, the Nordic countries, with 5% of the global boreal forest, removed approximately 150 million m^3 (over bark) in 2005, whereas the Russian Federation, which has 70% of the global boreal forest, removed approximately 180 million m^3 (over bark) (FAO 2006). In areas that are replanted after harvesting rather than being left to regenerate naturally, foresters have favoured conifers at the expense of other species. This practice can significantly alter forest composition, as it has in Finland. In North America, hardwood species have become an important source of various wood and paper products, whereas the use of boreal hardwoods in Russia is practically non-existent (Shvidenko and Apps 2006).

Illegal logging occurs in all boreal countries to some extent. According to World Bank estimates, governments lose revenues totalling approximately US$5 billion annually as a

Table 9. Designated primary function of forests in countries/areas that contain boreal forest (Source: FRA 2005[a], Table 6, p. 208)

Country/Area	Total Area of Forest and Other Wooded Land (1000 ha)[b]	Forest Production[c]	Forest Protection[d]	Forest Conservation[e]	Forest Social Services[f]	Forest Multiple Purpose[g]	Unknown[h]
Russian Federation	882975	76.9	8.7	2	1.5	10.8	–
Canada	402085	1.3	–	4.9	–	86.7	7.1
United States	303089	12	–	19.8	–	68.1	–
Finland	23300	91.2	0	7.2	0.2	1.5	0
Sweden	30785	73.1	0.1	12.2	–	14.5	–
China	284905	58	31.3	2.7	1.2	6.8	–
Kazakhstan	12000	0	0	15.9	12.8	71.3	0
Norway	18959	62.9	27.6	1.5	–	8	0
United Kingdom	2865	33.7	0.2	5.1	3.7	53.1	4.2
Iceland	150	19.8	10.4	0	14.8	54.1	0
St. Pierre and Miquelon	3	–	–	–	–	100	–
Global Boreal Forest		48.9	8	6.1	1	35	1.3

[a](FAO 2006)
[b]Source: Table 3, FRA 2005

Forest/other wooded land designated for:
[c]extraction of forest goods, including both wood and non-wood forest products.
[d]protection of soil and water.
[e]conservation of biological diversity.
[f]recreation, tourism, education and/or conservation of cultural/spiritual sites.
[g]any combination of: production of goods, protection of soil and water, conservation of biodiversity and provision of socio-cultural services and where none of these alone can be considered as being significantly more important than the others.
[h]which a specific function has not been designated or where the designated function is unknown.

Table 10. Change in extent of forest plantations 1990–2005 (Source: FRA 2005[a], Table 10, p. 238)

	Area of Forest Plantations			% of Total Forest Area			Annual Change Rate	
Country/Area	1990 (1000 ha)	2000 (1000 ha)	2005 (1000 ha)	1990	2000	2005	1990-2000 (ha/yr)	2000-2005 (ha/yr)
Russian Federation	12 651	15 360	16 962	1.6	1.9	2.1	270 920	320 420
Canada	–	–	–	–	–	–	–	–
United States	10 305	16 274	17 061	3.5	5.4	5.6	596 900	157 400
China	18 466	23 924	31 369	11.8	13.5	15.9	545 800	1 489 000
Finland	0	0	0	0	0	0	0	0
Sweden	523	619	667	1.9	2.3	2.4	9 600	9 600
Kazakhstan	1 034	1 056	909	30.2	31.4	27.2	2 200	-29 400
Norway	222	255	262	2.4	2.7	2.8	3 300	1 400
United Kingdom	1 877	1 934	1 924	71.9	69.2	67.6	5 700	-2 000
Iceland	8	21	29	30.4	56.1	62.2	1 370	1 460
St. Pierre and Miquelon	–	–	–	–	–	–	–	–
Global Boreal Forest	45 086	59 443	69 183				1 435 790	1 947 880

[a](FAO 2006)

result of illegal logging; losses to the national economies of timber producing countries add up to an additional US$10 billion per year. How much of this comes from the boreal is unknown. The World Bank (2006) estimates that in Russia alone, 60% to 65% of the total production is illegally logged.

Intensive plantation forestry

Between 1990 and 2005 there has been an increase in the area of forest plantations in the Russian Federation, the United States, China, Sweden, Norway, the United Kingdom and Iceland. The impacts of intensive plantation forestry, in the context of sustainable forest management, have not been fully characterized (Larsen 1995, Emborg and Larsen 1999, Gamborg and Larsen 2003) and there is debate over whether northern forests are as amenable to intensive plantation forestry over the long term as are their more temperate counterparts (Lousier 2000, Hartley 2002, Niemelä *et al.* 2005).

Forest certification and sustainable forest management

Forest certification has emerged as a market-based incentive for sustainable forest management. Originally, certification was intended to improve forest management practices in tropical forests; however, market forces have resulted in a concentration of certification in northern temperate and boreal forests (Taylor 2005). Only a small proportion of global forests are certified (4.2%) (van Kooten *et al.* 2005), and the majority (93%) are located in the northern hemisphere (Siry *et al.* 2005). Canada has the largest area of third-party, independently certified forests at 119 million ha and 75% of this is boreal forests. Canada's area of certified boreal forest is three times larger than any other country's area of certified forest. Firms and forest owners who exported a high proportion of their products were more likely to seek certification in order to satisfy their clients in the importing countries (van Kooten *et al.* 2005). The extent to which forest certification has enhanced the use of sustainable forest management practices is unclear (Ramesteiner and Simula 2003, Klooster 2005).

Although the intent is similar, the definition and scope of sustainable forest management, and the means by which sustainability are measured, are not universal (Wang 2004). Three separate major international initiatives are striving to define sustainability and establish criteria and indicators: the International Tropical Timber Organization, the Pan-European Process, and the Montréal Process (McDonald and Lane 2004). Although these processes are separate, they have similar and comparable themes. The Collaborative Partnership on Forests has used these themes as the basis for harmonization of data collection and reporting requirements (Gold *et al.* 2006). The first international forest certification program was established by the Forest Stewardship Council (FSC) in 1995. The FSC is an international non-governmental organization that has certified 80 million ha of boreal, temperate, and tropical forests in 74 countries. Hickey *et al.* (2006) found regulatory approaches to certification and monitoring, and information reporting practices are quite different between Canada, the United States, and Europe. The practical implication of this is that without harmonization, forest managers in certain jurisdictions could be placed at a competitive disadvantage.

Discussion and Conclusions

Although linked by a number of common issues, each circumboreal nation is unique. This uniqueness is due to differences in national circumstances (environmental, historical, social, and economic), and must be recognized and respected internationally. As a result of these differences, there can be no single and universal best practice formula for boreal forest management policies and measures. Appropriate boreal forest policies and measures must be determined by each sovereign country according to its own national circumstances, and supported by science.

At any given time and place, boreal ecosystems are the net result of the interaction of many variables, including a complex web of biotic (e.g., insects, animal herbivory), abiotic (e.g., climate, fire, soil development) and anthropogenic activities (e.g., land use, land use change, natural resource activities, policies and measures). Scientists have yet to arrive at a consensus on the number and the causes and effects of many of the individual variables—let alone their cumulative impacts. What is known is that circumboreal ecosystems have been, and will continue to be, characterized by significant variability through time and space. Ecosystem changes (both natural and anthropogenic) can have significant impacts on physical, chemical, and biological functions (Schindler *et al.* 1990), and can leave a long-term legacy on the landscape (Kurz and Apps 1999, Apps *et al.* 2000, Bhatti *et al.* 2003) and thus on its future uses.

Scientific research indicates that both natural and anthropogenic global changes will continue to alter circumboreal economic, natural, and social capital. Sustainable management and optimization for change will be critical to the development of future national and international sustainability and stewardship frameworks and good boreal policies and measures (e.g., technology promotion and opportunities, flexibility mechanisms, regulatory and economic instruments, voluntary initiatives, public education and outreach). Optimizing for change must also take uncertainty into account; maintaining biodiversity and variety in forest structures may be crucial when planning for an uncertain future. Historical forest policies resulted in significant shifts in costs, prices, technology and raw material supplies (e.g., United Nations Economic Commission for Europe 2005), and have had significant impact on the forest sector. Countries will continue to update their forest policies to incorporate changing paradigms and economic, social and cultural realities.

The keys to sustainable boreal forest management are ecological health and resilience, economic vitality, and social value and equity. If one element fails, then sustainability fails in the long term. Managing for these variables is a formidable challenge (Wang 2004). An important starting point in meeting the sustainability challenge is the development of a common language and framework. An understanding of the salient issues from a circumboreal perspective will aid in the development of such a framework for ensuring boreal forest sustainability (Shvidenko and Apps 2006).

An understanding of the different national circumstances across the circumboreal community will hopefully lead to a greater appreciation of the forest management context within which each nation exercises its stewardship mandate. The uniqueness of each nation must be acknowledged and understood, particularly when international initiatives regarding boreal forests are proposed.

Acknowledgements

We thank Suzanne Bayley, Department of Biology of the University of Alberta, for review of an earlier version of this manuscript and for insightful suggestions. We also thank Brenda McAfee, James Stewart, David Paré and Danny Grills of the Canadian Forest Service for valuable inputs and editorial assistance, respectively.

References

Aamlid, D.V., N. Vassilieva, P.A. Aarrestad, M.L. Gytarsky, S. Londmo, R. Karaban, V. Korotov, T. Rindal, V. Kuzmicheva, and K. Venn. 2000. The ecological state of the ecosystems in the border areas between Norway and Russia. Boreal Environment Research 5: 257–278.

Achard, F., D. Mollicone, H.J. Stibig, D. Aksenov, L. Laestadius, Z. Li, P. Popatov and A. Yaroshenko. 2006. Areas of rapid forest-cover change in boreal Eurasia. Forest Ecology and Management Forest Ecology and Management 237: 322–334.

Achard, F., H. J. Stibig, L. Laestadius, A. Yaroshenko and D. Aksenov. 2005. Identification of "Hot Spot Areas" of Forest Cover Changes in Boreal Eurasia. European Commission, Luxembourg. Available at http://ies.jrc.cec.eu.int/364.html.

Adams, J.M. and H. Faure. 1997. Palaeovegetation maps of the Earth during the last glacial maximum, and the early and mid Holocene an aid to archaeological research. Journal of Archaeological Science 24: 623–647.

Adams, J.M., H. Faure, L. Faure-Denard, J.M. McGlade and F.I. Woodward. 1990. Increase in terrestrial carbon storage from the Late Glacial Maximum to the present. Nature 348: 711–714.

Adams, M.B., J.A. Burger, A.B. Jenkins, and L. Zelazny. 2000. Impact of harvesting and atmospheric pollution on nutrient depletion in eastern US hardwood forests. Forest Ecology and Management 138(1-3): 301–319.

Alexeyev, V.A. and R.A. Birdsey. 1998. Carbon storage in forests and peat lands of Russia. General Technical Report NE-244. USDA Forest Service Northeastern Research Station, Radnor. 143 p.

Anderson, L.L., F.S. Hu, D.M. Nelson, R.J. Petit and K.N. Paige. 2006. Ice-age endurance: DNA evidence of a white spruce refugium in Alaska. Proceedings of the National Academy of Sciences 103: 12447–12450.

Andersson, R. and L. Östlund. 2004. Spatial patterns, density changes and implications on biodiversity for old trees in the boreal landscape of northern Sweden. Biological Conservation 118: 443–453.

Apps, M.J., J.S. Bhatti, D.H. Halliwell, H. Jiang and C. Peng. 2000. Simulated carbon dynamics in the boreal forest of central Canada under uniform and random disturbance regimes. *In* R. Lal, J.M. Kimble, and B.A. Stewart (eds.). Global Climate Change and Cold Region Ecosystems. pp. 107–121. CRC Lewis Publishers, Boca Raton, Florida.

Apps, M.J., W.A. Kurz, R.J. Luxmoore, L.O. Nilsson, R.A. Sedjo, R. Schmidt, L.G. Simpson and T.S. Vinson. 1993. Boreal forests and tundra. Water, Air, and Soil Pollution 70: 39–53.

Avery, S. 1996. Fate of caesium in the environment: distribution between the abiotic and biotic components of aquatic and terrestrial ecosystems. Journal of Environmental Radioactivity 30(2): 139–171.

Apps, M.J., D.T. Price and J. Wisniewski. 1995. Boreal Forests and Global Change. IBFRA. Kluwer Academic Publishers. 540 p.

Bayne, E.M., S.L. Van Wilgenburg, S. Boutin and K.A. Hobson. 2005. Modeling and field- testing of ovenbirds (*Seiurus aurocapillus*) responses to boreal forest dissection by energy sector development at multiple spatial scales. Landscape Ecology 20: 203–216.

Bergeron, Y., M. Flannigan, S. Gautier, A. Leduc and P. Lefort. 2004. Past, current and future fire frequency in the Canadian boreal forest: implications for sustainable forest management. Ambio 33: 356–360.

Bhatti, J.S., G.C. van Kooten, M.J. Apps, L.D. Laird, I.D. Campbell, C. Campbell, M.R. Turetsky, Z. Yu and E. Banfield. 2003. Carbon balance and climate change in boreal forests. *In* Burton, P.J., C. Messier, D.W. Smith and W.L. Adamowicz (eds.). Towards Sustainable Management of the Boreal Forest. pp. 799–855. NRC Research Press, Ottawa.

Binkley, D. and P. Högberg. 1997. Does atmospheric deposition of nitrogen threaten Swedish forests? For. Ecol. Manage. 92: 119–152.

Bohn H.L. 1976. Estimate of organic carbon in world soils. Soil Sci. J. Am. 40: 468–470.

Bonan, G.B., S. Levis, S. Sitch, M. Vertenstein and K.W. Oleson. 2003. A dynamic global vegetation model for use with climate models: concepts and description of simulated vegetation dynamics. Global Change Biology 9(11): 1543–1566.

Campbell, C., I.D. Campbell, C.B. Blyth and J.H. McAndrews. 1994. Bison extirpation may have caused aspen expansion in western Canada. Ecography 17: 360–362.

Campbell, I.D., M.J. Apps and C. Campbell. 2004. Effects of global warming on forests. In: Encyclopedia of Life System Sciences, developed under the auspices of the UNESCO, EOLSS Publishers, Oxford, UK. 21 p.

Campbell, I.D. and C. Campbell. 2000. Holocene vegetation history at the southern boreal forest margin in Alberta, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology 164: 279–296.

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. Stock. (eds.). Fire, Climate Change, and Carbon Cycling in the Boreal Forest. Ecological Studies. pp. 151–172. Springer, New York.

Campbell, I.D. and J.H. McAndrews. 1993. Forest disequilibrium caused by rapid Little Ice Age cooling. Nature 366: 336–338.

Canadian Council of Forest Ministers. 2005. Criteria and Indicators of Sustainable Forest Management: National Status 2005 [online]. Ottawa. Available at http://www.ccmf.org/current/ccitf_e.php.

Canadian Forest Service – Natural Resources Canada (CFS). 2001. Forest Fire: Context for the Canadian Forest Service's Science Program. Natural Resources Canada, Canadian Forest Service, Headquarters, Science Branch, Ottawa. Science Program Context Paper. 13 p.

Canadian Forest Service – Natural Resources Canada (CFS). 2007. Canada's National Forest Inventory (CanFI) 2001 [online]. Available at http://nfi.cfs.nrcan.gc.ca/overview_e.html.

Carroll, A.L. 2005. The mountain pine beetle in western North America: Management challenges in an era of altered disturbance regimes and changing climate. *In* G. Mery, R.I. Alfaro, M. Kanninen and M. Lobovikov (eds.). Forests in the global balance – changing paradigms. pp. 273–285. International Union of Forestry Research Organizations (IUFRO), Vienna, Austria, IUFRO World Series Vol. 17.

Carroll, A.L., J. Régnière, S.W. Taylor and L. Safranyik. 2004. Effects of climate change on range expansion by the mountain pine beetle. *In* T.L. Shore, J.E. Brooks and J.E. Stone (eds.). Mountain Pine Beetle Symposium: Challenges and Solutions, October 30–31, 2003, Kelowna, British Columbia. pp. 223–232. Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. 287 p.

Chapin, F.S., T.V. Callaghan, Y. Bergeron, M. Fukuda, J.F. Johnstone, G. Juday and S.A. Zimov. 2004a. Global change and the boreal forest: Thresholds, shifting states or gradual change? Ambio 33: 361–365.

Chapin, F.S., G. Peterson, F. Berkes, T.V. Callaghan, P. Angelstam, M. Apps, C. Beier, Y. Bergeron, A.S. Crepin, K. Danell, T. Elmqvist, C. Folke, B. Forbes, N. Fresco, G. Juday, J. Niemela, A. Shvidenko and G. Whiteman. 2004b. Resilience and vulnerability of northern regions to social and environmental change. Ambio 33: 344–349.

Cheng, L., K.M. McDonald, R.P. Angle and H.S. Sandhu. 1998. Forest fire enhanced photochemical air pollution a case study. Atmospheric Environment 32(4): 673–681.

Chung, Y.S. 2003. On the forest fires and the analysis of air quality data and total atmospheric ozone. Atmospheric Environment 18(10): 2153–2157.

CIA. 2006. The World Factbook. Central Intelligence Agency, Government of the United States of America [online]. Available at https://www.cia.gov/library/publications/the-world-factbook/index.html.

Conard, S.G., A.I. Sikhinin, B.J. Stocks, D.R. Cahoon, E.P. Davidenko and G.A. Ivanova. 2002. Determining effects of area burned and fire severity on carbon cycling and emissions in Siberia. Climatic Change 55: 197–211.

Cronan, C.S. and D.F. Grigal. 1995. Use of calcium/aluminum ratios as indicators of stress in forest ecosystems. Journal of Environmental Quality 24: 209–226.

DeHayes, D.H., P.G. Schaberg, G.J. Hawley and G.R. Strimbeck. 1999. Alteration of membrane-associated calcium leads to membrane destabilization and foliar injury in red spruce. Bioscience 49: 789–800.

Dienes, L. 2004. Observations on the problematic potential of Russian oil and the complexities of Siberia. Eurasian Geography and Economics 45: 319–345.

Dixon, R.K., S. Brown, R.A. Houghton, A.M. Solomon, M.C. Trexler and J. Wisnievski. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185–190.

Dubé, S., A.P. Plamondon and R.L. Rothwell. 1995. Watering up after clear-cutting on forested wetlands of the St. Lawrence lowland. Water Resources Research 31: 1741–1750.

Dyke, A.S. 2004. An outline of North American deglaciation with emphasis on central and northern Canada. *In* J. Ehlers and P.L. Gibbard. (eds.). Quaternary Glaciations – Extent and Chronology, Part II: North America. pp. 373–424. Elsevier, Amsterdam.

Emborg, J. and J.B. Larsen. 1999. How to develop plantations into forests—in order to achieve stability and functional flexibility? A North European perspective. *In* S. Barros and M.I. Campodónico. (eds.). Proceedings of the International Experts Meeting on the Role of Planted Forests in Sustainable Forest Management. pp.133–147. Corporación Nacional Forestal (CONAF). Ministerio de Agricultura, Santiago.

Eng, M., A. Fall, J. Hughes, T. Shore, B. Riel, A. Walton and P. Hall. 2006. Provincial-level projection of the current mountain pine beetle outbreak: update of the infestation projection based on the 2005 provincial aerial overview of forest health and revisions to "the model" (BCMPB.v3). British Columbia Ministry of Forests and Range. Victoria, British Columbia. 7 p. Available at www.for.gov.bc.ca/hre/bcmpb/BCMPB.v3.BeetleProjection.Update.pdf.

Federal Research Centre for Forestry and Forest Products. 2006. The condition of Forests in Europe [online]. Available at http://www.icp-forests.org/RepEx.htm.

Flannigan, M.D., Y. Bergeron, O. Engelmark and B.M. Wotton. 1998. Future wildfire in circumboreal forests in relation to global warming Journal of Vegetation. Science 9:469–476.

Fleming, W.D. and F.K.A. Schmiegelow. 2003. Response of bird communities to pipeline rights-of-way in the boreal forest of Alberta. The Seventh International Symposium on Environmental Concerns in Rights-of-Way Management. pp. 431–437. Elsevier Science.

Food and Agriculture Organization of the United Nations [FAO]. 2001. Global Forest Resources Assessment 2000 Main Report. FAO Forestry Paper 140. Rome. 479 p. Available at http://www.fao.org/forestry/site/24691/en/.

Food and Agriculture Organization of the United Nations [FAO]. 2006. Global Forest Resources Assessment 2005 Progress towards sustainable forest management. FAO Forestry Paper 147. Rome. Available at http://www.fao.org/forestry/site/24691/en/

Foote, L. and N. Krogman. 2006. Wetlands in Canada's western boreal forest: Agents of change. The Forestry Chronicle 82(6): 825–833.

Gamborg, C. and J.B. Larsen. 2003. "Back to nature" – a sustainable future for forestry? Forest Ecology and Management 179: 559–571.

Gamon, J.A., K.F. Huemmrich, D.R. Peddle, J. Chen, D. Fuentes, F.G. Hall, J.S. Kimball, S. Goezt, J. Gu, K.C. McDonald, J.R. Miller, M. Moghaddam, A.F. Rahman, J.L. Roujean, E.A. Smith, C.L. Walthall, P.J. Zarco-Tejada, B. Hu, R. Fernandes and J. Cihlar. 2004. Remote sensing in BOREAS: lessons learned. Remote Sensing of Environment 89: 139–162.

Gillett, N.P., A.J. Weaver, F.W. Zwiers and M.D. Flannigan. 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters 31(18), L18211, doi:10.1029/2004GL020876.

Gold, S., A.V. Korotkov and V. Sasse. 2006. The development of European forest resources, 1950 to 2000. Forest Policy and Economics 8: 183–192.

Gorham E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications 1: 182–195.

Gray, D.R. and W.E. MacKinnon. 2006. Outbreak patterns of the spruce budworm and their impacts in Canada. The Forestry Chronicle 82(4): 550–561.

Guenther A., C. Geron, T. Pierce, B. Lamb, P. Harley and R. Fall. 2000. Natural emissions of non-methane volatile organic compounds, carbon monoxide, and oxides of nitrogen from North America. Atmospheric environment 34(12): 2205–2230.

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

Hannon, S.J. and P. Drapeau. 2005. Bird responses to burning and logging in the boreal forest of Canada. Studies in Avian Biology 30: 97–115.

Hansen, J., M. Sato, R. Ruedy, A. Lacis and V. Oinas. 2000. Global warming in the twenty-first century: An alternative scenario. Proceedings of the National Academy of Sciences. 97: 9875–9880.

Hartley, M.J. 2002. Rationale and methods for conserving biodiversity in plantation forests. Forest Ecology and Management. 155: 81–95.

Heiner, H. 1995. Issues in international forestry. Journal of Forestry 93(10): 6.

Hickey, G.M, J.L. Innes, R.A. Kozak, G.Q. Bull and I. Vertinsky. 2006. Monitoring and information reporting for sustainable forest management: An inter-jurisdictional comparison of soft law standards. Forest Policy and Economics 9: 297–315.

Highwood, E.J. and R.P. Kinnersley. 2006. When smoke gets in our eyes: The multiple impacts of atmospheric back carbon on climate, air quality and health. Environment International 32(4): 560–566.

Hobbie, S. E., D.B. Jensen, and F. S. Chapin, III. 1994. Resource supply and disturbance as controls over present and future plant diversity. *In* E.D. Schulze and H.A. Mooney. (eds.). Biodiversity and ecosystem function. pp.385–408. Springer-Verlag, New York.

Hobson, K.A. and E. Bayne. 2000. Effects of forest fragmentation by agriculture on avian communities in the southern boreal mixedwoods of western Canada. Wilson Bulletin 112: 373–387.

Hogg, E.H. 1997. Temporal scaling of moisture and the forest-grassland boundary in western Canada. Agricultural and Forest Meteorology 84: 115–122.

Hogg, E.H. and P.Y. Bernier. 2005. Climate change impacts on drought-prone forests in western Canada. The Forestry Chronicle 81: 675–682.

Hogg, E.H. and A.G. Schwarz. 1997. Regeneration of planted conifers across climatic moisture gradients on the Canadian prairies: implications for distribution and climate change. Journal of Biogeography 24: 527–534.

Hogg, E.H. and R.W. Wein. 2005. Impacts of drought on forest growth and regeneration following fire in southwestern Yukon, Canada. Canadian Journal of Forest Research 35: 2141–2150.

Huser. B.J. and E. Rydin. 2005. Phosphorus inactivation by aluminum in Lakes Gårdsjön and Härsvatten sediment during the industrial acidification period in Sweden. Canadian Journal of Fisheries and Aquatic Science 62(8): 1702–1709.

Hytteborn, H., A.A. Maslov, D.I. Nazimova and L.P. Rysin. 2006. Boreal Forests of Eurasia. *In* F. Anderson and S. Gessel. (eds.). Coniferous Forests of the World. Ecosystems of the World no. 6. pp. 23–99. Elsevier, The Netherlands.

Intergovernmental Panel on Climate Change (IPCC). 2001a. IPCC Special Report on The Regional Impacts of Climate Change An Assessment of Vulnerability [online]. Available at www.grida.no/climate/ipcc/regional/049.htm

Intergovernmental Panel on Climate Change (IPCC). 2001b. Climate Change: Working Group II: Impacts, Adaptation and Vulnerability [online]. Available at www.grida.no/climate/ipcc_tar/wg2/247.htm

Iremonger, S., C. Ravilious and T. Quinton. 1997. A statistical analysis of global forest conservation. *In* S. Iremonger, C. Ravilious and T. Quinton. (eds.). A global overview of forest conservation. Including: GIS files of forests and protected areas, version 2. CD-ROM. CIFOR and WCMC, Cambridge, UK. Available at www.unep-wcmc.org/forest/data/cdrom2/index.html.

James, A., S. Boutin, D. Hebert, A.B. Rippin and A. Blair. 2004. Spatial separation of caribou from moose and its relation to predation by wolves. Journal of Wildlife Management 69(4): 203–216.

Jarvis, P. and S. Linder. 2000. Botany: Constraints to growth of boreal forests. Nature 405: 904–905.

Johansen, M.P., T.E. Hakonson, F.W. Whicker and D.D. Breshears. 2003. Pulsed redistribution of a contaminant following forest fire: cesium-137 in runoff. Journal of Environmental Quality 32(6): 2150–7.

Johnson, E.A., G.I. Fryer and M.J. Heathcott. 1990. The influence of man and climate on frequency of fire in the interior wet belt forest, British Columbia. Journal of Ecology 78: 403–412.

Karpachevskiy, M. 2004. Forest Fires in the Russian Taiga: Natural Disaster or Poor Management? Taiga Rescue Network Factsheet, Jokkmokk, Sweden.

Kasischke, E.S. and B.J. Stocks. 2000. Fire, Climate Change, and Carbon Cycling in the Boreal Forest. Ecological Studies 138: 49–65. Springer-Verlag, NY.

Kauppi, P.E., J.H. Ausubel, J. Fang, A.S. Mather, R.A. Sedjo and P.E. Waggoner. 2006. Returning forests analyzed with forest identity. Proceedings of the National Academy of Science 103(46): 17564–17579.

Kellomäki, S. 2000. Forests of the boreal region: gaps in knowledge and research needs. Forest Ecology and Management 132: 63–71.

Kim Y., H. Hatsushika, R.R. Muskett and K. Yamazaki. 2005. Possible effect of boreal wildfire soot on Arctic sea ice and Alaska glaciers. Atmospheric Environment 39(19): 3513–3520.

Kimball, J.S., K.C. McDonald, S.W. Running and S.E. Frolking. 2004. Satellite radar remote sensing of seasonal growing season for boreal and subalpine evergreen forests. Remote Sensing of the Environment 90(2): 243–258.

Klooster, D. 2005. Environmental certification of forests: The evolution of environmental governance in a commodity network. Journal of Rural Studies 21: 403–417.

Korpilahti, E., S. Kellomaki and T. Karjalainer. (eds.). 1995. Climate Change, Biodiversity and Boreal Forest Ecosystems. IBFRA. The Finnish Forest Research Institute, Helsinki, Finland. 315 p.

Kuri, S., A. Nikula, P. Helle and H. Linden. 2000. Landscape fragmentation and forest composition effects on grouse breeding success in boreal forests. Ecology 81: 1985–1997.

Kuuluvainen, T. and Laiho, R. 2005. Long-term forest utilization can decrease forest floor microhabitat diversity: evidence from boreal Fennoscandia. Canadian Journal of Forest Research 34: 303–309.

Kurz, W.A., M.J. Apps, B.J. Stocks and W.J.A. Volney. 1995. Global climatic change: disturbance regimes and biospheric feedbacks of temperate and boreal forests. *In* G.F. Woodwell and F. McKenzie (eds.). Biospheric Feedbacks in the Global Climate System: Will the Warming Feed the Warming? pp. 119–133. Oxford University Press, New York.

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.

Lambert, J.D. and S.J. Hannon. 2000. Short-term effects of upland timber harvest on ovenbird abundance, territory characteristics, and pairing success in riparian buffer strips. Auk 117: 687–698.

Larsen, J.A. 1980. The boreal ecosystem. Physiological Ecology. Academic Press, New York. 500 p.

Larsen, J.B. 1995. Ecological stability of forests and sustainable silviculture. Forest Ecology and Management 73**:** 85–96.

Lassig, R. and S.A. Mocalov. 2000. Frequency and characteristics of severe storms in the Urals and their influence on the development, structure, and management of the boreal forests. Forest Ecology and Management 135: 179–194.

Lavorel, S., M.D. Flannigan, E.F Lambin and M.C. Scholes. 2007. Vulnerability of land systems to fire: interactions between humans, climate, the atmosphere and ecosystems. Mitigation and Adaptation Strategies for Global Change 12(1): 33–53).

Lee, K.H., J.E. Kim, Y.J. Kim, J. Kim and W. von Hoyningen-Huene. 2005. Impact of the smoke aerosol from Russian forest fires on the atmospheric environment over Korea during May 2003. Atmospheric Environment 39(1): 85–99.

Löfman, S. and J. Kouki. 2003. Scale and dynamics of a transforming forest landscape. Forest Ecology and Management 175: 247–252.

Logan, J.A. and J.A. Powell. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist Fall: 162–172.

Lorenz, M., V. Mues, G. Becher, W. Seidling, R. Fischer, D. Langouche, D. Durrant and U. Bartels. 2002. Forest condition in Europe. Results of the large-scale survey. EC and UN/ECE. Brussels, Geneva.

Lousier, J.D. 2000. Northern forest management issues. Forest Ecology and Management 133: 1–3.

MacDonald, G.M., T.W.D. Edwards, K.A. Moser, R. Pienitz and J.P. Smol. 1993. Rapid response of treeline vegetation and lakes to past climate warming. Nature 361: 243–246.

Malcolm, J.R., A. Markham, R.P. Neilson and M. Garaci. 2002. Estimated migration rates under scenarios of global climate change. Journal of Biogeography 29: 835–849.

Malhi, Y., D.D. Baldocchi and P.G. Jarvis. 1999. The carbon balance of tropical, temperate, and boreal forests. Plant, Cell and Environment 22: 715–740.

Markov V.D., A.S. Olunin, L.A. Ospennikova, E.I. Skobeeva, P.I. Khoroshev. 1988. World Peat Resources. Nedra, Moscow. 383 p.

Masek, J.G. 2001. Stability of boreal forest stands during recent climate change: evidence from Landsat satellite imagery. Journal of Biogeography 28(8): 967 –976.

Mather, A.S. 2005. Assessing the world's forests. Global Environmental Change 15: 267–280.

Mayer, A.L., P.E. Kauppi, P.M., Tikka and P.K. Angelstam. 2006. Conservation implications of exporting domestic wood harvest to neighboring countries. Environmental Science and Policy 9: 228–236.

Mayer, A.L. and P.M. Tikka. 2006. Biodiversity conservation incentive programs for privately owned forests. Environmental Science and Policy 9: 614–625.

Mayfield, A.E., D.C. Allen and R.D. Briggs. 2005. Radial growth impact of pine false webworm defoliation on eastern white pine. Canadian Journal of Forest Research 25: 1071–1086.

McDonald, G.T. and M.B. Lane. 2004. Converging global indicators for sustainable forest management. Forest Policy and Economics 6: 63–70.

McGuire, A.D., J.W. Melillo, D.W. Kichlighter and L.A. Joyce. 1995. Equilibrium responses of soil carbon to climate change: Empirical and process-based estimates. Journal of Biogeography 22: 785–796.

Menon, S., J. Hansen, L. Nazarenko and Y. Luo. 2002. Climate effects of black carbon aerosols in China and India. Science 297(5590): 2250–2253.

Menz, F.C. and H.M. Seip. 2004. Acid rain in Europe and the United States: an update. Environmental Science and Policy 7(4): 253–265.

Merrill, E., M. Boyce, J. Allen, J. Frair, D. Visscher, N. Webb, D. Fortin and L. McInenly. 2005. Population monitoring, translocation, and the cumulative effects of industrial activities on elk (*Cervus elaphus*) in the east central foothills of Alberta, Canada. Completion report. Department of Biological Sciences, University of Alberta, Edmonton, AB.

Mielikäinen, K. and J. Hynynen. 2003. Silvicultural management in maintaining biodiversity and resistance of forests in Europe – boreal zone: case Finland, Journal of Environmental Management 67: 47–54.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: current state and trends: Findings of the Condition and Trends Working Group, Millennium Ecosystem Assessment Series. Island Press, Washington, DC.

Ministerial Conference on the Protection of Forests in Europe and United Nations Economic Commission for Europe (MCPFE). 2003. State of Europe's Forests 2003: The MCPFE Report on Sustainable Forest Management in Europe. Available at http://www.mcpfe.org/system/files/u1/publications/pdf/forests_2003.pdf.

Mollicone, D., H.D. Eva and F. Achard. 2006. Ecology: human roles in Russian wild fires. Nature 440: 436–437.

Mott, J.A., D.M. Mannino, C.J. Alverson, A. Kiyu, J. Hashim, T. Lee, K. Falter and S.C. Redd. 2005. Cardiorespiratory hospitalizations associated with smoke exposure during the 1997 Southeast Asian forest fires. International Journal of Hygiene and Environmental Health 208(1–2): 75–85.

National Roundtable on the Environment and the Economy. 2005. Boreal Futures: Governance, Conservation and Development in Canada's Boreal. Available at www.nrtee-trnee.ca/eng/programs/Current_programs/Nature/Boreal-Forest/Documents/Boreal-Futures/Boreal-Futures_Contents_E.htm.

Neff, J.C. and D.U. Hooper. 2002. Vegetation and climate controls on potential CO_2, DOC, and DON production in northern latitude soils. Global Change Biology 8: 872–884.

New Hampshire Department of Environmental Services. 2006. What's in that Smoke? [online] Available at www.des.state.nh.us/ard/smoke.htm.
New Scientist. 2006. Chernobyl haunts the Norwegian uplands. New Scientist 2575: 7.
Niemelä, J. 1999. Management in relation to disturbance in the boreal forest. Forest Ecology and Management 115: 127–134.
Niemelä, J., J. Young, D. Alard, M. Akasibar, K. Henle, R. Johnson, M. Kurttila, T.B. Larsson, S. Matouch, P. Nowicki, R. Paiva, L. Portoghesi, R. Smulders, A. Stevenson, U, Tartes and A. Watt. 2005. Identifying, managing and monitoring conflicts between forest biodiversity conservation and other human interests in Europe. Forest Policy and Economics 7: 877–890.
Nilsson, C. and F. Götmark. 1992. Protected areas in Sweden: is natural variety adequately represented? Conservation Biology 6: 232–242.
Nilsson, S. 1996. Do we have enough forests? IUFRO Occasional Paper, No. 5, IUFRO Secretariat, Vienna. Available at http://72.14.207.104/search?q=cache:liAYnMnzb6AJ:www.iufro.org/download/file/557/387/op5.pdf+Nilsson+Do+we+have+enough+forests%3Fandhl=en.
Nilsson, S. 2000. Challenges for the Boreal Forest Zone and IBFRA. Available at www.iiasa.ac.at/Research/FOR/papers/Overview_Boreal_Forest.pdf.
Nilsson, S., O. Sallnäs and P. Duinker. 1992. Future forest resources of Western and Eastern Europe. Parthenon Publishers, Lancaster, UK.
Nordin, A., J. Strengbom, J. Witzell, T. Nasholm and E. Lars. 2005. Nitrogen deposition and the biodiversity of boreal forests: Implications for critical load. Ambio 34: 20–24.
Oberg, P., C. Rohner and F.K.A. Schmiegelow. 2003. Responses of mountain caribou to linear features in a west-central Alberta landscape. pp. 455–464. *In* The Seventh International Symposium on Environmental Concerns in Rights-of-Way Management. Elsevier Science.
Ouimet, R.; L. Duchesne, D. Houle and P.A. Arp. 2001. Critical Loads and Exceedances of Acid Deposition and Associated Forest Growth in the Northern Hardwood and Boreal Coniferous Forests in Quebec, Canada. Water, Air and Soil Pollution 1: 119–134.
Paatalo, M.L. 1998. Factors influencing occurrence and impacts of fires in northern European forests. Silva Fennica 32: 185–202.
Parsons, K., D. Quiring, H. Piene and J. Farrell. 2003. Temporal patterns of balsam fir sawfly defoliation and growth loss in young balsam fir. Forest Ecology and Management 184: 33–46.
Parviainen, J. and G. Frank. 2003. Protected forests in Europe approaches-harmonising the definitions for international comparison and forest policy making. Journal of Environmental Management 67: 27–36.
Pastor, J., S. Light and L. Sovell. 1998. Sustainability and resilience in boreal regions: sources and consequences of variability. Ecology and Society. 2 p. Available at: www.consecol.org/vol2/iss2/art16/
Patriquin, K.J. and R.M.R. Barclay. 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. Journal of Applied Ecology 40: 646–657.
Peinado, M., J.L. Aguirre and M. de la Cruz. 1998. A phytosociological survey of the boreal forest (Vaccinio-Piceetea) in North America. Plant Ecology. 137: 151–202.
Perera, A.H., L.J. Buse and M.G. Weber. 2004. Emulating natural forest landscape disturbances. Columbia University Press, New York. 315 p.
Percy, K.E. and M. Ferretti. 2004. Air pollution and forest health: toward new monitoring concepts. Environmental Pollution 130(1): 113–126.
Peterson, G. 2000. Scaling Ecological Dynamics: Self Organization, Hierarchical Structure, and Ecological Resilience. Climatic Change 44: 291–309.
Pope, C.A. and D.W. Dockery. 2006. Health effects of fine particulate air pollutions: lines that connect. Journal of Air Waste Management Association 56(6): 709–742.
QEN, 1995. The Quaternary Environments Network Review and Atlas of Palaeovegtation during the last 20,000 years. Available at www.esd.ornl.gov/projects/qen/.
Rametsteiner, E. and M. Simula, M. 2003. Forest certification – an instrument to promote sustainable forest management? Journal of Environmental Management 67: 87–98.
Reimann C., F. Koller, G. Kashulina, H. Niskavaara and P. Englmaier. 2001. Influence of extreme pollution on the inorganic chemical composition of some plants Environmental Pollution 115(2): 239–252.
Rigina, O., A. Baklanov, O. Hagner and H. Olsson. 1999. Monitoring of forest damage in the Kola Peninsula, Northern Russia due to smelting industry. The Science of the Total Environment 229(3): 147–163.
Roland, J. 1993. Large-scale forest fragmentation increases the duration of tent caterpillar outbreak. Oecologia 93: 25–30.
Rosenberg, D.M., R.A. Bodaly, R.E. Hecky and R.W. Newbury. 1987. The environmental assessment of hydroelectric impoundments and diversions in Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 215: 71–104.
Royama, T. 1984. Population dynamics of the spruce budworm. Ecological Monographs 54: 429–462.
Sanderson, E.W., M. Jaiteh, M.A. Levy, K.H. Redford, A.V. Wannebo and G. Woolmer. 2002. The human footprint and the last of the wild. BioScience 52(10): 891–903.
Sapkota, A., J.M. Symons, J. Kleissl, L. Wang, M.B. Parlange, J. Ondov, P.N. Breysse, G.B. Diette, P.A. Eggleston and T.J. Buckley. 2005. Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore city. Environmental Science Technology 39(1): 24–32.
Saugier, J. R. and H.A. Mooney. 2001. Estimations of global terrestrial productivity: Converging toward a single number. *In* J. Roy, B. Saugier and H.A. Mooney. (eds.). Terrestrial Global Productivity. pp. 543–557. Academic Press, San Diego, CA.
Schilstra, A.J. 2001. How Sustainable is the use of peat for commercial energy production. Environmental Economics 39(2): 285–293.
Schindler, D.W., K.G. Deaty, E.J. Fee, D.R. Cruikshank, E.R. DeBruyn, D.L. Findlay, G.A. Linsey, J.A. Shearer, M.P. Stainton and M.A. Turner. 1990. Effects of climatic warming on lakes of the central boreal forests. Science 259: 967–970.
Schneider, R. R., J.B. Stelfox, S. Boutin and S. Wasel. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: a modeling approach. Conservation Ecology 7(1): 8. Available at www.consecol.org/vol7/iss1/art8/.
Scott, J.M., F.W. Davis, R.G. McGhie, R.G. Wright, C. Groves, J. Estes. 2001. Nature reserves: Do they capture the full range of America's biological diversity? Ecological Applications 11: 999–1007.
Shvidenko, A. and M. Apps. 2006. The International Boreal Forest Research Association: understanding boreal forests and forestry in a changing world. Mitigation and Adaptation Strategies for Global Change 11(1): 5–32.
Shvidenko. A. and S. Nilsson. 1994. What do we know about the Siberian forests? Ambio 23: 396–404.
Sigler J.M., X. Lee and W. Munger. 2003. Emission and long-range transport of gaseous mercury from a large-scale Canadian boreal forest fire. Environmental Science and Technology 37(19): 4343–7.
Siry, J.P., F.W. Cubbage and M.R. Ahmed. 2005. Sustainable forest management: global trends and opportunities. Forest Policy and Economics 7: 551–561.
Soja, A.J., N.M. Tchebakova, N.H. French, M.D. Flannigan, H.H. Shugart, B.J. Stocks, A.I. Sukhinin, E.I. Parfenova, F.S. Chapin III and P.W. Stackhouse Jr. 2007. Climate-Induced Boreal Forest Change: Predictions Versus Current Observations. Global and Planetary Change 56(3–4): 274–296.
Solberg, S., K. Andreassen, N. Clarke, J. Tørseth, O.E. Tveito, G.H. Strand and S. Tomer. 2004. The possible influence of nitrogen and acid deposition on forest growth in Norway. Forest Ecology and Management 192(2–3): 241–249.

Spence, J.R. 2001. The new boreal forestry: adjusting timber management to accommodate biodiversity. Trends in Ecology & Evolution 16: 591–593.
Spribille, T. and M. Chytry. 2002. Vegetation surveys in the circumboreal coniferous forests: a review. Folia Geobotanica 37(4): 365–382.
St Louis, V.L., W. Rudd, C.A. Kelly, B.D. Hall, K.R. Rolfhus, K.J. Scott, S.E. Lindberg and W. Dong. 2001. Importance of the forest canopy to fluxes of methyl mercury and total mercury to boreal ecosystems. Environmental Science Technology 35(15): 3089–98.
Stocks, B.J., M.A. Fosberg, T.J. Lynham, L.L. Mearns, B.M. Wotton, Q. Yang, J-Z. Jin, K. Lawrence, G.R. Hartley, J.A. Mason and D.W. McKenney. 1998. Climate change and forest fire potential in Russian and Canadian Boreal Forests. Climate Change 38: 1–13.
Stocks, B.J., J.A. Jason, J.B. Todd, E.M. Bosch, B.M. Wotton, B.D. Amiro, M.D. Flannigan, K.G. Hirsch, K.A. Logan, D.L. Martell and W.R. Skinner. 2002. Large forest fires in Canada, 1959–1997. Journal of Geophysical Research 107, 8149, doi:10.1029/2001JD000484.
Strahler, A. and A. Strahler. 1997. Physical Geography: Science and Systems of the Human Environment. John Wiley and Sons, Inc. 640 p.
Strum, M., C. Racine and K. Tape. 2001. Climate change: Increasing shrub abundance in the Arctic. Nature 411(6837): 546.
Stolyhwo, A. and Z.E. Sikorski. 2005. Polycyclic aromatic hydrocarbons in smoked fish – a critical review. Food Chemistry 91(2): 303–311.
STUK Radiation and Nuclear Safety Authority. 2003. EC recommendation sets new limits to cesium concentrations in wild food products on the market. Available at www.stuk.fi/stuk/tiedotteet/2003/en_GB/news_287/.
Su, Y. and F. Wania. 2005. Does the forest filter effect prevent semivolatile organic compounds from reaching the Arctic? Environment Science and Technology 39: 7183–7191.
Sverdrup, H., P. Warfvinge and B. Nihlgård. 1994. Assessment of soil acidification effects on forest growth in Sweden. Water, Air & Soil Pollution 78: 1–36.
Taylor, P.L. 2005. A fair trade approach to community forest certification? A framework for discussion. Journal of Rural Studies 21: 433–447.
Thuiller, W., S. Lavorel, M.B. Araujo, M.T. Sykes and I.C. Prentice. 2005. Climate change and threats to plant diversity in Europe. Proceedings of the National Academy of Sciences 102(23): 8245–8250.
Tremblay, A., M. Lambert and L. Gagnon. 2004. Do hydroelectric reservoirs emit greenhouse gas? Environmental Management 33, Supplement 1: S508–S517.
Turetsky, M., J.W. Harden, H.R. Friedli, M. Flannigan, N. Payne, J. Cook and L. Radke. 2006. Wildfires threaten mercury stocks in northern soils. Geophysical Research Letters 33(L16403): 1–6.
Tveten U., L.I. Brynildsen, I. Amundsen and T.D.S. Bergan. 1998. Economic consequences of the Chernobyl accident in Norway in the decade 1986–1995. Journal of Environmental Radioactivity 41(3): 233–233.
Ulrich, B., 1984. Die Rolle der Bodenversauerung beim Waldsterben: Langfristige Konsequenzen und forstliche Möglichkeiten. Forstwiss. Cbl. 105: 421–435.
United Nations Economic Commission for Europe. 2005. European Forest Sector Outlook Study: 1960–2000–2020: Main Report. United Nations, Geneva. 235 p.
United Nations Environment Program [UNEP]. 2005. Temperate and Boreal Forest Protected Areas [online]. Available at http://www.unep-wcmc.org/forest/boreal/region.htm.
United States Department of Agriculture, Forest Service Alaska Region, State of Alaska Department of natural Resources Division of Forestry [USDA *et al.*]. 2005. Forest Health Conditions in Alaska – 2004: A Forest Health Protection Report. 16 p. Available at http://www.fs.fed.us/r10/spf/fhp/cond_rept_links.htm
Uotila, A., J. Kouki, H. Kontkanen and P. Pulkkinen. 2002. Assessing the naturalness of boreal forests in eastern Fennoscandia. Forest Ecology and Management 161: 257–277.
Väätäinen, S. 2001. General information about the forest fire situation in the Finnish trial site. Available at: www.vtt.fi/tte/research/tte1/tte14/proj/forfait/finnish_trial_site_info.html
Vaisanen, R.A., O. Jarvinen and P. Rauhaula. 1986. How are extensive human-caused habitat alterations expressed on the scale of local bird populations in boreal forests? Ornis Scandinavica 17: 282–292.
van Kooten, G.C., H.W. Nelson and I. Vertinsky. 2005. Certification of sustainable forest management practices: a global perspective on why countries certify. Forest Policy and Economics 7: 857–867.
Wallenius, T.H., Pitkänen, A., Kuuluvainen, T., Pennanen, J. and Karttunen, H. 2005. Fire history and forest age distribution of an unmanaged *Picea abies* dominated landscape. Canadian Journal of Forest Research 35: 1540–1552.
Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416: 389–395.
Wang, S. 2004. One hundred faces of sustainable forest management. Forest Policy and Economics 6: 205–213.
Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo and D.J. Dokken, (eds.). 2000. Land Use, Land-Use Change, and Forestry. Special Report of the Intergovernmental Panel on Climate Change Cambridge University Press, UK. 375 p.
Westfall, J. 2006. 2005 Summary of forest health conditions in British Columbia. Forest Practices Branch, British Columbia Ministry of Forests and Range. Victoria, British Columbia. Pest Management Report Number 15. 50 p. Available at www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/2005/F%20H%202005%20Report%20April%201.pdf.
White, T.M. and W.A. Kurz. 2005. Afforestation on private land in Canada from 1990 to 2002 estimated from historical records. The Forestry Chronicle 81: 491–496.
World Bank. 2006. World Bank: Weak Forest Governance Costs Us$15 Billion A Year [online]. Available at http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,,contentMDK:21055716~menuPK:176751~pagePK:64020865~piPK:149114~theSitePK:244381,00.html.
Wotowa, G. and M. Trainer. 2000. The influence of Canadian forest fires on pollutant concentrations in the United States. Science 288: 324–328.
Yoschenko V.I., V.A. Kashparov, V.P. Protsak, S.M. Lundin, S.E. Levchuk, A.M. Kadygrib, S.I. Zvarich, Y.V. Khomutinin, I.M. Maloshtan, V.P. Lanshin, M.V. Kovtun and J. Tschiersch. 2006. Resuspension and redistribution of radionuclides during grassland and forest fires in the Chernobyl exclusion zone: Part I. Fire experiments. Journal of Environmental Radioactivity 86(2): 143–163.
Yu, Z., I.D. Campbell, C. Campbell, D.H. Vitt, G.C. Bond and M.J. Apps. 2003. Carbon sequestration in western Canadian peat highly sensitive to Holocene wet-dry climate cycles at millennial timescales. The Holocene 13: 801–808.
Zhang, Y.H., M.J. Wooster, O. Tutubalina and G.L.W. Perry. 2003. Monthly burned area and forest fire carbon emission estimates for the Russian Federation from SPOT VGT. Remote Sensing of the Environment 87: 1–15.
Zimov, S.A., J.P. Chanton, D. Verbyla and F.S. Chapin III. 2006. Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. Nature 443(71): 75.
Zoltai, S. and P.J. Martikainen. 1996. The role of forested peatlands in the global carbon cycle. *In* M.J. Apps and D.T. Price (eds.). Forest Ecosystems, Forest Management and the Global Carbon Cycle. pp. 47–58. NATO ASI, Springer-Verlag, Heidelberg.