PART IV

Regional Examples of Forest Related Challenges and Opportunities

CIFOR

14 Sustainability of Boreal Forests and Forestry in a Changing Environment

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Abstract: The circumpolar boreal forest is the fourth largest terrestrial biome on the planet. It is entering a period of relatively rapid transition, propelled by climate change and economic development. Warming conditions threaten to alter processes as diverse as permafrost retention, insect outbreaks, and transportation. Thawing permafrost and increased levels of natural and anthropogenic disturbance may result in net releases of carbon dioxide and methane, while forest cover with greater biomass can be expected to expand onto the arctic tundra. Human use in some parts of northern forests is becoming more centralised and industrialised, with cumulative impacts from hydroelectric development, the oil and gas sector, mining, timber harvesting, and transportation. Communities tend to be widely spaced, and are either highly dependent on resource-based commodity exports or on subsistence-based lifestyles supported by local biodiversity. Efforts are underway in many jurisdictions to curtail illegal logging and environmentally damaging industrial development, to account for non-timber forest values in the course of forest management, and to promote the economic diversification of communities. In order to preserve the integrity of ecosystem processes, efforts are being directed in some jurisdictions to better emulate natural disturbance regimes and forest structures in the implementation of ecosystem-based management. The ecosystems and people of the world's boreal forests are vulnerable to impending changes in climate and socio-economics, although regions within the biome differ markedly in their exposure to dramatic changes in climate and forest products markets and also in the adaptive capacity of communities and infrastructure. Despite the changes that can be expected, the boreal zone will continue to present opportunities to undertake land management over largely natural forests in a manner that respects the need for sustaining biodiversity, economically viable enterprises, and northern communities. If regional economies can diversify as well, such an advantage may also facilitate ecotourism and attractive lifestyle options in the circumboreal region.

Keywords: biodiversity, climate change adaptation, ecosystem management, extensive forest management, peatlands, permafrost, subarctic forest, taiga

14.1 Background

Looking at a detailed map or satellite image of the Earth's northern continents, one cannot help but be impressed with the vast areas of lichen woodlands and dense conifer forests. Interspersed with bare rock, rivers, lakes, and peatlands, these are the world's subarctic, cold boreal forests (Photo 14.1). The term "taiga" is borrowed from the Russian "*тайга*," and has been introduced as a worldwide descriptor of this important biome, though in Canada this term is restricted to the open-canopied conifer forests of the far north. The boreal region is so vast, so rich in unexploited resources, so diverse in its administration and management, so important in the culture and economies of northern nations, that this chapter can only provide a superficial overview of selected issues and trends affecting this part of the globe.

Table 14.1 Key statistics on boreal forests and their populations.

	Boreal land area (km^2)	Percentage of total land area in boreal	Population in boreal	Population density (people/ km^2)	Forest area in boreal (mill. ha)	Forest area per capita in boreal (ha/ person)	Percentage of total forest in boreal	Forest area as % of boreal land area	Boreal forest sector employment
China									
Heilongjiang	47 000	10	na	na	na	na	na	na	na
Inner Mongolia	93 300	8	na	na	na	na	na	na	na
Canada	5 446 170	56	3 692 445	0.7	224.0	61	72	41	127 763
Newfoundland	385 070	96	512 930	1.3	10.7	21	100	28	2 566
Quebec	1 099 710	72	1 305 828	1.2	59.4	45	81	54	44 045
Ontario	764 210	71	939 122	1.2	40.0	43	74	52	49 874
Manitoba	564 070	89	192 411	0.3	18.1	94	95	32	4 395
Saskatchewan	411 340	63	177 127	0.4	19.5	110	97	47	3 308
Alberta	452 910	69	441 403	1.0	24.8	56	90	55	17 973
BC	288 900	31	61 211	0.2	15.6	255	27	54	3 901
Yukon	475 370	98	28 674	0.1	7.9	276	100	17	na
Northwest Territories	901 080	70	33 739	0.0	27.3	809	96	30	na
Finland	293 321	97	3 797 347	12.9	19.5	5	98	66	82 000
Iceland	1 340	1,3	293 577	219.1	0.03	0,1	100	23	..
Kazakhstan	15 000	~1	na	na	na	na	na	na	..
Mongolia	63 000	4	na	na	~1.2	na	12	20	..
Norway	270 752	84	1 321 665	4.9	5.1	4	77	1	18 974
Russia	12 484 890	73	51 781 600	4.1	673.0	13	85	54	732 600
European Russia	3 458 800	90	13 501 100	3.9	149.8	11	~50	43	277 200
Western Siberia	2 341 450	81	20 644 800	8.8	107.9	5	~100	46	89 000
Eastern Siberia	5 136 660	71	12 100 700	2.4	335.2	28	~100	65	267 300
Russian Far East	1 547 980	50	5 535 000	3.6	105.9	19	~100	68	99 000
Sweden	306 260	74	3 763 317	12.3	18.0	5	75	55	52 500
USA – Alaska	656 600	41	146 542	0.2	17.0	116	33	26	na
World	19 678 000		61 104 000	3.1	957.0	15.7		49	1 014 000

na = not available; .. = ~0
Country Notes:
Canada: Statistics Canada, Bogdanski 2008, Natural Resources Canada.
China: Estimates based on approximate area of boreal forest.
Finland: Finish Statistical Yearbook of Forestry 2008; 90% of employment estimated to be dependent on boreal resources.
Iceland: UN country profile (http://www.un.org/esa/earthsummit/icela-cp.htm#chap11) and Statistics Iceland (http://www.statice.is).
Kazakhstan and Mongolia: Estimates based on approximate area of boreal forest.
Norway: Statistics of Norway 2007. Employment estimated using proportion of roundwood sourced from the boreal forest region.
Russia: FAOSTAT and Roshchupkin 2008. Employment estimated using proportion of harvest from boreal region. Total employment from Lebedys 2008. Population estimates from Federal State Statistical Service (www.gks.ru).
Sweden: Statistical Yearbook of Forestry 2008. Employment in wood and paper sectors estimated using roundwood sourced from boreal region.
United States, Alaska: Halbrook et al. 2009, Wurtz et al. 2006, Alaska Department of Labour and Workforce Development.

Boreal forests account for over one-quarter of the planet's forest area (i.e., almost 1 billion hectares), are home to several tens of millions of people, and provide direct employment to over one million people (Table 14.1). Boreal forests are found on three continents – Asia, Europe, and North America – mostly in Russia, Canada, the state of Alaska in the United States of America (USA), Finland, and Sweden (Figure 14.1). Russia accounts for three-quarters of the boreal forest zone. Smaller areas of boreal forest are present in Norway, Iceland, Kazakhstan, Mongolia, and China. All forests in Iceland, Siberia, Yukon Territory, Northwest Territories and Newfoundland & Labrador are located in the boreal zone; its proportion in other jurisdictions varies from 12% (in Mongolia) to 98% (in Finland) (Table 14.1).

This chapter focuses on the "true boreal" zones of the world, excluding the hemi-boreal or sub-boreal regions that contain temperate tree species or are montane outliers discontinuous with the central cir-


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Photo 14.1. Wild boreal forest in central Quebec, Canada.

cumboreal region (Brandt 2009). We include consideration of the northern ecotone with the arctic tundra, variously referred to as open taiga or boreal woodland, even though this region plays a negligible role in forestry. Conversely, it is the southern hemi-boreal or sub-boreal regions (which we do not address) that experience some of the heaviest concentrations of human population, forest industry development, and land use pressures. The universal constraints to ecosystem and community persistence at the northern limits of tree growth are reviewed, while highlighting important regional differences in development history. Current trends and issues associated with accelerating demand for boreal resources in an era of climate change are discussed. In the globally enviable position of expecting largely natural and productive landscapes to prevail in the foreseeable future, several regions of the circumboreal biome are nevertheless in the process of addressing particular forest management issues.

14.1.1 Natural History

Much of the boreal region was glaciated during the Pleistocene epoch, leaving behind gently rolling terrain with deposits of glacial till or lacustrine sediments alternating with shallow-soiled uplands and rounded rock outcrops. Elsewhere, in much of central Siberia (Russia), Alaska (USA), and Yukon (Canada), large portions of the boreal region remained unglaciated, though not necessarily forested, and served as glacial refugia for many subarctic plant and animal species. Uplands are widely characterised by poorly developed cambisols or acidic podzols, while low-lying areas are dominated by histosols and plinthosols (FAO 2003). Poorly drained wetlands and organic soils are common, as are widespread zones (or isolated pockets) of cryosol or permanently frozen soil (permafrost), typically insulated from the summer warmth by thick beds of living or partially decayed mosses.

The boreal or subarctic climate is defined by cold snowy winters without the moderating influence of open ocean waters, and a short growing season. Walter (1985) suggests that the true boreal zone is bracketed by conditions where daily mean temperatures are (on average) greater than 10°C for 30 to 120 days of the year, and with freezing temperatures

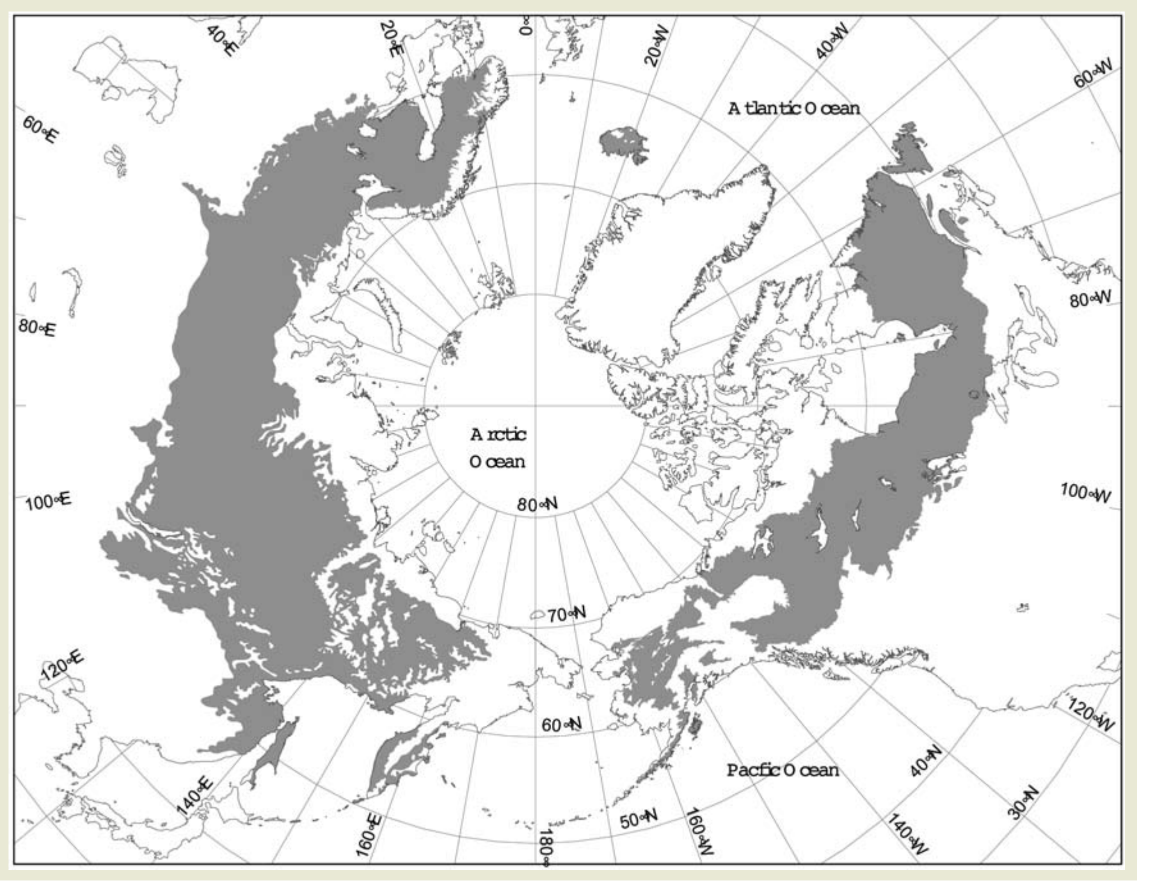

Figure 14.1. Distribution of the circumboreal forest (based on Olson et al. 2001).

occurring for 6 to 8 months. Although precipitation varies strongly across longitudinal gradients, it is relatively low, averaging 150 to 450 mm/year (Walter 1985). Cool temperatures mean that evapotranspiration is low too, so forest soils often remain moist and cold, except during conditions of persistent high pressure in mid-summer, when air temperatures can reach 30°C, the vegetation dries out, and forest fires are easily started (Johnson 1992). These forests are characterised by relatively few tree species, with the same genera dominating both Eurasian and North American regions: the conifers *Pinus* (pines), *Picea* (spruces), *Abies* (firs), and *Larix* (larches), and the more successional broadleaf *Populus* (poplars, cottonwoods, aspens), *Betula* (birches), *Salix* (willows), *Alnus* (alders), and *Sorbus* (rowan or mountain ash). All boreal tree species (approximately 15 in North America and 35 in Siberia [Zasada et al. 1997], but only 5–7 in Fennoscandia) have relatively wide distributions. Their ranges have contracted and expanded repeatedly under past climatic changes, generally providing them with a large degree of genetic variation and the potential to react successfully to environmental changes (Hagman 2003).

Boreal soils typically have a distinct organic layer resting on mineral soil: a thin layer on water-shedding sites and a thick layer on water-receiving sites. The accumulation of conifer leaves on the forest floor reduces the rate of decomposition and results in low nutrient levels and acidic soil conditions. The understorey is dominated by ericaceous dwarf shrubs, mosses, and lichens (Huhta et al. 1998) and relatively few species of vascular plants. Many boreal species have adapted to these harsh conditions through symbiotic associations (e.g., mycorrhizae, actinorrhizae, lichens), parasitism, and insectivory. Harsh conditions and frequent disturbances (in the form of fire, insect outbreaks, and wind damage) in these landscapes generate abundant dead wood that serves as habitat for many specialised species of fauna and flora, such as saproxylic insects, woodpeckers, and other wood-boring or cavity-dependent animals. Some species groups, including most songbirds and ungulates, adapt to seasonal variation and large-scale disturbance impacts by means of migration.

Slow tree growth produces strong, narrow-ringed wood with excellent properties as construction timber, and uniform fibres suitable for paper-making. Though low in annual productivity, large expanses of forest result in the circumboreal region holding some 45% of the world's growing stock of timber (Kuusela 1992, Conard and Davidenko 1998). Cool condi-


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Photo 14.2 Organic terrain is widespread in the boreal region.

tions mean slow decomposition rates and accumulation of an organic layer in mires or bogs (typically dominated by *Sphagnum* mosses) and fens (typically dominated by *Carex* sedges) and on the forest floor. Nutrients may be tied up in this organic material for a long time, with natural disturbances playing an important role in maintaining forest productivity and diversity.

Ecosystem recovery after fire is distinct from patterns observed after windthrow or insect attack, and is characterised by the rapid establishment of wind-dispersed or rhizomatous species, such as fireweed (*Epilobium angustifolium)* and reedgrass (*Calamagrostis* spp.). Depending on fire severity and biogeographic realm, there may also be an abundance of seed-banking species (e.g., some sedges [*Carex* spp.], raspberries [*Rubus* spp.], and wild cherries [*Prunus* spp.]), stump-sprouting willows (*Salix* spp.) or root-sprouting aspens (*Populus tremula* or *P. tremuloides*), and (in North America but not in Eurasia) tree seedlings newly germinated from seeds released by serotinous or semi-serotinous coned species of pine or spruce. As trees grow and the canopy closes, many herbaceous and shrubby species decline in abundance and a long period of moss and lichen growth and forest floor build-up follows. Other disturbances may accelerate succession by releasing understoreys of "dark conifers" (shade-tolerant spruces and firs); tall shrubs, such as willows and alders, are also effective colonisers and grow rapidly in open patches. But there is often little floristic succession, and most vascular plant species can persist to some extent through all seral stages (Carleton and Maycock 1978, Andison and Kimmins 1999). Where soils are wet and fire is uncommon, however, the growth of mosses and ericaceous shrubs can, over the course of two or three centuries, prevent self-replacement by conifers (see Photo 14.2), while soils become paludified and the site becomes less dominated by tree cover (Wardle et al. 2004, Fenton et al. 2005).

Boreal soils and peatlands represent an important carbon sink at the global level (Schulze et al. 1999, Turetsky et al. 2002), and peat can be an important resource for energy generation and horticultural use. It has been estimated that the boreal region contains more than 35% of the terrestrial carbon stocks on Earth, most of it in the peatlands that occupy 18% of the region (Kasischke et al. 1995). The boreal zone is also characterised by large rivers, lakes, and wetlands, with more surface freshwater than any other biome on Earth. Boreal forests provide important breeding grounds for many waterfowl and songbird species (see Boreal Songbirds Initiative 2009). Mammal populations may be strongly migratory on an annual basis (e.g., reindeer or caribou [*Rangifer tarandus]*) or cyclic over longer periods (e.g., varying hare [*Lepus americanus]*). Humans and other animals must cope with high populations of mosquitoes and black flies during the short summer season.

14.1.2 Boreal Economies

Indigenous peoples across northern North America and northern Eurasia share traditions of hunting, fishing, plant-gathering, and trading based on an intimate knowledge of the land; herding practices were traditionally limited to Europe and Asia. Today, over 60 million people live in the boreal forest region (Table 14.1), most of whom are concentrated in a relatively few southern cities. With the exception of boreal Sweden and Finland, population density is very low across the circumboreal region relative to the rest of the world. People primarily work in mining and mineral exploration, oil and gas development, forest products harvesting and processing, public administration, and social services. Relatively few people today are dependent on agricultural, hunting, or herding lifestyles in these regions, and there is increasing diversification into construction, manufacturing, retail, and hospitality (tourism) sectors.

Boreal timber resources support over a million direct jobs in the forestry and forest products industries. The contribution of non-timber resources to regional boreal economies and the livelihoods of boreal forest residents can be as great or greater, although exact numbers are unknown and their importance varies regionally within and among nations (Kushlin et al. 2004, Erdenechuluun 2006, Wurtz et al. 2006, Bogdanski 2008). For many people, the forest provides materials for shelter, fuel, and food, while supporting other values such as recreation and cultural identity. Boreal forests are also the source of many rivers that provide fresh water for human and industrial consumption, and that power turbines in hydroelectric dams that are the source of electricity often transmitted long distances to the south. It is estimated that the value of ecosystem services (water regulation and purification, carbon sequestration, bird habitat, non-timber forest products, etc.) provided by Canada's boreal forests alone is in the range of USD 90 billion per year (Anielski and Wilson 2005), and the Eurasian boreal forest likely makes an even greater contribution.

The annual industrial roundwood harvest from the world's boreal forests is approximately 300 million m^3, or about 17 % of the global harvest (Table 14.2). A significant amount of non-industrial roundwood is also harvested in the boreal region. For some boreal regions, such as in much of Russia and those Asian countries with some boreal forest, non-industrial roundwood (typically used for fuel) makes up a significant share of total wood harvest from the forest (Table 14.2).

The forest resources of Canada, Scandinavia, and Russia support significant wood and paper industries (Table 14.2). Of the world's boreal regions, Canada's boreal forest supports the largest wood products industry, while that of Finland supports the largest paper products industry. The boreal timber resources of the Asian region and Alaska, while not supporting a globally significant forest industry, support small and locally important timber and wood products industries (Kushlin et al. 2004, Erdenechuluun 2006, Wurtz et al. 2006).

Most boreal forest lands are publicly owned in Russia, Canada, and Kazakhstan; in contrast, about 70% of the forests in Finland, 76% in Sweden, and 80% in Norway are under private and corporate ownership. All countries have central federal forestry agencies, although their departmental affiliations and responsibilities differ. Meanwhile, real administration and management are often in the hands of subnational authorities. Compared to many temperate forests, vast areas of boreal forest are under rather centralised control, and hence lend themselves to integrated landscape management (see Chapter 22).

14.2 Drivers and Challenges to Boreal Sustainability

The northern forests of continental North America and Asia grow under particularly severe climatic conditions. As a result, most boreal or taiga forests are coniferous, dominated by tree species well adapted to short growing seasons, severe cold, and low nutrient availability. Much of the boreal "forest" is actually open woodland and wetlands. For example, more than 30% of the forested area of Siberia is considered to be of low density, with basal areas only 30–50% the levels of fully stocked stands. In these low-density stands (mostly located in Eastern Siberia and the Russian Far East), timber stocking is less than 80–100 m^3/ha. More than 40% of the Siberian forests are growing on poor sites, predominantly in the Russian Far East (Sokolov et al. 2003).

Almost 80% of forests located in the Asian part of Russia grow on permafrost and long-frozen soils (Pozdnyakov 1986). Permafrost is a natural phenomenon of global scale; it occupies no less than 25% of the Earth's land area. In Russia alone, the area of permafrost (under both forest and tundra) occupies approximately 11.1 million km^2, which is about 65% of the nation's land area. In North America, the area of permafrost is about 7.2 million km^2, with its southern limits between 52 and 56°N, which is much more northerly than its southern limits in Asia, where mountainous relief combined with continental cold extends permafrost as far south as 44°N (Konishchev 2001).

In marked contrast to wet tropical forests and many of the world's temperate forests, unmanaged boreal forests are largely shaped by stand-replacing disturbance regimes, mainly dominated by wildfire. The average return intervals of wildfires are

Table 14.2 Boreal Forest Management and Industry (2004).

	Industrial roundwood harvest million m³	Sawnwood production million m³	Panel products production million m³	Pulp million mt	Paper and paperboard million mt	Value added wood and paper million USD	*Wood fuel production million m³	% of total harvest
China							211.3	69
Heilongjiang	na	na	na	na	na	na		
Inner Mongolia	na	na	na	na	na	na		
Canada	83.4	28.3	10.7	10.60	8.20	11 316	2.8	1
Newfoundland	2.4	0.0	..	na	na	162		
Quebec	24.5	11.3	2.5	na	na	3 441		
Ontario	20.1	7.0	1.8	na	na	4 383		
Manitoba	2.1	0.6	0.5	na	na	477		
Saskatchewan	6.1	1.2	1.0	na	na	537		
Alberta	23.5	8.1	3.2	na	na	1 971		
BC	4.6	2.4	1.7	na	na	345		
Northwest Territories	0.0	na	..	..	..	na		
Yukon	0.0	na	..	..	..	na		
Finland	52.4	12.2	1.8	11.4	12.6	6 310	5.1	9
Iceland	..	..	..	..	..	..		
Kazakhstan	na	na	na	na	na	na	0.2	43
Mongolia	0.1	na	..	..	..	na	0.7	95
Norway	5.4	2.2	0.6	2.4	2.3	1 363	1.4	16
Russia	96	15.8	5.4	4.4	4.9	3 725	47.8	27
European Russia	36	na	na	na	na	na		
Western Siberia	12	na	na	na	na	na		
Eastern Siberia	35	na	na	na	na	na		
Russian Far East	13	na	na	na	na	na		
Sweden	46.5	9.9	0.6	8.5	8.1	4 550	5.9	9
United States – Alaska	0.021	0.10	..	..	..	na	na	na

Country Notes:
Canada: Statistics Canada, Bogdanski 2008. Panel production data from Spelter et al. 2006.
China: Industrial harvest in Inner Mongolia and Heilongjiang 3.8 and 5 million, respectively (Chinese Forestry Statistical Yearbook). Amount sourced from boreal region unknown.
Finland: Finish Statistical Yearbook of Forestry 2008; 90% of wood and paper production estimated to be dependent on boreal resources.
Iceland: No forest industry.
Kazakhstan: Official industrial roundwood harvest estimate is 270 000 cubic metres (FAOSTAT). Amount sourced from boreal forest is unknown.
Mongolia: Erdenechuluun 2006. Official roundwood harvest is 40 000 sawlogs while unofficial is around 650 000. Amount sourced from boreal forest is unknown.
Norway: Statistics of Norway 2007. Value added estimated using proportion of roundwood sourced from the boreal forest region.
Russia: FAOSTAT and Roshchupkin(http://www.rosleshoz.gov.ru/english/media/appearance/13. Cited 08 Jun 2009). Industrial roundwood estimates calculated.
Sweden: Statistical Yearbook of Forestry 2008. Value added estimated using proportion of roundwood sourced from boreal forest region.
United States, Alaska: Halbrook et al. 2009.
Value added estimated using Lebedys 2008 and estimated share of harvest from boreal.
Wood fuel production data from FAO. Actual harvest for Kazakhstan, Mongolia and Russia may be signficantly higher due to illegal/non-reported harvesting.

often not much different from tree ages that forest managers would choose for harvesting to maximise wood production. This generalisation is often used as the basis for even-aged forest management and the systematic replacement of natural disturbances with the harvesting of trees for economic use. Yet there are important regional differences in the natural disturbance regime, and the widespread conversion of "wild" forests to regulated, even-aged stands is resulting in the extirpation of older forests from many parts of the boreal region (Box 14.1). Even though even-aged, single-species stands exist in wild boreal forests, unmanaged forest landscapes nevertheless retain important biological legacies (large snags, logs, and patches of undisturbed vegetation) and a diversity of stand types and ages, including areas

Box 14.1 Old growth in the Canadian boreal forest

Yves Bergeron and Sylvie Gauthier

Although Canada's boreal forest is dominated by relatively young fire-generated even-aged stands, a significant proportion of the land base is occupied by old-growth forest due to longer natural fire intervals. Some old stands have been relatively undisturbed for many centuries, even millennia (Cyr et al. 2005). Long fire cycles are not unique to recent historical times but were common during most of the Holocene (Flannigan et al. 2001, Cyr et al. 2009), and old-growth forests can be considered as having been a permanent feature of the Canadian boreal forest for at least the last 10 000 years.

Old forests in the boreal zone possess unique characteristics (such as more structural variation, greater compositional diversity, and processes of patch and gap dynamics) not observed in younger even-aged stands. Current forest management practices that use relatively short even-aged rotations do not reproduce the historical age structure, potentially affecting biodiversity (Bergeron et al. 2002). Table 14.3 provides the expected proportions of forest greater than 100 years, 200 years, and 300 years of age for different ecoregions in boreal Canada, according to historical burn rates and random fire starts. If managed according to a 100-year industrial forest harvest rotation with a uniform age-class distribution, between 15% (in the boreal shield west) and 47% (in the boreal shield east) of the region would not have historical levels of these important older forests. These differences, largely driven by climate, provide important points of reference as templates for forest ecosystem management.

While the forest sector operates on only about one-third of the boreal region of Canada (Bogdanski 2008), this doesn't mean that surplus quantities of old growth exist, because wildfires continue and logging is concentrated in the southern ecozones. If maintaining or re-establishing the abundance of old-growth forest found in pre-industrial landscapes becomes an objective, more research would be required. Better data on stand ages, structural attributes and disturbance history are clearly needed for both managed and unmanaged forest landscapes across the country. The ongoing research in Canada into ecosystem management and the development of silvicultural techniques that maintain or restore old-growth forest composition, structure and function at different scales in the landscape is important to future options. These techniques generally centre around variable rotation lengths, different criteria for the selection of tree removals during partial cutting, and different patterns of structural retention (Burton et al. 1999, Bergeron 2004, Bouchard 2009).

Table 14.3 Historical fire frequency (% of the area burned per year) and its inverse, the fire cycle (years), together with the proportion of forest expected to be older that 100, 200, and 300 years under a natural fire regime characterised by a negative exponential distribution of time since fire for the Canadian boreal ecozones.

	Area (km^2)	Historical fire frequency (%/yr)	Historical fire cycle (yrs)	% Area expected >100 yrs old	% Area expected >200 yrs old	% Area expected >300 yrs old
Taiga cordillera	267 029	0.20	495	82	67	55
Boreal cordillera	470 502	0.39	255	68	46	31
Taiga plains[a]	645 014	0.70	142	49	24	12
Boreal plains	733 170	1.48	68	23	5	1
Taiga shield west	631 679	0.85	118	43	18	8
Boreal shield west	946 260	1.92	52	15	2	<1
Hudson plains[a]	374 482	0.12	813	88	78	69
Taiga shield east	758 763	0.60	166	55	30	16
Boreal shield east	931 062	0.77	131	47	22	10
Total	6 148 148			45	24	15

[a]Current fire frequency (last 50 years) was used for these ecozones as no long-term studies were available.

Source: Bergeron and Harper 2009.

of old growth. A program of clear-cutting and optimised timber production can bring the composition, age structure, and patch structure of a boreal forest landscape far outside the limits of natural or historical variation (Cyr et al. 2009, Kuuluvainen 2009). Simply put, forest management needs to take more into account than matching a uniform rotation age to a mean fire return interval or fire cycle.

At both stand and landscape levels, it is now clear that human disturbances are not equivalent to natural disturbances (Drapeau et al. 2000, Haeussler and Kneeshaw 2003). Road-building, mining, and logging are not necessarily benign just because forest fires, pest outbreaks, and windthrow are widespread natural processes in the boreal zone. Any forest disturbance has the potential to disrupt some species, or even lead to their extirpation, though the widespread disturbance-adapted flora and fauna of boreal forests makes this danger not as great as it is in tropical forests. Indeed, boreal forests require a degree of disturbance in order to remain productive, diverse, and healthy. Identifying an appropriate balance of protection and disturbance at stand and landscape levels has emerged as an important challenge for boreal foresters.

Despite a century or more of industrial use and management in some parts of the world, boreal forests continue to provide people with many essential goods and services. But boreal ecosystems are not insensitive to climate and disturbance severity. Where fire or logging intervals are relatively short and where silvicultural management is lacking, pine and spruce have been replaced with birch, aspen, and alder. Conversely, forest management practices such as drainage, artificial regeneration, vegetation control, and thinning have promoted uniform stands of conifers, often resulting a degree of homogeneity not found in nature (Jetté et al. 2009).

Life in the world's northern forests has always been a challenge. With climate and soils rarely suitable for locally self-sufficient agriculture (which has allowed for the growth of large human populations elsewhere on the planet), livelihoods in the subarctic have largely depended on wild rather than managed resources. Trees typically grow slowly, are slow to regenerate, and are at risk of mortality from wildfire or insects. On the other hand, large areas of land under little threat from agriculture, urbanisation or commercial forestry sustain some of the world's last remaining wilderness landscapes, in which natural food webs and unmanaged disturbance processes still prevail. On an increasingly human-populated planet, such wilderness areas have growing non-use values, in addition to providing ecosystem services and opportunities for ecological research and ecotourism.

Most of the human population dwelling in the boreal is currently concentrated in cities, so large areas are characterised by low populations, limited employment opportunities, and long distances to markets and centres of commerce (Burton et al. 2003). These attributes, coupled with the inherent instability of primary industries dependent on export markets, perpetually constrain economic viability and stability in northern regions (Jovanovic 2003, Beier et al. 2009). As part of the resource hinterland of larger national and global economies, boreal regions have long been exporters of furs, timber, tar, electricity, and minerals, while often relying on food, finished goods, expertise, and investment from the south.

14.2.1 Biodiversity

The remaining large areas of unmanaged wilderness are one of the boreal forest's greatest assets. Intact boreal forests are a global refuge for many species. Boreal forests are generally poorer in species, genera, and families compared to temperate and tropical ecosystems, probably reflecting levels of solar energy, productivity, and environmental patchiness (Blackburn and Gaston 1996). However, taxonomic work and sampling are very incomplete (especially outside of Fennoscandia), particularly when it comes to the arthropods, fungi, and microorganisms that are very abundant in northern forests. It has been estimated that the world's boreal forests contain over 100 000 species, 95% of which are arthropods and microorganisms, with only some 20% of these taxa identified taxonomically (Nilsson 1997). Low species richness may reduce both conflicts and options with respect to forest management, compared to other parts of the world. The concentration of rare or endemic species that might be endangered by habitat disruptions (including industrial forestry and land use conversions) is lower than in temperate or tropical forests. At the same time, low tree species diversity can also make these forests susceptible to host-specific insect and fungal pests, and there are not as many silvicultural choices in terms of crop tree species and associated silvicultural systems. According to the worldwide Red List of threatened species (IUCN 2008), no boreal forest species are known to have become extinct in the recent era, and comparatively few boreal forest species are at risk of extinction (Box 14.2). However, extirpations (local extinctions) have occurred in heavily exploited areas such as Scandinavia (Hanski 2000, Angelstam et al. 2004). The impacts of extirpations on ecosystem integrity remain to be better understood, although most boreal countries have governance policies and processes in place to address threatened species.

While threats to boreal biodiversity may be relatively low at the global level, a number of regional conservation issues are evident. Vistnes and Nel-

Box 14.2 IUCN red-listed species in the boreal forest

Brenda J. McAfee

The International Union for Conservation of Nature (IUCN) is responsible for compiling the IUCN Red List describing the global conservation status of plant and animal species (IUCN 2008). The annual list highlights species that are facing a high risk of global extinction, based on information supplied by a network of thousands of scientific experts from around the world. Plant and animal species are assigned to one of eight Red List Categories following criteria linked to population trend, population size and structure, and geographic range (IUCN 2001, Mace et al. 2008). This analysis allows comparison of biodiversity status at various scales across the globe. Each species assessed is assigned to one of the following categories: Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, and Data Deficient. Species classified as Vulnerable, Endangered, and Critically Endangered are collectively regarded as Threatened.

No species from boreal forests have been listed as extinct. In 2008, the following eight species (representing only 0.14% of the world's 5704 threatened forest-related species) were listed as threatened: European Bison (*Bison bonasus*), Kittlitz's Murrelet (*Brachyramphus brevirostris*), Boreal Felt Lichen (*Erioderma pedicellatum*), Mosor Rock Lizard (*Lacerta mosorensis*), Siberian Musk Deer (*Moschus moschiferus*), Snow Leopard (*Panthera uncial*), Whitebark Pine (*Pinus albicaulis*), and Spotted Greenshank (*Tringa guttifer*). Fewer threatened species are found in boreal forests than in the other forest types classified by the IUCN. For example, on the 2008 Red List, 38 species from temperate forests, 257 (4.5%) from subtropical/tropical and moist lowland forests, and 3172 from subtropical/tropical moist montane forests are listed as threatened. However, the IUCN defines boreal forest as the forest distributed across the high latitudes of the northern hemisphere (occurring between 50° and 60°N) in a broad belt across Eurasia and North America, and hence is somewhat different than the region mapped in Figure 14.1 as defined by floristic or climatic criteria, or by individual national forest inventory programs. Reporting by ecological zones as well as jurisdictions would greatly facilitate appropriate comparisons.

Figure 14.2 shows the change in status of threatened species in the boreal forest from 2002 to 2008. The analysis covers this time period to be consistent with the new categories and criteria adopted by the IUCN in 2001 (IUCN 2001), and excludes some species found in the specified latitudinal band but not in a boreal region. The number of threatened species remained relatively constant, although there were some species that moved to a category of higher risk during this period. There were also three species, Wolverine (*Gulo gulo*), Pond Bat (*Myotis dasycneme*), and Boreal Toad (*Anaxyrus boreas*) that improved their status and were removed from the threatened category.

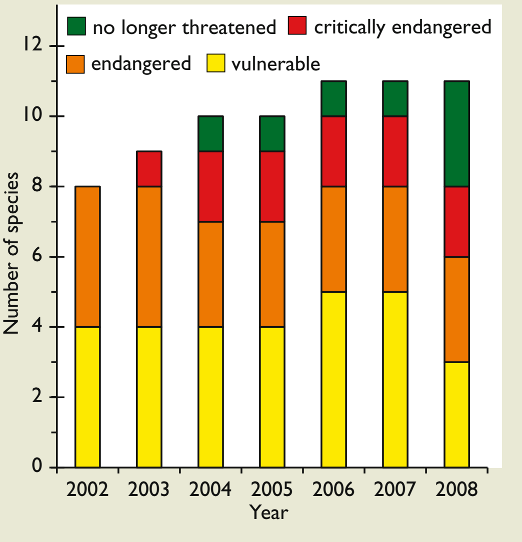

Figure 14.2 Change in status of threathened species in the boreal forests from 2002 to 2008.

lemann (2007) point out the degree to which wild reindeer and woodland caribou are constrained by human activities (road development and forest fragmentation) in both hemispheres. More than a century of population pressures and intensive forestry in Norway, Sweden, Finland, and parts of Russia have made many forest-dwelling species exceedingly rare. The Evaluation of Threatened Species in Finland 2000 (Rassi et al. 2001) recognised 564 species found primarily in forest habitats under the IUCN categories of critically endangered, endangered, or vulnerable, with another 416 forest species listed as near-threatened. Forest changes and forestry practices are identified as the principal threat to these organisms, consisting primarily of invertebrates (252 species), and fungi and lichens (250 species) (Rassi et al. 2001). Furthermore, 51 of the 73 forest habitat types recognised in Finland have been evaluated as threatened (Raunio et al. 2008). A disproportionate importance of the boreal forest for bird life in the Americas was also demonstrated by Blancher and Wells (2005). Their analysis of data compilations on bird species in the boreal forest of North America determined that nearly half of all of the North American bird species rely on the boreal forest, and over 90% of these birds breed in boreal forests. Despite low tree species diversity, variation in the frequency and severity of fires and other disturbances generates much of the boreal habitat diversity (Burton et al. 2008) that is so important to sustaining many species of animal and plant life.

The importance for large areas of relatively untouched tracts of boreal forest to function as ecological benchmarks and provide a range of ecosystem services should not be overlooked in the face of global change (Angelstam et al. 2004). Because the boreal forest is not considered a hotspot of biodiversity, it has been suggested that insufficient attention has been paid to tracking species that are not currently threatened, but that could become threatened (Bradshaw et al. 2009). Kareiva and Marvier (2003) point to the importance of conserving these biodiversity "coldspots" as resources for future evolutionary innovation.

14.2.2 Forest Management

Boreal forests have been commercially harvested for solid wood and pulp-based products for well over a century. The dominant forest management model practised in northern Europe since the mid-1900s is based on the principles and practices articulated a century earlier in Germany and other central European countries. Various selective or unregulated harvesting systems (deemed unsustainable and leaving stands difficult to inventory) were replaced with more efficient approaches and even-aged, single-species stands destined for clear-cutting after approximately 100 years. North American foresters have generally adopted the same practices for all northern conifer forests. More recently, some degree of structural retention (protection of wildlife trees and key habitats) has been incorporated into the management regime for the purposes of biodiversity conservation (Vanha-Majamaa and Jalonen 2001, Work et al. 2003). Yet while knowledge of alternative harvesting methods and forest management models is increasing, their uptake remains limited.

Emphasis is generally placed on the harvesting and production of conifers for dimensional softwood lumber and pulp production, but with increasing use of poplars and aspens for pulping and use in engineered wood products such as oriented strand-board (Burton et al. 2003). The harvesting and management of birch species seems to be much more local and less industrially oriented. Large areas of Siberia and eastern Canada are left for natural regeneration (through release of advance regeneration or by in-seeding) after forest harvesting, whereas the planting of nursery-grown seedlings is more widespread in Fennoscandia and western Canada.

Site preparation through the broadcast burning of slash used to be common, but is now rare because of fire escape risks (and associated liabilities), human health concerns associated with smoke dispersion, efforts to avoid carbon dioxide release, and the channelling of waste wood and logging slash to bioenergy uses (see Chapter 10 for forests and bioenergy production). Mechanical site preparation prior to planting was very popular in the 1980s and 1990s, but now appears to be used much more selectively. Mechanical or chemical methods are used to control grasses, shrubs, and broadleaf trees where necessary to assure free-growing stands of conifers, but intermediate cuttings are standard only in Fennoscandia and near populated areas in Russia. In general, managed boreal forests support a wide range of interventions: from simple exploitation (with little consideration for forest renewal) through extensive management with only basic silviculture, to intensive management characterised by multiple and diverse interventions (Lieffers et al. 2003).

Fundamental changes in forest structure and dynamics as a result of classical forest management have taken place over the past half-century in some parts of northern Europe, and are ongoing in Siberia and Canada today (Cyr et al. 2009, Kuuluvainen 2009). It seems that the magnitude of this change at the landscape level has not generally been recognised. Research on natural forests as a point of reference for evaluating forestry practices only became widespread in the late 1990s, when biodiversity became an important issue (Bergeron et al. 1999, 2002; Korpilahti and Kuuluvainen 2002; Burton et al. 2003).

14.2.3 Economics and Trade

One important aspect of the boreal forest industry is its heavy reliance on trade due to its large timber resources relative to small domestic demand (Table 14.4). All the boreal countries export a significant share of their production. Canada is arguably the most dependent on trade, mainly with the USA, but all boreal countries are heavily trade-dependent. In addition, the Scandinavian and Chinese industries are strongly dependent on Russia for their industrial roundwood supply (see Box 14.3; Mutanen et al. 2005, Gerasimov and Karjalainen 2009). Thus, changes in forest policy in any of these countries can have significant impacts not only on their own industries but on their neighbours and trade partners.

Table 14.4. Estimated production and exports of wood and paper products derived from boreal forests.

	Sawnwood		Wood-Based Panels		Paper and Paperboard		Wood Pulp	
	Exports (mill. m³)	Share of production	Exports (mill. m³)	Share of production	Exports (mill. m³)	Share of production	Exports (mill. m³)	Share of production
Canada	19.09	67 %	8.62	81 %	6.46	79 %	4.61	44 %
Finland	7.41	61 %	1.41	80 %	11.44	91 %	0.33	19 %
Norway	0.48	22 %	0.27	45 %	2.00	87 %	0.62	26 %
Russian Federation	9.29	59 %	1.49	28 %	1.94	40 %	1.17	27 %
Sweden	6.58	67 %	0.17	27 %	7.15	88 %	2.48	29 %
Boreal Total	43.81	64 %	12.25	64 %	28.64	79 %	9.07	33 %
Global Share	33 %	16 %	16 %	8 %	26 %	10 %	21 %	16 %

Source: FAOSTAT, Statistics Canada, Statistics of Norway 2008, Finish Statistical Yearbook of Forestry 2008, Swedish Statistical Yearbook of Forestry 2008, and own calculations. Exports values calculated using estimated boreal production shares.

Each region faces different challenges. For the advanced economic areas, such as Canada and Scandinavia, the main challenge is to maintain global competitiveness in existing export markets while continuing to achieve social and environmental objectives. Russia, on the other hand, is a region in transition and aims to double its industry over the next 10 to 15 years (Bolshakov 2008). Inevitably, such an industrial expansion will require improved labour productivity and consequent reduced employment in the forest industries. Employment reduction in some regions will pressure governments to diversify their economies. The challenges are very different in the commercially marginal lands of the boreal regions. The main challenge for these regions is to successfully undertake and regulate wood harvesting in such a manner as to provide economic value while protecting other socially and environmentally significant values. Failure to do so may undermine the ability of people in these regions to improve their standard of living and sustain their cultures.

With world population growth continuing for the foreseeable future, boreal forest resources will increasingly be looked upon to provide more wood and other materials. These new demands will be from local and distant markets. While pressures will differ across each region of the global boreal forest economy, the basic challenge will be the same: how to utilise boreal forest resources while maintaining or enhancing other forest-related values and contributing positively to local and regional economies. Areas capable of supporting compatible values must be mapped, trade-offs identified where values are not compatible, and in many cases, difficult decisions will have to be made about what constitutes the greatest value in broad segments of the boreal landscape.

14.2.4 Social Realities

Social expectations and valuations of the world's boreal forests are diverse and often contradictory. On the one hand, indigenous peoples in the region (Native Americans in Alaska, First Nations in Canada, the Sami of Fennoscandia, and the "numerically small peoples of the North" in Russia) are trying to develop a balance of traditional land-based lifestyles and integration into modern economies. In recent years, the rights of aboriginal peoples have been reaffirmed in a number of jurisdictions, either through court/judicial decisions, or with formal treaties or resource management agreements signed in various regions across the subarctic, but such arrangements are still lacking throughout much of the region (Fondahl and Poelzer 2003). While incorporating modern technology (in housing, transportation, communications, etc.), indigenous peoples typically wish to draw upon the resources (e.g., wild game, fish, furs, reindeer, berries, fuelwood) of their immediate environment (Beltrán 2000). At the same time, local jobs are needed as communities seek to integrate into the cash economy. Employment opportunities are typically concentrated in the primary resource industries such as logging and mining.

Local communities in the sparsely populated northern forests often face trade-offs and internal division over their commitment to place and traditional lifestyles versus the need for a strong wage-based economy. Long-time northern residents typically share a desire to maintain local forests and waters in a wild state for cultural and aesthetic reasons, and for recreational and sustenance purposes. Yet these same people need wage income to survive in the modern world, so resource development is often a welcome source of employment. Northern resource-dependent communities are not only particularly vulnerable to a

Box 14.3 Recent efforts to promote wood processing in Russia

Victor Teplyakov

Since the demise of the Soviet Union, Russia's forest sector exports have been dominated by products with low added value. Roundwood exports from Russia increased threefold over a period of 15 years, from approximately 18 million m^3 in 1992, to 54 million m^3 in 2007, making Russia the world's greatest exporter of raw logs. Export policies regarding roundwood have now changed. In early 2007, the Government of the Russian Federation implemented a three-stage increase of customs fees to be applied to the export of roundwood: 6.5% to 20% of the product value applied after July 1, 2007; then up to 25% applied from April 1, 2008; and finally up to 80% of the sale price (but not less than 50 Euros/m^3) scheduled for January 1, 2009, but then postponed until January 1, 2010. On June 4, 2008, Maxim Medvedkov, Head of the Department of Trade Negotiations of the Russian Ministry of Economics and Development, announced that further consideration of export taxes on raw timber will be discussed after resolution of all remaining issues related to the Russian Federation joining the World Trade Organisation.

The Russian government also has implemented other methods to stimulate changes in the structure and global competitiveness of its wood products sector. It has cancelled export duties on practically all kinds of processed wood and fibre products, including sawn timber, raw cellulose (wood pulp), wood-particle boards, and specific items of paper and cardboard. Also, the customs duties for importing wood processing equipment have been cancelled. To stimulate the development of wood processing in the country, the federal government has also implemented some policies favourable to industrial development. In 2007, the mechanism of "priority investment projects" was developed, which included granting preferences to proposed projects with total capital investments in forest infrastructure and wood processing facilities of >300 million rubles (7.55 million Euros). If an investment project is assigned to the "List of Priority Forest Projects," forest harvesting rights will be awarded to the investor without auction, and contractual payments for forest resources are reduced by 50% until the original investment is recouped.

As with many export duties and investment incentives applied around the world, the goal of these combined measures is to stimulate domestic manufacturing. However, the terms and methods employed in implementing the new tariff policy have put a severe strain on a forest industry centred primarily on the harvest and transport of logs. Despite the 18-month phase-in period, the domestic capacity for wood processing remains unevenly distributed and poorly advanced. For example, the capacity for timber processing in the Russian Far East is no more than 20% of the volume harvested from the region. The second phase of duties has been quite effective in reducing the levels of timber export. For the first six months of 2008, the port of Nahodka (in Primorsky Krai) shipped total timber cargoes only one-third of that handled during the same period in 2007, with raw log shipments down to 28% of previous levels.

lack of sustainability on the part of industry or government initiatives (Teitelbaum et al. 2003), but are also more exposed to the vagaries of global markets and a shifting climate than those which are economically diversified (Davidson et al. 2003).

So, despite low population densities and little land use pressure from agriculture and urbanisation, the world's boreal regions must still achieve a balance of social, economic and ecological values. As elsewhere, this balancing exercise inevitably results in some potential for tension within and among communities, and between proponents of greater development and those of greater environmental protection in society at large.

14.3. Ongoing Threats and Emerging Issues Facing the Boreal Forest

With large variation by jurisdiction, boreal forests at the global level face ongoing threats and emerging issues that include poaching, illegal logging, illegal settlements, mining and energy development, climate change, contamination and pollution, unemployment and poverty, unsustainable timber harvesting, uneven promotion of forest values, and low public awareness. These issues might be grouped according to those related to cumulative impacts and the sustainability of forest values under industrial forest management, the multiple dimensions of climate change, and the viability of northern forest communities and lifestyles. Conversely, the sheer expanse of wild subarctic forests, with relatively few endangered species and some potential benefits from climate change, is such that many parts of this region present a real opportunity to practice holistic ecosystem management and proactive adaptation to a changing environment.

14.3.1 Industrial Expansion and Reform

Based on an assessment conducted over a decade ago (Bryant et al. 1997), boreal forests were estimated to constitute 48% of the world's remaining frontier forests, defined as "primarily forested, of sufficient size to support viable populations of the full range of indigenous species associated with that particular forest ecosystem, given periodic natural disturbance episodes" (WRI 2010). Nevertheless, the boreal forest has been exploited and fragmented by man (as a result of roads, timber harvesting, pipelines, mineral extraction, etc.) over much of its area (Bryant et al. 1997, Aksenov et al. 2002, Wade et al. 2003). The extent of commercially operable or managed forest varies considerably among boreal jurisdictions: only 35% of the Canadian boreal forest (Bogdanski 2008), compared to about 76% in Russian (Burton et al. 2003) and 90% in Finland (Suvi 2009), for instance. Much of that operable landbase outside of Fennoscandia continues to be brought under management for sustained yield production. While large portions of the circumboreal region remain beyond operable limits for commercial forestry or is protected, industrial use the world's northern forests remains controversial. The controversy is due to perceptions that conservation interests are not being met, that resource use practices are not sustainable, or that governance structures are failing to balance public interests.

Poorly coordinated forestry, mining, petroleum and transportation sectors in some boreal landscapes are resulting in cumulative impacts that stress ecosystems more than any one sector alone (MacKendrick et al. 2001, Forbes et al. 2004). Negative and avoidable effects of multi-sector development have been demonstrated on aquatic and forest interior habitats, and result in the loss of productive forest land base (Ross 2002, Ripley et al. 2005). Schneider et al. (2003) illustrate the environmental benefits of integrated landscape management, which results in reduced development costs as well as mitigated impacts. Governments have recently tried to facilitate such coordination (e.g., Osborne 2010).

It is being increasingly argued that ongoing threats to biodiversity and non-timber forest values reflect, at least in part, a mismatch of the industrial model of forest management with the complexity and dynamics of unmanaged forests and the multitude of habitat needs that homogenous stands of conifers simply cannot meet (Hunter 1990, Lindenmayer and Franklin 2002, Kuuluvainen 2009). The protection of rare species, and the role of forests in conservation, are important to northern nations, and this importance is expected to increase if the decline of biodiversity continues in those forests that are used intensively (Hanski 2000, Auvinen et al. 2007). Reflecting such concerns, there are political initiatives to halt the increasing endangerment of rare species and habitats in the near future (e.g., the EU Countdown 2010 declaration). It has been suggested that the current negative association of rare species with managed plantations will not be reversed simply by making superficial modifications to forest practices (Kuuluvainen 2009). Rather, radical land use changes, coupled with conscious efforts at ecosystem restoration and more ecologically oriented forest management at stand and landscape scales, may be required if the flora and fauna indigenous to many regions of northern Europe are to be protected (Angelstam 1998, Kuuluvainen 2002). Conversely, knowledge gained from rehabilitating degraded forests in Europe may facilitate forest management reforms elsewhere.

Since the boreal zone as a whole does not have a high concentration of endemic species, and is not experiencing excessive loss of habitat, this region has not been considered among the world's biodiversity hotspots (Meyers et al. 2000). Nevertheless, some conservation biologists have argued for a more cost-effective and comprehensive approach to ecosystem protection, guided by the value of ecosystem services and proactively addressing the prospect of future threats (Kareiva and Marvier 2003, Anielski and Wilson 2005, Underwood et al. 2008). By their reasoning, more protected areas and more ecologically sensitive development would be warranted in much of the circumboreal region.

As with much of Europe, a long history of intensive forest management in Fennoscandia has resulted in drastic reductions in the amount of old forest and dead wood (Kuuluvainen 2009). This has been reflected in a deficit of native flora and fauna in the boreal forests of Norway, Sweden, and Finland (Bradshaw et al. 2009, Kuuluvainen 2009). Reduced biodiversity in managed, secondary forests is well documented for certain classes of fungi (Penttilä et al. 2004), cryptograms (Kruys and Jonsson 1999), and insects (Martikainen et al. 2000), largely related to the paucity of dead wood. Other organisms have become rare because of the reduced incidence of fire as an agent of natural disturbance, and forest structure changes due to forest management (Wikars 2001). The local extirpation and reduced population vigour of some bird and mammal species reflect habitat changes (e.g., the loss of large old trees for nesting or denning) and also the loss of interior forest refuges as managed landscapes have become increasingly fragmented and well roaded (Angelstam 1998, Rassi et al. 2001). When drastic and relatively abrupt changes in forest habitat properties in managed landscapes are combined with the small area and often poor quality of protected areas, it is no surprise that a biodiversity decline has been observed in some jurisdictions (Berg and Tjernberg 1996) and is projected to continue (Rassi et al. 2001, Auvinen et al. 2007). For example, in Finland 564 forest species have been classified as threatened and 62 forest species as extinct (Rassi et al. 2001). Consequently, efforts to reform forest practices (Puettmann et al. 2008) and restore forest composition, structure, and biodiversity to more natural conditions (Angelstam 1998, Korpilahti and Kuuluvainen 2002, Vanha-Majamaa et al. 2007) have become topical themes of public discussion in much of northern Europe.

In order to support indigenous biodiversity in the working forest, some progress has been made in developing guidelines and regulations for leaving more dead wood (both standing and fallen) in managed forests (Siitonen and Martikainen 1994, Ehnström 2001), but recruitment of large trees to serve this purpose in the future remains a challenge. Likewise, patches of green trees are often retained within large clearcuts (DeLong 2002, Burton et al. 2006), somewhat mimicking the "skips" of large wildfires, to provide structural diversity and some habitat continuity over time (Vanha-Majamaa and Jalonen 2001, Work et al. 2003). Efforts to integrate biodiversity conservation with product-oriented forest management continue to play an important role in forest research and extension programs in northern regions and around the world (Voller and Harrison 1998, Hunter 1999, Lindenmayer and Franklin 2002). Such efforts often emphasise the emulation of natural disturbances (in terms of the retention of biological legacies, disturbance patterns and frequencies) as a "coarse filter" approach to integrating the conservation of biodiversity and ecosystem processes with resource harvesting (Perara et al. 2004, Burton et al. 2006, Gauthier et al. 2009). Some forest researchers are further extending the need to restore degraded forests by calling for the purposeful design of forests with high levels of compositional and structural complexity (Puettmann et al. 2008) –perhaps even beyond those found in nature – as a means of enhancing their adaptive capacity in the face of an uncertain future.

Other land use impacts cannot emulate natural changes. Forest recovery after petroleum exploration and development, industrial air pollution, and surface mining (see Chapter 13 for extra-sectoral drivers) takes several decades (e.g., Gunn et al. 1995, Lee and Boutin 2006), or requires investments in land remediation and reclamation. Nevertheless, some forest lost (e.g., for transportation infrastructure) is considered necessary and permanent (Schneider 2002).

14.3.2 Climate Change

Evidence suggests that direct and indirect climate change impacts are likely to be more pronounced at high latitudes than in most other parts of the world (Christensen et al. 2007). As a result, a rapidly changing climate is already one of the most pronounced agents of change in the arctic and subarctic regions of the world. Boreal forests are likely to experience increases of 4°C to 5°C in mean annual temperature over the next century, although different model and scenario combinations generate mean annual temperature increases ranging from 2°C to 8°C (Christensen et al. 2007). Such changes are expected to have profound implications to forest productivity, disturbance risks, and land use potential. While at first glance, warmer conditions and a longer growing season might seem beneficial to subarctic forests, suitable soils for enhanced tree growth remain limited. Furthermore, a warmer climate is also amenable to forest pests (see Chapter 7 for forest health in a changing environment), forest fires, drought, the thawing of permafrost, and competitive displacement by species from the south (Stewart et al. 1998, Stocks et al. 1998, Volney and Fleming 2000).

Of the projected changes in forest disturbance regimes, the potential for increased fire danger has received the most attention. To date, research suggests a general increase in area burned and fire occurrence (Flannigan et al. 2000). There is a lot of spatial variability in these projections, with the greatest impacts projected for Siberia, Alaska, and west-central Canada, and with some areas expected to undergo no change or even decreases in fire frequency and area burned (Stocks et al. 1998). In the eastern Canadian boreal forest, predicted increases in burn rate will not move ecosystem conditions beyond those encountered in the past (Bergeron et al. 2010). Fire seasons are lengthening for temperate and boreal regions and this trend is expected to continue in a warmer world. Future trends of fire intensity and severity are difficult to determine owing to the complex and nonlinear interactions between weather, vegetation and people (Flannigan et al. 2009). Such shifts in fire regime will not only put human infrastructure and commercial timber at risk, but will be expressed as shorter fire return intervals, compressed forest age-class distributions, and net transfers of carbon to the atmosphere (Stocks et al. 2008). A recently developed Canadian Wildland Fire Strategy (CCFM 2005) identified a number of emerging vulnerabilities that will affect forest fire activity, impacts, and manage-

Box 14.4 More insect damage to come: the spruce budworm in Canada's boreal forest

René I. Alfaro

Natural disturbances, such as fire and insect pests, play an important role in maintaining ecological processes in the boreal forest. The spruce budworm (*Choristoneura fumiferana*) is a native defoliating insect of this forest, and one of the most important forest insects in North America. This insect feeds primarily on balsam fir (*Abies balsamea*) and white spruce (*Picea glauca)* over an extensive range of Canada's boreal forest (Kettela 1983, Figure 14.3). As a native insect, spruce budworm is always present in the Canadian boreal forest in small numbers, but the defoliation it causes during non-outbreak years is usually not noticeable. Periodically, however, the population reaches epidemic levels and extensive damage to trees can occur for several years (Blais 1985). Damage caused by the spruce budworm is of concern to forest managers because of the severe losses it inflicts to important timber and non-timber resources of the boreal forest. In addition to timber volume, budworm defoliation can negatively affect biodiversity by altering key attributes of areas set aside for nature conservation. However, effects of spruce budworm outbreaks can be highly variable depending on stand characteristics, location, and outbreak intensity (Bouchard et al. 2007). Studies in eastern Canada (New Brunswick, Quebec, and Ontario) using dendrochronology and defoliation maps suggest that spruce budworm populations cycle with an average period of 35 years (Royama 1984, Candau et al. 1998). In north-eastern British Columbia, patterns of spruce budworm outbreaks in white spruce stands were reconstructed using dendrochronology and were found to occur on average every 26 years (Burleigh et al. 2002).

Despite the large economic losses, recurrence of spruce budworm defoliation is not necessarily a sign of an unhealthy forest. As a natural component of the boreal ecosystem, budworm larvae serve as food to birds and small mammals, and ungulate wildlife benefit from forage growing in openings created by budworm-caused tree mortality. However, it is predicted that as the climate warms, there will be changes in the severity, frequency, and spatial distribution of spruce budworm outbreaks (Fleming and Volney 1995), which could drastically impact natural disturbance regimes of the boreal forest. A study on spruce budworm outbreaks in eastern Canada predicted future outbreaks to be an average of six years longer with 15% greater defoliation between 2081 and 2100 (Gray 2008). These impacts could not only have adverse effects on Canada's boreal ecosystem and forest products industry, but could also reduce the amount of carbon sequestered by boreal forests and further contribute to global warming in a positive feedback mechanism. Thus, forest managers have an opportunity to contribute to climate change mitigation by developing strategies to keep spruce budworm populations at endemic levels, such as maintaining appropriate proportions of the broadleaf trees that harbour the budworm's predators and parasites (Campbell et al. 2008). Using budworm management as a climate mitigation option requires decision support systems capable of predicting future frequency and intensity of spruce budworm outbreaks in a changing environment. These tools could guide forest management efforts to minimise impacts of spruce budworm defoliation and climate change.

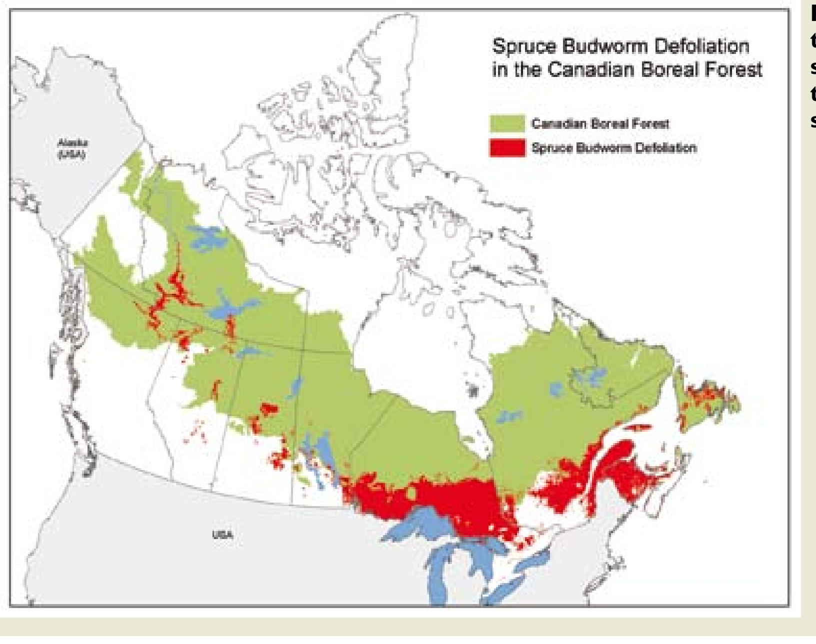

Figure 14.3 Historic distribution (1986–1996) of spruce budworm defoliation (modified from Simpson and Coy 1999).

ment in the coming decades. Many of the concerns related to increasing risk and vulnerability apply to other boreal countries as well. These vulnerabilities centre on climate change, forest health, competition for the forest land base, expanding communities, and fire management capabilities. Adaptation to more frequent and severe fire impacts will likely result in a gradual reassessment and realignment of protection priorities wherein natural fire is likely to be permitted over larger areas, while intensive protection efforts will focus more narrowly on high-value areas and resources (Stocks et al. 2008).

The prospect of a resurgence in the use of prescribed fire (for the maintenance or restoration of biological diversity) and anticipated increases in natural fires in northern forests presents a dilemma in environmental management, for those fires will release carbon dioxide from forests rather than keeping carbon sequestered (Kasischke et al. 1995, Amiro et al. 2001). There are also concerns about the vulnerability of forest communities to any increased incidence or extent of forest fires. One widespread solution being proposed (though perhaps limited in the area of forest it can influence) is to remove flammable fuels from around northern communities to reduce the risk of wildfires destroying infrastructure and private property, with small-scale processing facilities to utilise chipped or pelletised wood for the generation of heat or electricity, thereby also reducing some dependencies on petroleum products (Chapin et al. 2008).

Warmer temperatures are expected to accelerate population growth and range expansion of many forest insects and fungal pathogens (Dale et al. 2001, Logan et al. 2003), and many such trends are already being observed. In western Canada, for example, the mountain pine beetle (*Dendroctonus ponderosae*) has broken out of its core sub-boreal and montane habitats into the western boreal forest, from which it could spread into jack pine (*Pinus banksiana*) forests across Canada (Nealis and Peter 2008). While a regional glut of susceptible host (primarily lodgepole pine, *P. contorta* var. *contorta*) contributed to the outbreak that was growing since the mid-1990s, the absence of severe cold for the last several decades is largely regarded as having facilitated explosive population growth (Safranyik and Wilson 2006). Similar outbreaks of spruce beetle (*Dendroctonus rufipennis*) have killed white spruce (*Picea glauca*) in south-western Yukon and its hybrids with Sitka spruce (*Picea sitchensis*) in Alaska (Berg et al. 2006). Because the growth and reproduction of many insect and fungal pests are strongly responsive to changes in temperature and humidity, projections for a number of individual pest species suggest a risk of expansion and increased tree mortality in various regions of the circumboreal. For example, outbreaks of a defoliating Lepidopteran, the spruce budworm (*Choristoneura fumiferana*), are expected to be more frequent, more severe, and affect larger areas of Canada (Box 14.4). Similarly, Finland is bracing for an expansion of root and butt rots in conifers due to range expansion and increased virulence of *Heterobasidion parviporum* (Box 14.5). With greater frequency and areas of tree mortality due to fire, insect outbreaks, and windstorms, more and more of the harvested wood supply in many parts of the world is now being salvaged from damaged forests, a practice that can have additional environmental impacts (Lindenmayer et al. 2008).

Surface air temperatures north of 60°N have risen 1–2°C since the 1960s and 1970s, approximately twice the global average rate (McBean et al. 2005). Some changes in forest productivity and tree survivorship have already been observed, especially at the margins of the boreal forest. For example, considerable mortality of trembling aspen (*Populus tremuloides*) was noted after several dry years and a persistent outbreak of forest tent caterpillar (*Malacosoma disstria*) in the forest-grassland ecotone of western Canada (Hogg et al. 2008). In Russia, spruce species appear to be undergoing dieback in response to the combined impacts of bark beetle outbreaks, deterioration of hydrological regimes, and an apparent change in virulence of the fungal pathogens *Fomitopsis annosa* and *Armillaria mellea* (Teplyakov 2007). Hinzman et al. (2005) documented a variety of observed climate change impacts, including a steady advance of the arctic treeline into tundra, lengthening growing season, and thermokarst development (soil collapse as a result of permafrost thawing) in the boreal forests of Alaska. Within the last decade, northwestern North America experienced widespread forest fires, with a record 2.7 million ha burned in Alaska in 2004 (Stohl et al. 2006), and a doubling of annual area burned across the North American boreal forest during the last 20 years compared to earlier decades (Murphy et al. 2000); similarly, 23 million ha in Russia burned in the extreme fire year of 2003 (Teplyakov 2007).

The polar treeline of Siberian, Soyan, and Ural Mountains forests has shifted northward over the past 50 years, although the treeline has remained stable in other regions (Teplyakov 2007). Projections for climate-mediated changes over the next century are even more dramatic. For example, models of vegetation response to the Hadley general circulation model (GCM) and moderate scenarios for economic trends suggest that northern treeline boundaries with the tundra biome will advance an average of 175 km by the 2090s, ranging from about 50 km (in the Mackenzie and Lena River drainages and western Europe) to about 450 km into Greenland (Kaplan et al. 2003). Over the same period of time, climate suitable for hemi-boreal and temperate forests is projected to expand into current boreal terrain, such that the over-

Box 14.5 *Heterobasidion parviporum* in Finland: expectations for climatic change

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Historically, the climate in Finland has consisted of four distinct seasons. As climatic change is expected to increase average temperatures, winters characterised by freezing air temperatures and snow cover will decrease; summer conditions are expected to persist longer in the year. In addition, rainfall during the autumn, winter, and spring is consistently expected to increase. However, projections regarding summer rainfall are less certain: precipitation may either increase or decrease, depending on the model and scenario.

In Finland, *Heterobasidion parviporum* is economically the most important tree disease, causing root rot and butt rot in mature conifers (Tamminen 1985). Its distribution in the country is primarily southern, and the fungus is only rarely observed in the northern parts of the country. The reasons for the southern distribution of *H. parviporum* are not clear. It could be due to (a) the climatic demands of the fungus, (b) the soil type, which in northern parts of the country is dominated by peatlands compared to mineral soils in south, or (c) simply due to the short history of intensive forest utilisation and management in northern Finland.

The spread of the *H. parviporum* to new forest sites is based on spore dispersal to fresh stump surfaces during the summer (phase I), after which the disease moves through the root systems to neighbouring trees (phase II). Phase I of the disease can be controlled by the timing of cuttings (as no spore dispersal occurs in winter), or, in the summer, stump surfaces can be protected by biological or chemical deterrents. Removal of stumps from the cutting area will also decrease infection by spores (Piri 2003), although this method can be expensive and contributes to the loss of dead wood from the forest ecosystem. Control of phase II *Heterobasidion* spread is more problematic. Tree species rotation (i.e., growing hardwood species instead of conifers) would be effective in limiting the spread of *H. parviporum* (Piri 2003), but the grazing of moose (*Alces alces*) often causes considerable damage, and therefore forest owners are not interested in hardwood plantations. The desirability of alternating tree crops is also constrained by the lower value land owners can expect from the sale of hardwood logs compared to conifer logs.

Climate change is expected to affect *H. parviporum* in several different ways. A shortening of the winter season will increase harvest operations in the summer, when infection by spores can occur. Also, more damage is caused by machinery as tree roots are less protected by snow and frozen ground. Both of these factors create more dispersal routes for *H. parviporum*, which simultaneously is expected to have a longer spore production season and accelerated mycelial growth rates. Both mycelial growth and spore production are partially temperature-dependent, so the warming and lengthening of the summer season will increase the spread and virulence of *H. parviporum*. This may be partially compensated for by accelerated growth rates for some tree species on some sites, which could lead to reduced rotation times and a reduced chance of fungal infection at fatal levels.

Finally, wind storms are expected to increase in Finland with climatic warming. Forest susceptibility to damage will be directly connected to the extent of root rot and butt rot, as trees with decayed root systems are more susceptible to wind throw than healthy ones. Blowdown of diseased trees will create openings in the forest, and allow strong winds later to bring down nearby healthy trees as well. Further, this will have a direct effect on the spread of *H. parviporum*, as the fungus can use stumps left from wind throw to start new infections. This, in turn, increases the susceptibility of forest trees to strong winds, inducing a positive feedback system of increasing damage.

Overall, most of the effects of the expected climatic change in Finland seem to benefit *H. parviporum* species if no preventive human actions are taken. In order to block the resulting forest deterioration, forest owners should be motivated to use the control actions already available to retard the spread of the fungus. Furthermore, the research and innovation sector should be supported in its efforts to develop novel means to remove the disease from already contaminated growing sites.

all area of boreal climate in Russia is expected to decline by 19% (Krankina et al. 1997). A linear trend analysis suggests that ice roads (built over lakes, bogs and mires, as well as solid ground) in Canada's Northwest Territories, which now provide an average 65-day period of safe travel, will only support an average of 54 days of safe travel per year by 2020 (McGregor et al. 2008). Sub-arctic ponds have been decreasing in area, apparently as a result of increased evaporation rates associated with warmer temperatures (Riordan et al. 2006). Other examples include reduced growth rates of white spruce in some parts of Alaska, apparently as a result of heat stress (Barber et al. 2000), although improved growth and treeline advancement might be expected in eastern Canada, where moisture is less limiting. Across boreal North America, the trend of satellite-sensed photosynthesis rates since 1982 has been largely negative (Goetz et al. 2005). All of these trends are expected to continue and intensify over the course of the 21st century (see Section 2.2.2 for the impacts of climate change on the world´s forests).

14.3.3 Forest Ecosystem Management in Canada

At the end of the last century, the Canadian Council of Forest Ministers embraced a commitment to sustainable forest management (SFM) (CCFM 1995), reflecting the growing adoption of legislation and policies that promoted broader concepts of sustainable forestry (e.g., BCMF 1995). Since then, several Canadian jurisdictions (e.g., OMNR 2001, QMNF 2009) have actively promoted the emulation of natural disturbances as a guiding principle in forest management. There is an increasing will to modernise the traditional forest management model and to ensure that ecosystem management is at the centre of public forest management. Despite the interest in ecosystem-based management and some experimental implementation, its practical aspects are not fully developed, and it plays a limited role to date in the managed forests in Canada's boreal zone (Gauthier et al. 2009).

Ecosystem-based forest management is based on sound knowledge of natural forest dynamics. Forest dynamics are characterised by long-term disturbance regimes (various combinations and severity of fire, wind, insect outbreaks, etc.) and by stand structure and composition changes following these disturbances. Development and implementation of management strategies based on natural forest dynamics include several steps and options, including the determination of a regionally appropriate age class distribution (Box 14.1), forest composition, internal stand structure, spatial configuration at stand and landscape levels, maintenance of soil productivity, and the protection of key biotopes and microhabitats (Gauthier et al. 2009).

One of the main ecosystem management objectives is to ensure that forestry allows for some variability within a system's natural historical range of variation. In recent years, observed differences between natural landscapes and those generated by forestry led to the identification of critical differences between natural disturbance regimes and forest management regimes (Cyr et al. 2009, Jetté et al. 2009). Important issues for biodiversity preservation were identified, for instance, in Eastern Canada and Fennoscandia, such as the loss of mature and old-growth forests that dominated in natural forest landscapes, the loss of large forest landscapes to increased landscape fragmentation, low levels of green tree and structural retention within managed areas compared with naturally disturbed landscapes, and the absence of fire as a catalyst for nutrient recycling in some regions (Gluck and Rempel 1996, Angelstam 1998, Imbeau et al. 2001). To address these differences, various practices have been proposed, such as aggregating and increasing spacing between cutting areas in order to maintain larger areas of continuous forest, increasing retention in cutblock layout and in vegetation control, variable rotation lengths, and using soil scarification and controlled burning for site preparation and ecological restoration (Bergeron et al. 1999, Spence 2001, DeLong 2002, Hauessler and Kneeshaw 2003, Angelstam and Kuuluvainen 2004). Unfortunately, few statistics are compiled and reported on the extent to which these alternative practices have been adopted.

There are some problems impeding the practical development and implementation of ecosystem management concepts in the world's boreal forests:

(1) the need for detailed spatially explicit data on ecosystem (soil, biota, climate) and natural disturbance regime (event size, frequency, selectivity, severity) attributes, rarely available on an operational basis or over large areas;
(2) large management areas and high labour costs result in a standard mid-intensity approach (i.e., clearcut logging, which translates to high disturbance intensity at the canopy level, coupled with forest practices guidelines and widespread winter logging that promote low disturbance intensity at the soil level) being applied to the whole territory rather than practices being well adapted to local ecosystem particularities;
(3) a small number of forest specialists having experience with uneven-aged silviculture, variable retention and other partial cutting methods suitable for application in boreal forests, or whose training is sufficiently appropriate to guide management based on local ecosystem dynamics; and
(4) reluctance on the part of regulatory agencies and environmental groups to accept large clearcuts (with variable levels and configurations of retention) that more closely match the scale and variability of natural forest fires.

There are three pilot projects in Quebec where formal implementation of the ecosystem management approach is ongoing: the Tembec project (Belleau and Légaré 2009), the Triad Project in central Québec, and the Laurentian Wildlife Reserve project. The Triad Project has been underway in the Haute-Mauricie region since 2003. Initiated by a multi-sectoral table in the Mauricie and coordinated by the forest industry (AbitibiBowater), this pilot project aims to apply the concept of triad zoning, i.e., spatially organising forest management activities according to three alternative priorities so that different portions of the forest are dedicated mainly to 1) wood or fibre production, 2) ecosystem management, and 3) conservation. Further details on this approach are provided in Chapter 22.

Another project in the Laurentian Wildlife Reserve, managed by the Ministère des Ressources Naturelles du Québec (MNRF), aims to develop an adaptive forest management approach that uses forest ecosystem management as a reference point (Leduc et al. 2009). To date, the main differences between natural and managed landscapes have been identified and strategies to minimise these differences have been presented for preliminary public consultation. Moreover, diverse silvicultural trials have been established. The Tembec project has produced its first ecosystem management plan (Belleau and Légaré 2009). Since 2007, two strategies have been tried operationally before their large-scale application: 1) the implementation of a logging area trial where one of the harvesting treatments aims to maintain residual forest; and 2) trials using adapted silvicultural practices that aim to conserve the cover and attributes of old-growth forests. For each trial conducted in the area, a direct follow-up with regard to costs, outputs, and environmental impacts is made. The achievement of the initial objectives will also be evaluated and strategies adjusted so that the global strategy more fully addresses the landscape management issues of the forest management unit. An analogous large-scale EBM-inspired trial can be found in western Canada at the >1000-ha EMEND research site in north-western Alberta (Work et al. 2004; see EMEND 2006).

In other locations across Canada, several forestry companies have begun to integrate forest ecosystem management principles into harvest planning. For instance, Tembec in Ontario (see Tembec 2010), Mystik Management Ltd. in Saskatchewan (see Mistik 2010), and Alberta-Pacific Forest Industries Inc. in Alberta (see Al-Pac 2010) have implemented strategies inspired by natural disturbances in their forest management planning. In much of British Columbia, the use of clear-cutting with reserves, snag retention, and cutblock aggregation have become standard operating procedures (DeLong 2002, Work et al. 2003). Numerous advantages, including improved potential for forest certification, ensure that companies have much to gain by integrating an ecosystem management approach into their planning and operations.

14.3.4 Different Management Imperatives Where Commercial Forestry Does Not Prevail

Forest ecosystem management takes on different forms in different parts of the circumboreal forest, reflecting regional ecologies and economies. Alaska, for example, is a distinctive part of the North America boreal forest region from biophysical, ecological, and socioeconomic standpoints. Interior valleys experience persistent cold air inversions and are usually permafrost-dominated black spruce woodland or stunted forest, while low elevation sites on the floodplain terraces of major rivers and slopes near major rivers covered with thick loess deposits support productive forests. Because of this landscape heterogeneity, few parts of boreal Alaska support unbroken forest canopy. Alaska supports numerous plant and animal species not found elsewhere in the Americas, in part due to its biogeographic history as an ice-free refugium during the Pleistocene and its proximity to Asia. Alaska has become widely known for its wildlife and scenery, and the large established parks, refuges, and wilderness areas are assets for tourism, scientific study, and provisioning traditional users in their homeland.

As in the neighbouring Yukon and Northwest Territories, and in much of northern Ontario and Quebec in Canada, the sporadic, isolated occurrence of productive forest sites in interior Alaska has been a significant disincentive to investments (road access, processing facilities, etc.) required for large-scale commercial timber production. In the boreal zone of Alaska, the area of forest totals 46–66 million ha (as variously defined), of which only about 12% is of potential commercial value. The largest national parks and national wildlife refuges in the USA occur in Alaska. The proportion of protected forest land is higher in Alaska (about 40%) than anywhere else in the boreal region (Juday 1997). At least 25% of Alaska's most productive boreal timberland is reserved by law from forest harvest (Labau and Van Hess 1990). No single goal of management dominates the use of the Alaskan boreal forest, notably not commercial timber harvesting and production.

Natural disturbances, particularly insect-caused tree death or defoliation and wildland fire, and not forest management, overwhelmingly predominate in non-commercial boreal forests around the world. Large wildland fires are a regular feature of summers in interior Alaska, and the last decade has included several years of more than 1 million ha burned. Nearly two-thirds of interior Alaska is maintained under an essentially natural fire regime of negligible suppression activity, many large lightning-caused fires, and few human ignitions. About 17% of interior Alaska is zoned for fire suppression because of the presence of communities and roads, and this suppression effort has been demonstrated to have effectively achieved a 50% reduction in the proportion of area burned from 1992 through 2001, compared to areas without suppression (DeWilde and Chapin 2007). The remaining 16% of land receives some suppression and experiences an intermediate fire regime.

There is a small-scale wood industry in Alaska, but the volume of wood needed to supply it can be met with a very small fraction of the allowable harvest. This has created a unique situation in which most Alaska residents live in a forested environment, but are not dependent on timber harvesting for their livelihood, and many see industrial harvesting as contrary to their interests. As a result, there is no consensus to expand forest harvest nor to establish or expand forest products processing in Alaska. However, there is a working consensus that the high cost of energy in rural Alaska, especially where petroleum or major hydroelectric systems are not practical, represents a potential application for renewable biomass energy facilities and forest management programs to feed them. Similar community-centred initiatives are under way in Yukon and the Northwest Territories; this means that many areas of taiga, considered commercially inoperable a decade ago, may soon be brought under management, with employment opportunities in woodland and processing operations.

The philosophy of environmental protection found in Alaska can also create cumbersome review and approval processes that can, for example, pose significant challenges for even widely supported goals and projects such as renewable energy facilities. But looming as a question over all activities and future plans is the scale and pace of climate change effects that are already evident and that are expected to continue. For example, the apparent drying of wetlands across nearly all of Alaska (Riordan et al. 2006) appears to interfere seriously with benefits of a network of wildlife refuges. Efforts at developing alternative economic activities in Alaska, and throughout the circumboreal region, seem particularly sensitive to the state of the world economy, the price of petroleum, and the vagaries of climate.

14.3.5 The Boreal Position in the Global Economy

The future of forest product industries in the boreal region is uncertain and varied. One possible driver of change may be global efforts to constrain greenhouse gas concentrations in the atmosphere. A carbon-constrained world will challenge forest managers to rebalance management priorities and still achieve SFM goals. If climate change mitigation policies are fully adopted worldwide, this will provide an incentive to maintain and enhance biological carbon stocks on the one hand, but (in the drive to use renewable rather than petroleum-based energy and raw materials) increase demand for wood and fibre products on the other. The net effect on the boreal forest industries is not clear. Not knowing the exact rules of a future global climate mitigation framework or to what extent increased demand for wood products will be met by supply in non-boreal regions means the future structure and size of boreal forest industries is particularly uncertain.

14.4. Social, Economic, and Institutional Trends

There is considerable geographic variation in the development opportunities and challenges faced by boreal forests and boreal communities, and in their ability to absorb expected changes. Fennoscandia is embarking on modest programs of biodiversity conservation and forest restoration, supported by a strong infrastructure and community capacity. North American boreal forests remain largely intact, with strong regulatory frameworks, and economically and socially sustainable communities in place, but with the prospect of massive resource developments. Northern Russia still seems to be coping with problems of under-regulated industrial impacts coupled with social problems (Forbes et al. 2004).

A recent component of the social equation affecting public demands and expectations associated with boreal forests is the focused attention of many international environmental non-governmental organizations (ENGOs). These recent environmental protection efforts highlight wilderness values and ecosystem services as much as conservation of biodiversity. For example, the Canadian Boreal Initiative (Canadian Boreal Initiative 2010) was launched in 2003 with considerable underwriting from the Pew Foundation based in the USA; it has mobilised industry, other ENGOs, and public opinion to promote the designation of protected areas and sustainable resource management. Even while other parts of Canada's boreal forest are still being brought under industrial development for timber production or other primary resources (e.g., Schneider 2002), Canadian governments have subsequently expanded protection for wild boreal landscapes. In July 2008, the government of Ontario announced its intention to protect 225 000 km^2 under its "Far North Planning Initiative." In March 2009, the government of Québec announced that it would be doubling its protected areas network to 8.12% of the land area, with the goal of protecting 12% by 2015, primarily through additions in boreal and subarctic regions. In June 2009, the Canadian federal government and the Dehcho

First Nation jointly announced legislation to increase the area of Nahanni National Park (Northwest Territories) by more than six times. Global Forest Watch Russia (Global Forest Watch 2010) and Greenpeace Russia (Greenpeace Russia 2010) are active in raising greater awareness of Russia's forest resources and sustainable forest management issues. However, there has been little protection offered to wild forest landscapes in Russia over the last 15 years.

Indigenous peoples across the boreal forest have formed alliances with ENGOs and have joined them in various campaigns for wilderness protection and improved forestry standards (Holmes 2003). There has also been progress in reconciling their needs for sustainable access to both subsistence resources and to good jobs, primarily by means of joint ventures and co-management agreements between forest companies and First Nations (Natcher 2008).

14.4.1 Enforcement and Encouragement of Higher Forestry Standards

There is some debate in many boreal countries on whether current timber harvesting levels (including the illegal logging that occurs in some jurisdictions) are justifiable in the light of environmental goals, biodiversity protection, and principles of SFM. A consciously non-renewable approach to timber harvesting is rare today, but has been problematic in the past in regions where governance structure or oversight was poor or where forest growth and renewal were poorly understood. Illegal logging, in particular, can compromise local and regional conservation plans, sustainability of the timber supply, and the generation of government revenues. A Europe and Northern Asia Forest Law Enforcement and Governance (ENA FLEG) Ministerial Conference in 2005 addressed some of these issues. The Russian government adopted a national action plan to combat illegal logging and promote more domestic processing of wood products (Box 14.3). The Russian Federal Forestry Agency was assigned to follow this plan and introduce a monitoring system over the vast area of Siberia and the Russian Far East using aerial surveys and ground labelling in support of certification schemes, among other means. Climate change is another significant issue affecting the projected sustainability of timber supplies in many boreal jurisdictions because losses due to the incidence, severity, and extent of pests and wildfire could be unpredictably high.

There are positive trends in boreal forest management, including the development of new approaches to forest management based on participation of interested parties in decision-making, landscape-level planning, community-based forest management, and partnerships between industrial and aboriginal organisations (Burton et al. 2006, Teplyakov 2006). The Model Forest concept, initiated in Canada in 1990 and since extended to 17 countries, promotes innovative and exemplary community-based approaches to SFM (see IMFN 2008). Many countries are reviewing national forest policies towards sustainable forest use (e.g., national action plans against illegal logging within the ENA FLEG Ministerial process), are introducing principles of forest ethics, and are developing and implementing best management practices to shift towards the protection of ecological values (Saint-Laurent et al. 2005).

The last decade has seen global expansion of the use of third-party forest certification to demonstrate to markets that wood and paper products are being produced from sustainably managed forests. Many northern forest products companies and jurisdictions have joined the certification movement to be competitive in the international arena. In Europe, the most widespread forest certification takes place under the Pan-European Forest Certification (PEFC) Sustainability Benchmark and the Forest Stewardship Council (FSC) system. In North America, the USA-led Sustainable Forestry Initiative (SFI), and the Canadian Standards Association (CSA) have certified much of the timber production lands of boreal and sub-boreal Canada. For more information on the certification of forests and forest products, see Section 23.5.1 and MetaFore (2007).

Russia has recently made progress in integrating the principles of planning and sustainability into its forest policies and practices. Russian forest policy has been characterised by a tension between centralised vs. local authority, and the reassertion of administrative and professional control after almost two decades of poorly regulated forest exploitation after collapse of the Soviet Union. Upon adoption of the Forest Code of the Russian Federation in 2006, a period of decentralisation began, which has its advantages and disadvantages. The emerging trends and challenges in Russian forest administration and management consist of:

- a more decentralised system of forest management;
- an expanded list of forest types considered suitable for timber utilisation;
- more opportunity to use forest lands for infrastructure development and mining;
- the identification of priority investment areas to promote forest utilisation; and
- preparation for the introduction of long-term forest tenures (leases).

The new Forest Code of the Russian Federation, in effect since January 1, 2007, became fully operational in 2009; it consists of more than 60 legal instruments altogether. To date, there have been six amendments to the Code, most recently in March 2009. The system of forest management has been fundamentally changed. In the near future, it is supposed to resolve issues concerning new regulations for final and intermediate harvesting, the role of green zones near settlements, the designation of protection forests, and so on. It is proposed that about 16 decisions or orders of the Government of the Russian Federation need to be passed, and about 30 supporting documents of the Russian Ministry of Agriculture remain to be adopted in order to complete the bylaws to the Forest Code (Giryaev 2009).

14.4.2 Climate Change Adaptation and Sustainable Forest Management

While there is considerable research documenting current and projected impacts of climate change on the boreal forest, discussion on how, when, and where to adapt boreal forest management to climate change is relatively limited. Adaptation seeks to reduce or moderate risks associated with climate change and is important in the boreal forest for three reasons: 1) climate change is already occurring in this region and is having an impact on forest ecosystems and forest-dependent communities; 2) even with aggressive measures to control greenhouse gas emissions, current atmospheric concentrations of carbon dioxide mean that warming will continue regardless; and 3) proactive approaches to adaptation are more likely to avoid or reduce negative consequences of climate change than are reactive responses.

Forest management can reduce vulnerability to climate change by increasing resilience and enhancing adaptive capacity, but climate change, in turn, will complicate the ability to achieve SFM (Innes et al. 2009, Seppälä et al. 2009). While the scale and scope of climate change effects on forest ecosystems are not fully appreciated, the reality of climate change poses some basic questions about our fundamental management paradigms. Can sustainability be assured or even aimed for under changing conditions and a newly uncertain future? Is strong sustainability (i.e., the sustained protection or production, at some level, of all current values; Neumayer 2003) an appropriate goal for forest management? Regardless, the principles and practices of SFM embody many of the activities that will be required to respond to the effects of climate change on forests (Spittlehouse and Stewart 2003, Ogden and Innes 2007). Failure to implement SFM limits the capacity of forests and forest-dependent people to adapt to climate change. To meet the challenges of adaptation, ongoing commitment to achieving the internationally recognised goals of SFM for the boreal forest is needed at all levels (Hall 2001, Seppälä et al. 2009).

A logical starting point for climate change adaptation in the forest sector is to proactively identify management practices and policies that have a higher likelihood of achieving management objectives across a wide range of potential climate futures (Ogden and Innes 2007, 2008); one small example is provided in Box 14.6. Another example is the implementation of policies for the facilitated migration of tree species and seed lots (Krankina et al. 1997, McKenney et al. 2009). Such policies are being designed in a "no regrets" context (Heltberg et al. 2009) so that results will be satisfactory regardless of whether or not climate changes unfold as predicted (Table 14.5). Because of the uncertainties involved, such programs must include monitoring of their effectiveness in an adaptive management context.

An effective policy for climate change adaptation must be responsive to multiple objectives. This is particularly true for the boreal forest sector, where socioeconomic and environmental systems are intricately linked. Adaptation strategies are more likely to be successful if they are mainstreamed into existing decision-making processes (Ford et al. 2006), and if they are developed by local actors who are more likely to ensure their consistency with local priorities, norms, goals, and institutions (Lim and Spanger-Siegfried 2005, Chapin et al. 2006).

The diversity of forest conditions, climate change impacts and vulnerabilities, and management objectives across the boreal, and the uncertainties involved in making projections about how climate will change at a particular location, make it unfeasible to provide prescriptive recommendations for how to adapt forest management practices and policies. Since there is no universally applicable measure for adapting to climate change, boreal forest managers should have sufficient flexibility to deploy the adaptation measures that are most appropriate for their local situations (Innes et al. 2009, Seppälä et al. 2009). This flexibility is typically expressed through the dual promotion of diversity and adaptive management: (1) diversification of crop trees, stand structures, silvicultural practices, saleable goods and services from the forest, wood products, and markets; and (2) monitoring mechanisms to evaluate the ongoing suitability of forest practices and policies, coupled with receptivity to make adjustments in response to new realities.

Krankina et al. (1997) recommend a set of adaptive measures for Russian forest management, which can be considered widely applicable. These include: (1) greater use of artificial reforestation and afforestation to facilitate northward migration of species and provenances; (2) silvicultural measures to influence the species mix of stands and to maintain productivity under future climates; (3) identifying forests at risk (from climatic stress, pests, or fire) and devel-

Table 14.5. Summary table of no-regrets adaptation measures* identified by practitioners for the Forest Management Zone in the Champagne-Aishihik Traditional Territory, south-western Yukon. No-regrets measures were defined as those considered by the group of practitioners as a whole to be important to implement across a wide range of possible future climate conditions.

Objectives of sustainable forest management	Impact of climate change on ability of forest practitioners to achieve management objective	No-regrets adaptation measures identified by practitioners for the Champagne-Aishihik Traditional Territory to aid in reaching management objective in light of current and projected climate change
Conserve biological diversity	Alteration of plant and animal distribution	Minimise fragmentation of habitat and maintain connectivity
	Increased frequency and severity of forest disturbance	None noted
	Habitat invasions by non-native species	None noted
Maintain productive capacity of northern forest ecosystems	Increased frequency and severity of forest disturbance	Apply silvicultural techniques that maintain a diversity of age stands and mix of species
	Species are no longer suited to site conditions	None noted
	Decreased forest growth	Minimise disturbance to forest soils
	Invasions by non native species	None noted
Maintain the health and vitality of forest ecosystems	Increased frequency and severity of insect and disease disturbance	None noted
	Decreased health and vitality of forest ecosystems due to cumulative impacts of multiple stressors	None noted
Conserve and maintain soil and water resources	Increased soil erosion due to increased precipitation and thawing of permafrost	Minimise density of permanent road network to maximise productive forest area and forest sinks Deactivate and rehabilitate roads to maximise productive forest area and forest sinks
	Increased terrain instability due to extreme precipitation events or thawing of permafrost	Avoid constructing roads in landslide-prone terrain where increased precipitation and thawing of permafrost may increase the hazard of slope failure Maintain, decommission, and rehabilitate roads to minimise sediment runoff due to increased precipitation and thawing of permafrost
	More/earlier snow melt resulting in changes in the timing of peak flows and volume in streams	None noted
Maintain forest contributions to global carbon cycles	Decrease in forest sinks and increased CO_2 emissions from northern forested ecosystems due to declining forest growth and productivity	None noted
	Decrease in forest sinks and increased CO_2 emissions form northern forested ecosystems due to increased frequency and severity of forest disturbance	None noted

* measures which will be beneficial regardless of future climate change.

Source: Ogden and Innes 2009a

Objectives of sustainable forest management	**Impact of climate change on ability of forest practitioners to achieve management objective**	**No-regrets adaptation measures identified by practitioners for the Champagne-Aishihik Traditional Territory to aid in reaching management objective in light of current and projected climate change**
Maintain and enhance long-term multiple socio-economic benefits to meet the needs of societies	Decreased socio-economic resilience	Foster learning and innovation, and conduct research to determine when and where to implement adaptive responses Diversify forest economy, e.g., explore deadwood product markets, value-added products Diversify regional economy (non-forest based) Diversify the regional economy by promoting non-timber forest products Enhance dialog among stakeholder groups to establish priorities for action on climate adaptation in the forest sector
	Increased frequency and severity of forest disturbance	Protect higher-value areas from fire through "fire-smart" techniques Increase amount of timber from salvage logging of fire- or insect-disturbed stands Review forest policies, forest planning, forest management approaches and institutions to assess our ability to achieve social objectives under climate change; encourage societal adaptation Include risk management in management rules and forest plans, and develop and enhanced capacity for risk management Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions in regard to fuels management and community protection
Ensure the appropriate legal, institutional and economic framework is in place for forest conservation and sustainable management	Forest management plans and policies lack the flexibility that is required to respond to climate change	Practice adaptive management – a management approach that rigorously combines management, research, monitoring, and means of changing practices to gain credible information and modify management activities by experience. Measure, monitor, and report on indicators of climate change and sustainable forest management to determine the state of the forest and identify when critical thresholds are reached. Evaluate the adequacy of existing environmental and biological monitoring networks for tracking the impacts of climate change on forest ecosystems, identify inadequacies/gaps in these networks, and identify options to address them.
	Forest management plans and policies enhance the vulnerability of forests and forest dependent communities to climate change	Support research on climate change, climate impacts, and climate adaptations and increase resources for basic climate change impacts and adaptation science. Support knowledge exchange, technology transfer, capacity building, and information sharing on climate change; maintain or improve capacity for communications and networking. Incorporate new knowledge about the future climate and forest vulnerability into forest management plans and policies. Involve the public in an assessment of forest management adaptation options.
	Forest management policies and incentives do not encourage adaptation to climate change	None noted

Box 14.6 A Case study of sustainable forest management in a changing climate: Champagne-Aishihik Traditional Territory, South-west Yukon, Canada

Aynslie Ogden

There is accumulating evidence that climate change is having an impact on forests and forest-dependent communities in the Champagne-Aishihik Traditional Territory of south-western Yukon. This region, characterised by large tracts of mature white spruce (*Picea glauca*), has experienced the largest and most intense recorded outbreak of spruce beetle (*Dendroctonus rufipennis*) in Canada. Climate conditions have played a critical role in increasing the population of beetles to epidemic levels and weakening the defences of the spruce trees. Widespread mortality of white spruce has led to the loss of merchantable timber, significant changes to the regional ecology, increased flammability and extent of forest fuels, and heightened vulnerability to wildfire.

The beetle infestation has driven forest management and planning in this region since the mid-1990s. In November 2004, the Government of Yukon and the Champagne-Aishihik First Nation approved the first community-directed strategic forest management plan in the Yukon that identifies reduction of fire hazard, forest renewal, economic benefits, and preservation of wildlife habitat as forest management and planning priorities. While the plan incorporates some examples of "best management practices" for sustainable forest management that are consistent with appropriate climate adaptation responses (Ogden and Innes 2007), the plan does not explicitly identify climate change vulnerabilities and actions that will be taken to reduce those vulnerabilities and manage risks. As such, the plan is characterised as a "Reactive-Indirect" plan, with respect to how it addresses climate change (Ogden and Innes 2008).

An examination of forest management actions that could be undertaken to reduce the vulnerability to climate change of forest ecosystems and the people and economies that depend on them was undertaken (Ogden 2007). Activities included a workshop on "Our Changing Boreal Forest," hosted by the Champagne-Aishihik First Nation and the Alsek Renewable Resource Council, and involving local residents, governments and management agencies, and researchers (McKinnon 2006). The workshop outcomes provided a foundation for a preliminary research framework to support forest management decision-making in the changing climate of south-western Yukon (Ogden and Innes 2009b).

Research also has been conducted to document the perspectives of local forest practitioners on the effectiveness of forest management adaptation options under a range of potential future climate conditions (Ogden and Innes 2009a). In this study, practitioners identified 24 adaptation options that they considered important to implement in order to achieve the regional goals and objectives of sustainable forest management in light of climate change (Table 14.5). The following targeted research needs were also identified: 1) local residents highlighted the importance of formalising a monitoring network based on local knowledge as part of a broader adaptive management framework; and 2) practitioners expressed a need for research to identify forest management tactics that would enable them to achieve community-directed forest management objectives in light of climate change (Ogden and Innes 2009b). In this region, climate change is providing the impetus and a forum for discussion on the need for more comprehensive research and monitoring programs to support the sustainable management of forest resources.

oping special management adaptation measures for them; (4) alternative products, processing, and uses of wood and non-wood products from future forests; and (5) evaluation of infrastructure and transport systems (especially in thawing permafrost zones) for maintenance, reconstruction, and rerouting needs.

14.5. Conclusions – A Boreal Prospectus

Boreal forests, forest industries and forest communities are largely sustainable even in the face of changing physical and economic conditions, even though individual regions face particular challenges. Climate change and its effects are already evident in the world's boreal forests. But large areas of wilderness and dominance by wide-niched and disturbance-adapted species suggest that the boreal biome has good capacity for resilience and adaptation. Limited agricultural capabilities, long distances from markets, and historic dependence on a few primary industries may threaten the stability of local economies, but northern communities (especially indigenous ones) are exhibiting a new assertive involvement in planning and development. Because boreal forests worldwide are primarily on public land, in regions with low populations, and few competing land uses (at a worldwide level), there is an opportunity to act proactively through landscape and regional planning, integrated multi-sectoral land management, and alternative models of governance that collectively facilitate adaptation to shifts in climate and markets.

Many boreal jurisdictions are already considering climate change adaptation measures for forestry, such as facilitated migration of crop tree species and seed lots, coupled with programs of genetic conservation. Much of the world's boreal region can be expected to continue as generally low-productivity but large areas of forest managed for fibre production by native trees. This boreal model of extensive forestry, with few silvicultural interventions and comparatively long rotations, may have a relative advantage from environmental and sustainability perspectives (Booth et al. 1993). There also exists the (as yet largely unrealised) potential to manage disturbance frequency and severity to approximate those of natural disturbance regimes under a program of ecosystem-based management. Such a management regime facilitates protection of ecological processes and wilderness values while extracting commodities and promoting sustainability in the international marketplace.

Additional research is required to reduce current uncertainties about the impacts of climate change on boreal forests, and to improve knowledge about the effectiveness of alternative management and policy measures. Even if adaptation measures are fully implemented, unmitigated climate change would, during the course of the current century, exceed the adaptive capacity of many forests. Global efforts to reduce greenhouse gas emissions are needed to ensure that boreal forests retain their mitigative and adaptive capacities. We must not forget the global responsibility of maintaining (or, preferably, enhancing) the role of boreal landscapes in sequestering greenhouse gases. It is estimated that approximately 35% of the world's carbon is currently stored in boreal forests and soils (Kasischke et al. 1995), with stocks found in peatlands especially uncertain and especially vulnerable to thresholds of temperature and moisture. Consequently, management policies and practices that result in a net loss of carbon dioxide or methane from northern forests, peatlands, and soils must be avoided if at all possible. Despite relatively low productivity (and hence low carbon fixation) rates, boreal forests have the capacity to both sequester additional carbon and to retain that carbon for a long time. The challenge is to find the right balance in each landscape between those young growing forests and the old forests that contain high carbon stocks (Kellomäki 2000). Targeted management practices, such as enhanced fire protection around high carbon stocks and the promotion of higher stocking throughout a rotation (Garcia-Gonzalo et al. 2007), can demonstrably increase carbon sequestration and retention in boreal forests.

The comparative advantage of boreal forests and forestry (slow-growing, strong fibre, forest harvesting sustainable while maintaining ecological processes and wilderness attributes) can be expected to persist in the global economy, though not from all boreal regions at all times. Many northern communities would benefit from diversification and education to enhance their adaptive capacity and global competitiveness, and thereby avoid some of the risks of unemployment and wide population swings associated with single-industry dependence. For large areas of the circumboreal region in which commercial forestry is not viable now or in the foreseeable future, the land may have greater value in supporting carbon sequestration, freshwater retention, wilderness, and wildlife habitat than for the production of timber or pulp. Although a potentially renewable alternative to fossil fuels, current initiatives to develop a wood-based biofuel sector should consider the sustainability of forest production and renewal.

Despite a superficial similarity in composition, structure, and driving factors around the world, the world's boreal forests are a collection of social-ecological systems representing a wide range of challenges and opportunities (Forbes et al. 2004, Angelstam et al. 2007). In addition to regional differences in historical climate and current climatic trends, there is also a diversity of socio-political histories and cultural values found throughout the circumboreal region. The last decade or two has seen some dramatic shifts in biophysical and socioeconomic considerations for forest management, and the coming decades can be expected to be just as dynamic. In Europe, for example, we are seeing a changing emphasis on forest values both in western countries, where more environmental values are now espoused, and in eastern countries, where commercial potentials are being explored along with a renewed commitment to timber sustainability (Angelstam et al. 2005). The intensively managed forests of Fennoscandia provide a warning to other boreal jurisdictions that industrial efficiencies may be achieved at the expense of biodiversity, while the wild forests of Russia and Canada provide important templates for restoration and ecological management. In all circumboreal socio-ecological regions, however, there seem to be modest stepwise movements to the "triple-bottom line" approach – i.e., with equal consideration to environmental and social benefits as well as economic ones – in evaluating industrial proposals and new government policies in an effort to achieve sustainability and adaptive governance.

Forest researchers, managers, and policy-makers will be facing some challenges and dilemmas in the years to come. For example, reliable statistics compiled not only by political jurisdiction, but by ecological region as well, are difficult to come by, yet are essential to gauge the state of sustainability of a biome. Other issues centre on how much managers can or should resist forest loss associated with local climate shifts and land use change. For example, if ecosystem conversion from forest to parkland or grassland is projected as being warranted in adjustment to the future climate, are we actually engaged in sustainable environmental management? Is strong sustainability a reasonable goal in times of high disturbance risk or dramatic environmental change? Perhaps the spatial scales over which we evaluate sustainability need to be reconsidered at the same time as we implement adaptive practices. The organisms and ecosystems we manage today probably faced similar or analogous challenges in the past. The difference today is that humans have already constrained the viability of many populations and have fragmented the continuity of habitat over large areas. In addition, we have constructed complex infrastructure and economies based on the status quo, so are less flexible in our response to a changing environment, though we are also potential agents of action to mitigate changes. The challenge is to improve our ability to make decisions in a changing world and to be wise enough to make the most constructive and adaptive choices.

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