The Heat is on in the Northern Exposures

The Dalton Highway in Alaska runs through a boreal forest, livened her by fall colors. Photo courtesy Dennis R. Green, BLM

By Valerie Brown
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"With every day that passed came more news: the river Yenisei was free of ice, and at this time of year, too...[T]he port at the mouth of the Yenisei River in chaos, with fishermen trying to sell their meager catches of unknown kinds of fish to the canning factories; with shipowners angry about the harbor charges the authorities had raised to cope with the floods; and with hunters and fur trappers drifting into town unable to work because of the rapidly thawing forest and the disordered behavior of the animals."

Thus reads a passage in Philip Pullman's *The Subtle Knife,* the second book of the fantasy trilogy *His Dark Materials.* In Pullman's world, natural processes, especially in the northern climate, have been abruptly disturbed by human action. The same thing is happening in our world, although not by the same methods. Yet because the earth's climate is changing fastest in the poleward latitudes, where relatively few people live, most remain only dimly aware of the magnitude of the change.

In North America, between about fifty and seventy degrees north latitude, lies a vast swath of trees called the boreal forest (from Boreas, the ancient Greek god of the north wind). The forest stretches from eastern Alaska all the way to Canada's Maritime Provinces, encompassing approximately 1.4 billion acres—more than 2 million square miles, or nearly half the country's land area—in Canada alone. The Alaskan portion is almost 110 million acres—171,000 square miles. The same type of forest blankets northern Scandinavia and Russia.

Climate change is well under way in the boreal forest, creating a cascade of effects for the entire ecosystem. Unfamiliar land animals and fish are appearing, while familiar creatures vanish. The permafrost that is the physical foundation of the ecosystem and human structures is destabilizing.

Climate change is staring Canadians in the face. Unlike its southern neighbor, there is no debate in Canada about whether climate change is occurring or whether it is caused largely by human activities. The Canadian government has committed to spending more than $5 billion from 2005 to 2010 on adapting to and mitigating climate change. In the United States, while the Bush administration proposes a fiscal year 2006 climate change expenditure of nearly $5.5 billion, the only actual funding increases are for energy tax incentives, while scientific research is cut by $26 million. The Department of Agriculture is slated to lose $13 million under the Climate Change Technology Program. However, Dan Jiron, national press officer for the U.S. Forest Service, says the 2005 agency budget included $17 million for climate research, and the Forest Service is "committed to understanding a lot more about the nature of the issue."

Most of the people living with climate change every day in Canada are native to the far north country. About 80 percent of Canada's First Nations live in the northern forest. Like many aboriginal groups, they are struggling to maintain traditional lifeways and improve their economic status at the same time. Members of the Dene Nation who live in the far north of the Northwest Territories have reported that caribou migration patterns have changed so that hunters must travel farther to reach the herds. Dene Nation lands and environment researcher Shirley Cook says she considers climate change "a number-one issue." The Dene are also concerned about a proposed oil and gas pipeline in the Mackenzie River drainage. "If the pipeline goes through, it's only feeding more global warming," she says.

The boreal nurtures nearly 200 species of birds as well as large mammals such as woodland caribou, woodland bison, bear, wolves, moose and numerous smaller mammals, all of which will be profoundly affected by climate change. For example, woodland caribou are dependent for winter food on the ground and tree lichens that will likely vanish as the boreal ecosystem changes.

But the boreal forest is not important solely to those who live and work there. It is so vast that it affects the entire planet, not least because it holds huge amounts of stored carbon. Like the earth's other forests, the boreal suffers most directly from deforestation due to logging, burning and insect infestations. Mineral and petroleum extraction, hydropower systems and general development also take a toll. These activities are both dwarfed by the magnitude of climate change and are major contributors to it.

The boreal is part of what's now termed "frontier forest," or the last remains of a global ocean of trees that included immense temperate and tropical expanses as well. After the last ice age ended, conifers spread north into the boreal latitudes, then retreated southward as the Arctic ice cap re-expanded. Over the past 5,000 years the forest took on its present character, dominated by spruce, pine and fir trees. Today people have removed almost half of the world's frontier forest, and the boreal forests in North America and Russia make up 70 percent of the remainder, according to a 1997 World Resources Institute report.

Most people understand by now that we are pumping tons of carbon into

the atmosphere, where it prevents reflected sunlight from escaping the planet. This greenhouse effect has raised average global temperatures by about 0.6 iC since the beginning of the Industrial Revolution, and the Intergovernmental Panel on Climate Change predicts that temperatures may further increase by as much as 5.8 iC by 2100. The carbon dioxide released by burning fossil fuels is the single largest contributor to the greenhouse effect. Methane, another carbon compound, is the second-largest contributor. The concentration of methane in the atmosphere is now nearly triple that of 150 years ago.

Carbon dioxide's role is well understood, but two recent studies have jolted assumptions about methane's role in climate change. Researchers at the Max Planck Institute for Nuclear Physics in Germany were shocked to discover that living plants produce methane and emit ten to 1,000 times more of it than dead plant material does. The value of trees as carbon sinks may have to be recalculated. And in a paper under review at *Nature,* University of Alaska Fairbanks graduate student Katey Walter reports that the amount of methane bubbling from permafrost melt lakes has been underestimated. Because of the gas's powerful greenhouse effect, methane releases of the magnitude Walter has observed in Siberian lakes carry a risk of triggering a runaway feedback that will increase the rate of warming.

For reasons that are not entirely clear even to climate scientists, the effects of climate change are not uniform over the whole planet. "Of all the forest regions of the world, the magnitude of climate change seems to be greatest in the boreal forest," says Glenn Juday, a professor of forest ecology at the University of Alaska Fairbanks. Juday's unpublished research on boreal daily high and low temperatures and growing season length has shown "not a lot of change in highs [during the growing season], but the overnight lows were just amazing." At one test location the change was more than 3 iC, he adds. "That is huge. That is as much as the scenarios for warming over the next century or so. In central Alaska the low temperatures have already gone up historically as much as current scenarios indicate the future warming will be. In fact, the growing season increased over the last century by 50 percent."

Predicting climate change is complicated by the enormous number of processes it affects, some of which amplify each other and some of which cancel each other out. Most researchers expect the boreal forest, especially along its southern boundary with the prairies, to dry significantly despite the fact that enormous amounts of moisture are stored in ice, permafrost and lakes. Higher temperatures hasten evaporation from open water, soil and trees, and evaporation will outpace precipitation.

The most obvious and immediate change is an expansion of familiar processes. "The disturbance dynamic is going to become much more frequent," says Faisal Moola, a forest ecologist and chief scientist at the David Suzuki Foundation. Drought-stressed trees can't fight off insects effectively. Trees weakened by both insects and drought make excellent fuel for hotter-burning and wider-ranging fires. A longer growing season also aids tree pathogens such as fungi, spruce budworms and pine beetles, which are already common forest pests. Cold has historically limited the range of some insect pests, says Ted Hogg, a Canadian Forest Service climate change researcher in Edmonton, Alberta, but he and many other forest experts believe that protection is almost gone. Warmer temperatures will also enable new pests, like Europe's larch casebearer moth, to invade.

Fires in the boreal are increasing rapidly. Juday notes that the summer of 2005 was the third-highest year for acres burned in Alaska; 2004 was the highest. "The two-year total area burned was equivalent in area to Ireland," he says, and because most of the fires were in the state's most heavily forested area, nearly a quarter of the state's forests burned. "Obviously you can only have eight years of that and you will have burned up everything," says Juday.

Much of the boreal open freshwater is expected to disappear too, to the detriment of migratory birds. A study by University of Alaska Fairbanks researchers comparing the surface area of closed-circulation basin lakes (with no inlet or outlet) in Alaska between the 1940s and the 1990s found a net decrease in open water in all but one of the nine regions examined.

Despite its vulnerability to familiar disturbances, the boreal forest is very different from the forests of the lower latitudes. Two of its distinguishing features are permafrost and peat. Permafrost forms where the average annual air temperature is below the freezing point of water. About half of Canada's land surface is underlain by permafrost. In the northernmost boreal, permafrost can be hundreds of feet thick and extend for hundreds of miles. In the south, permafrost is more patchy.

In the boreal forest, organic material that would decompose in a warmer climate merely congeals into the acidic, spongy stuff known as peat. Much of the water in the boreal is stored in peatlands, which cover about 12 percent of the Canadian landmass.

There are numerous peaty microenvironments—bogs, fens and muskeg—scattered in the forest. What decomposition does occur in peat is handled by anaerobic bacteria that produce methane. Warming and drying will slow the production of methane and speed the release of carbon dioxide from the peatlands, but if deeper layers of peat thaw, even vaster stores of methane will likely burst into the atmosphere, according to the *Atlas.* Nearly two-thirds of Canadian peatlands are "expected to be severely affected by climate warming," the *Atlas of Canada* states.

Boreal trees don't spring from a generous layer of nutrient-laden topsoil, as trees do in the temperate forests along the West Coast or in the Appalachians. Instead, they cling to a thin spongy mat called the "active layer," which rests on permafrost. The active layer, often mere centimeters thick, melts and refreezes repeatedly every year, making tree stability precarious. This is one reason for the typically small diameter of boreal trees relative to temperate-forest trees. As the ice that formed a kind of structural lattice holding up the permafrost melts, trees, buildings and oil and gas pipelines tend to sag, fall over, or sink. Where the topography is uneven, soils slide downhill.

There are still some parts of the boreal where vast stands of one species extend for hundreds of miles, but much of the forest consists of mixed black and white spruce, jack pine and quaking aspen. The conifers are adapted to an environment where the forest floor is often saturated with water because drainage is poor in the relatively flat topography and cold temperatures inhibit evaporation. Long winters and the low angle of the sun make for a short and slow growing season. But the climate is changing so rapidly that it's not certain whether the normal succession will prevail in burned zones, where temperate species may replace the boreal ones. Thus, squeezed between the Arctic tundra and the temperate regions, boreal conifers may not be able to migrate to more hospitable northern areas fast enough to escape extinction.

Of all the anthropogenic disruptions, logging is by far the biggest. The 1997 report from the World Resource Institute notes that 84 percent of the North American frontier forest is threatened by logging, compared with a total of 43 percent by mining, roads, construction, agricultural clearing and other disturbances combined (the threats overlap, making the numbers exceed 100 percent).

The boreal forest is logged mainly for pulp and paper. Most of Canada's timber harvest comes from old-growth stands, and most is taken by clear-cutting. A "Boreal Forest Backgrounder" from ForestEthics, a San Francisco–based conservation group, notes that nearly half the North American boreal forest has been allocated to logging companies. Both the number of acres logged and the percentage logged by clear-cutting have exploded since 1975, according to a recent Greenpeace report. In that year nearly 2,812 square miles were logged, more than 80 percent of them by clear-cutting. In 2000, more than 3,900 square miles were logged, nearly all by clear-cutting.

Moola, of the David Suzuki Foundation, points out that logging is especially damaging in peatlands because loggers use a modified tractor called a skidder, which drags the logs off the clear-cut site, making deep ruts in the peat. Logging companies also modify the peatland after harvest to "expose a mineral substrate more amicable to growing trees," Moola says. "They scoop up all the peaty soil and push it to the side, or pull giant pieces of metal attached to the back of the tractor across the clear-cut." Log dragging and peat scarification release more carbon in addition to that accounted for by the logs themselves. In fact, logging in the boreal currently releases more than twice the carbon emitted by all the cars in Canada, according to a factsheet from the Canadian Boreal Initiative.

If the changes in the boreal were simply regional, the rest of the world would find it easier to disregard them. But the boreal forest has been providing ecosystem services since the last Ice Age. Its benefits include oxygen production, air and water filtration, carbon storage, prevention of soil erosion and floods, pest control by birds, recreation and subsistence hunting and gathering, according to a report prepared for the Boreal Initiative by economic analysts Mark Anielski and Sara Wilson.

These services are valuable. The Initiative estimates total carbon storage in Canadian boreal vegetation, soil and peatlands to be 73 billion tons. Boreal trees' carbon sequestration is worth about $185 billion a year. Anielski and Wilson estimate that "the total non-market value of boreal ecosystem services is two and a half times greater than the net market value of boreal natural capital extraction."

Climate change may already have lost its brakes, and it may be impossible to save the boreal forest as is. But if crucial decisions are made to allow the boreal's plants and animals the widest leeway in adapting, the change may not be wholly tragic. Whether the massive inertia of life as we know it can be redirected in time is another question.

Some forest products companies have committed to climate-mitigating actions. More than 3,000 companies worldwide participate in the Forest Stewardship Council's certification program for ecosystem-protective wood harvest and products practices, including the Canadian companies Tembec and Al-Pac. Weyerhaeuser, which owns or manages some 37 million acres in Canada (compared with 6 million acres in the U.S.) harvests mostly by clear-cutting, according to the company's "Roadmap for Sustainability" report. Weyerhaeuser is not Forest Stewardship Council–certified, but is a member of the Climate, Community and Biodiversity Alliance, a

Washington, D.C., organization that promotes standards for assessing climate mitigation projects, according to documents provided by Weyerhaeuser's public relations office.

There is also some cause for optimism on the policy front. Canadian government policies with respect to climate change in the boreal forest are under intense review and, says Cook, governments are seriously consulting with First Nations in the process. In the United States, climate change has not yet been factored into U.S. Forest Service policies regarding issues like fire response or timber harvest, according to Jiron, but he stresses that the agency's latest National Forest System Land and Resource Management Planning Rule is structured so that new climate change knowledge can be incorporated periodically.

Despite the boreal forest's uncertain future, Moola remains optimistic. "There is a way forward, the third way," he says, by which he means efforts to develop policy that will protect the boreal forest while allowing human activities to continue. "We need to make the right decisions now. If we don't do that, in twenty to thirty years' time, we're going to be in a much worse situation." We can only hope that by then, real climate fact will be less strange than Pullman's darkling fiction.

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