The Migrating Boreal Forest

by Rebecca Lindsey • design by Robert Simmon

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Just south of the tundra that rings the Arctic Circle lie vast, cold-adapted, evergreen forests. Spruce and pine predominate over a smaller contingent of hardy deciduous trees such as aspen and birch, all eking a living out of frigid winter temperatures, frozen soils, minimal moisture, and frequent fires. These vast tracts of uninterrupted, spruce-dominated forest create a sense of uniformity, even changelessness—a stillness of time.

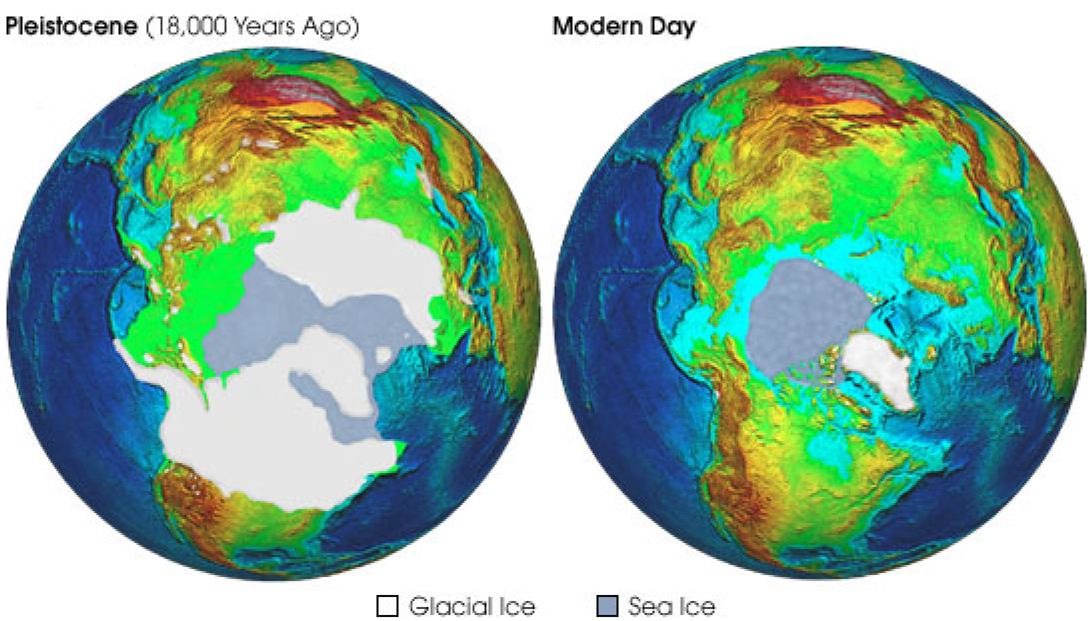
Hardy evergreens such as spruce, pines, and firs dominate the boreal forests. Along with larch, aspens, and birch, these trees are able to withstand the long, dark winters of the far north. Moss and lichen cover the forest floor. (Photographs copyright David P. Shorthouse, University of Alberta, Image 1450078, and William M. Ciesla, Forest Health Management International, Image 3948095. ForestryImages.org)

Uniformity and changelessness are illusions, however—a product of the shortness of our lives compared to geologic time. In their studies of the Earth's climate history, scientists have accumulated evidence that far from being staid and static, the tree species we think of today as belonging to the boreal forest have done a bit of globe trotting, migrating back and forth over entire continents, heading south with advancing ice age glaciers on their heels, and then north as climate warmed and glaciers retreated.

Changes in the distribution of trees associated with the boreal forest have been studied extensively in North America. The evidence of all that cross-continental tree traveling is recorded in fossilized plant parts, including macrofossils, like cones, leaves, and stems, as well as microfossils like pollen grains. Linking the appearance and disappearance of tree remains in different regions of the continent with the Earth's temperature and carbon dioxide record, scientists have put together a history of the travels of boreal forest species that highlights life's remarkable capacity to fill whatever niche the Earth provides, but adds a cautionary tale about the rate at which species can adapt, and the consequences when they can't. This history may help scientists trying to predict how the boreal forest of today might fare in a world much warmer than the one in which we now live.

Not In Kansas Anymore

According to physicist Forrest Hall of NASA's Goddard Space Flight Center, vegetation at the height of the Pleistocene Ice Age about 20,000 years ago was profoundly different from today's. "For example," says Hall, "we know that spruce—a species that we think of as belonging to the boreal forest—was common in the central United States, including Kansas, Oklahoma, and even reaching as far south as Texas."



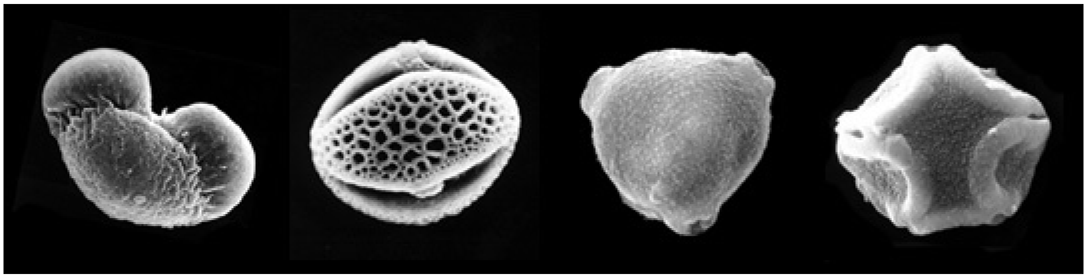
At the height of the Wisconsin glaciation during the Pleistocene Ice Age, the Laurentide ice sheet covered nearly half of North America

The last glacial advance of the Pleistocene Epoch was also one of its most severe. At its peak about 20,000 years ago, a vast ice sheet called the Laurentide covered much of North America, blanketing Canada and parts of the U.S. with a wall of ice as much as 3.2 kilometers (two miles) thick. While the continents had roughly the same size and shape that they do now, terrestrial biomes were compressed in the remaining ice-free terrain. Vegetation colonized newly exposed areas of coastline that appeared as glaciers consumed more and more of the Earth's moisture and sea levels began to drop. Many scientists believe that precipitation dropped dramatically during this period—perhaps by as much as 50 percent or more in some regions. The differences between ice age forests and modern forests were probably not just because the ice age was cold, but because it was simultaneously cold and dry.

(left). Today, the polar ice cap is greatly diminished (right). (Image courtesy National Oceanic and Atmospheric Administration Paleoclimatology Program.)

As temperatures dropped and more and more of the Earth's water began to be tied up in the massive polar ice sheets, sea levels dropped. The map of North America (left) shows the familiar outline of modern sea levels (light green) as well as sea levels at the peak of the Pleistocene ice age (blue) and the sea level that would result if the polar ice caps melted (dark green). (Images by Robert Simmon, NASA GSFC)

Margaret Davis, an ecologist at the University of Minnesota, studies fossilized tree pollen in order to describe North American vegetation since the end of the last glacial maximum. Most of her work is based on fossilized pollen buried in lake sediments. By comparing modern forests and the pollen records they leave behind to pollen records from thousands of years ago, Davis has created a picture of ancient forests. Her meticulous studies of North America's fossil pollen record show that although trees associated with modern forests existed many thousands of years ago, forests as we know them today—dense, continuous stands of trees whose branches form a closed canopy overhead— were likely very rare at the last glacial maximum.



Botanists use fossil pollen to map the past distribution of forests. These images show pollen from modern boreal tree species. From left to right: pine, aspen birch, and alder. (Micrographs courtesy USDA Pollen Lab)

Stephen Jackson, a botanist at the University of Wyoming, agrees. Jackson has used both pollen and macrofossils to describe the North American landscape since the height of the Wisconsin glaciation. According to Jackson, "It appears that in upland regions, woody vegetation was indeed sparse, and canopies were relatively open. Whether this was savanna-like, with clumps of trees separated by open, non-woody vegetation, or parkland, with low tree density, remains unresolved. But I suspect, based on the pollen data, that 'forests' as we think of them today were restricted to riparian areas along rivers and other sources of water."

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Changes Since the Last Ice Age

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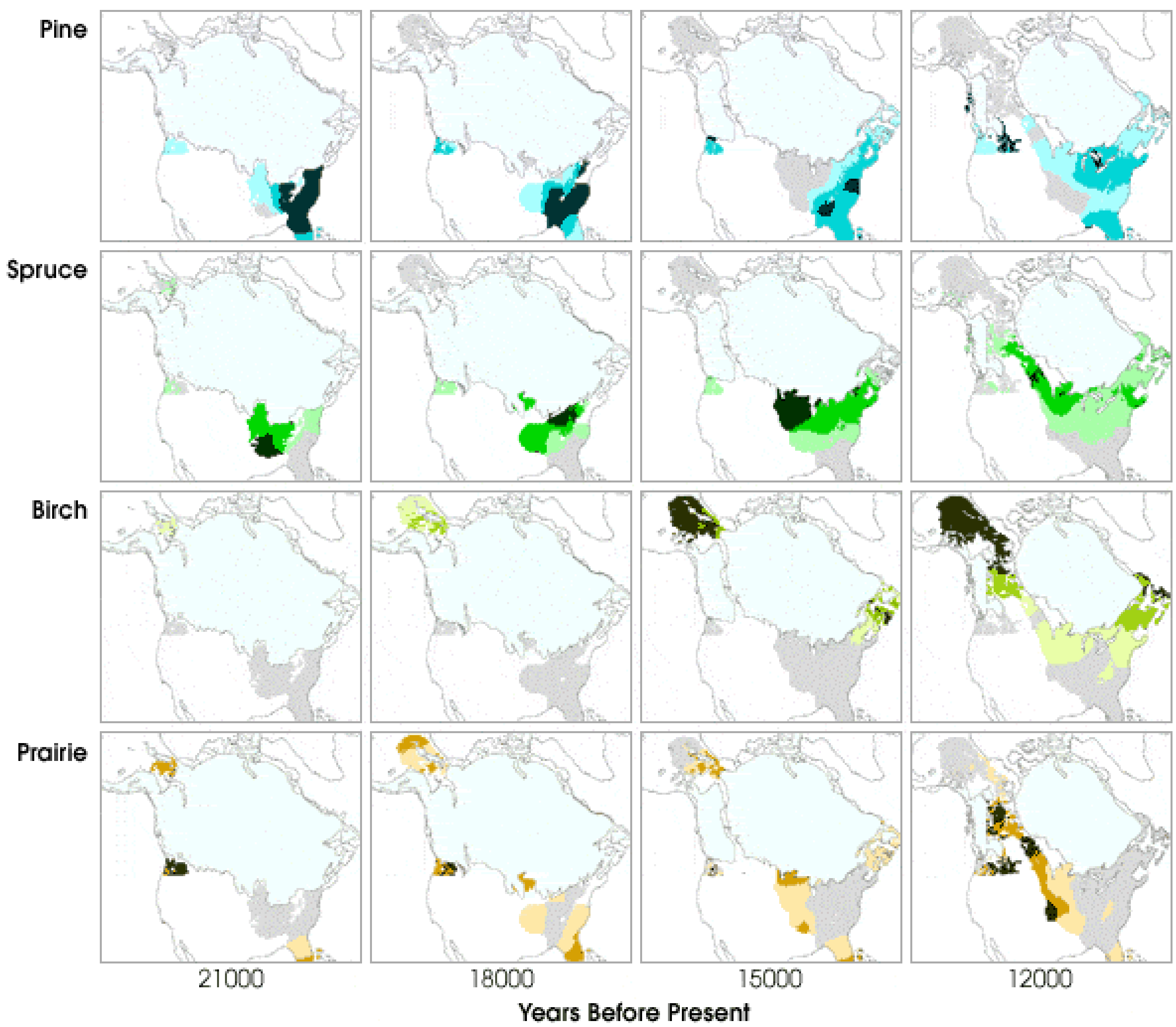
When most of us hear the word “migration” we think mainly of birds or other animals. Few of us would think of trees. And yet to survive climate change during and since the last ice age, trees and plants have climbed and descended mountains and traipsed across continents in every direction. When the last ice age began to release the Earth from its wintry grip, warmer temperatures nibbled away at the southern margin of the Laurentide, and tundra plants began to re-colonize the newly exposed soil. Many of the boreal species that had sought refuge in the southern latitudes began to “relocate” to the north.

Spruce and northern pines, both of which had become established in the South began to retreat northward on the heels of the ice sheet 18,000 years ago. Around 15,000 years ago, the ice age’s dominant spruce species, P. critchfieldii, had gone extinct. By 12,000 years ago, the southern limit of remaining spruce and northern pines extended little farther than mid-continent, while their northern limit reached almost to Newfoundland, Canada. Fir and birch require more precipitation than spruce, and lagged the northward trek by several thousand years.



The end of the full glacial episode began the Holocene period, our modern era. The

Since the height of the last ice age, the geographic range and abundance of tree and plant species

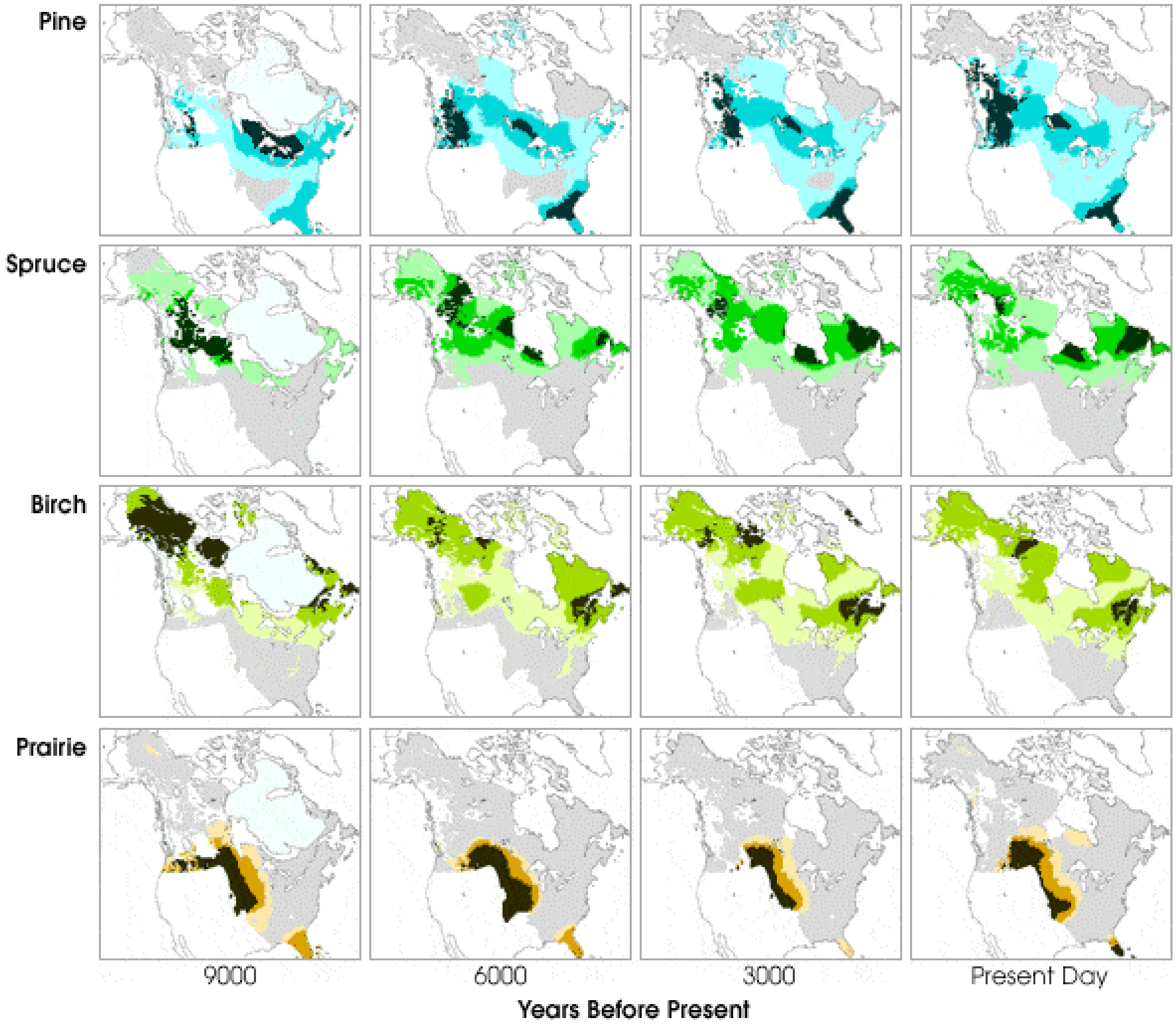
Holocene period, our modern era. The gradual warming experienced during the Holocene was punctuated by several flickers in climate, during which conditions would briefly become cooler, but overall the Earth was becoming warmer and most probably wetter. Between 12,000 and 9,000 years ago, spruce, fir, northern pines, and birch were all coexisting south of the edge of the glacier, which still covered much of Canada. Rapid increases in warmth during this period—probably in the form of summer temperature increases—caused spruce to decline, and northern pines dominated the early boreal forest.

This change in species abundance is what Davis is talking about when she says that in many cases, forests that have existed since the last ice age are unlike any we have today. According to Davis, we have to be cautious about thinking that a whole forest ecosystem, has ever migrated, en masse, in response to climate change, or that it could do so again. “The important aspect of boreal forest

inÊNorth America have changed, with many modern boreal species migrating northward. The images above show changes from 21,000 to 12,000 years ago in pine, spruce, birch, and non-grass prairie vegetation.

Increasing color intensity represents increasing concentration of pollen, which is proportional to the amount of that species in a given area. The Laurentide Ice Sheet is pale blue, and areas where no data were collected are white.

Spruce and pine were found in abundance in the central United States for several thousand years. About 12,000 years ago, the Great Plains began to appear more prairie-like, with spruce and pine retreating northward. (Images courtesy Department of Geological Sciences at Brown University, the National Center for Ecological Analysis and Synthesis, and the Department of Geography at the University of Oregon) migration is that the forest didn't migrate as a community. Individual species shifted ranges and fluctuated in abundance. Spruce was very much less abundant about 10,000 years ago than it is today. As spruce is such a signature species for boreal forests, can we really say we had a boreal forest at that time? Certainly it was very different from the boreal forest of today.”



Even as recently as 9,000 years ago, both spruce and birch, by that time well established in Canada and the northern United States, were still not settled into the present range, and actually began to spread southward once again. Around 6,000 years ago, the last of the continental ice sheets had melted, and the boreal forest was beginning to resemble its current self.

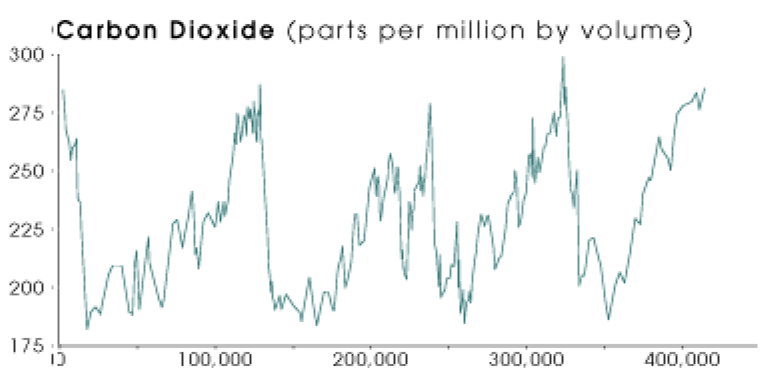
Around 9,000 years ago, the ice age was ending, and the Earth was entering the Holocene interglacial period, when moisture as well as temperature is generally thought toÊhave beenÊincreasing. The images above show changes in North American vegetation fromÊ9,000 years ago to the present. In each case, increasing color intensity represents increasing concentration of pollen, as in the images above. Southern pine species began to take hold again in the southeast, while spruce and birch were migrating farther north. (Images courtesy Department of Geological Sciences at Brown University, the National to resemble its current self.

Center for Ecological Analysis and Synthesis, and the Department of Geography at the University of Oregon)

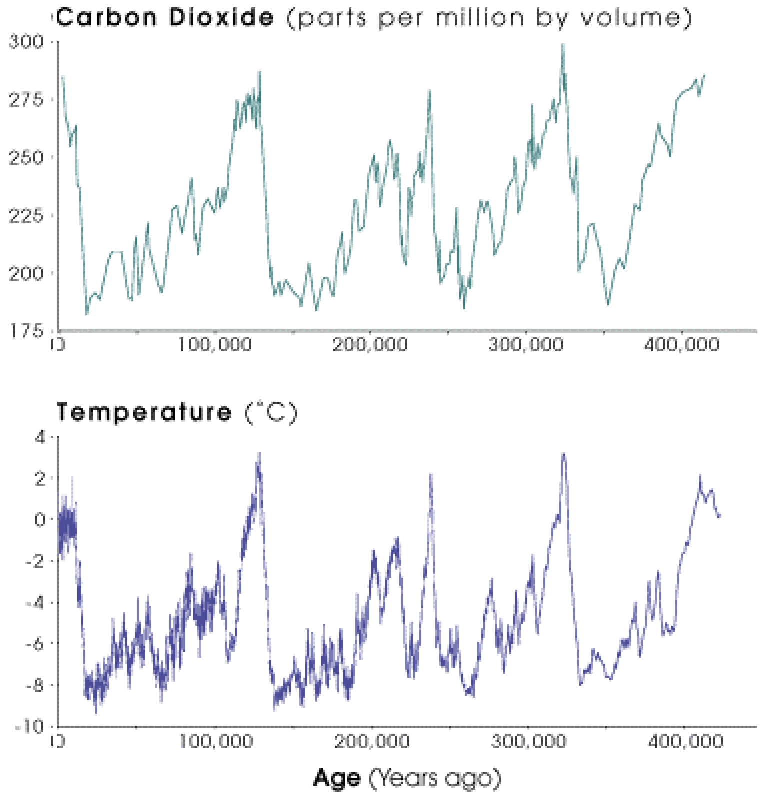
The Future of the Boreal Forest

So what does the history of the boreal forest tell us about its future? Combining knowledge of forest history with future climate simulations, scientists are trying to predict what will happen to today's forests if the Earth continues to warm at its present rate. And quite a lot hinges on the rate of change.

Says Hall, "Ice core studies from Greenland and Antarctica reveal that the Earth's climate has varied cyclically over the past 450,000 years or so, see-sawing over the plus or minus ten degree range. Temperatures have cycled almost in lockstep with variations in atmospheric carbon dioxide." As if the Earth is inhaling and exhaling over millennia, carbon dioxide has risen and fallen, ice sheets have advanced and retreated, and vegetation has been forced to adapt. It is this relationship of carbon dioxide and temperature that scientists refer to as the greenhouse effect.



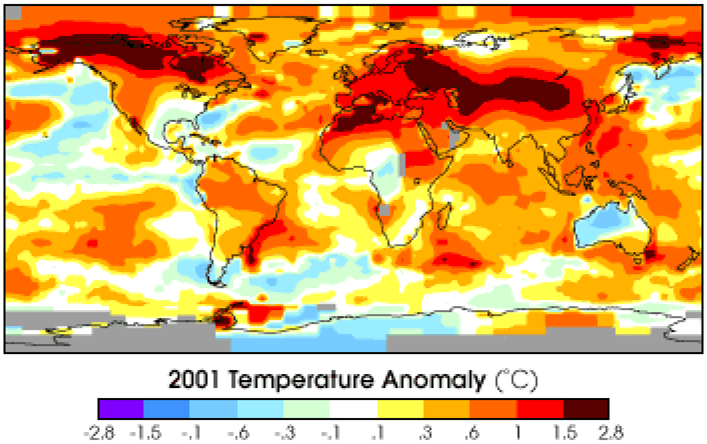
The long-term record of atmospheric carbon dioxide obtained from Antarctic ice cores shows that the Earth seems to inhale and exhale carbon dioxide over hundreds of thousands of years. Periods of low carbon dioxide concentration correspond to ice ages, while higher carbon dioxide concentrations are linked to warmer periods. At the



end of Pleistocene, carbon dioxide levels rose from below 200 parts per million to about 280 parts per million. This transition occurred between 20,000 years ago and the present day (0 on the graph). The end of the last ice ageÊcorresponds to the first big drop on the graph. Each subsequent drop in carbon dioxide was associated with an even more ancient ice age. (Graph by Robert Simmon, based on data from the NOAA Paleoclimatology Program)

According to Hall, we are currently in a very warm period—quite probably as warm as the Earth has been in the last 450,000 years. Warming is occurring very rapidly, especially at higher latitudes. Rapid warming in continental interiors, which are separated from the moderating influence of oceans, puts interior boreal forests at high latitudes at high risk from climate change. According to Hall, swings in the atmospheric concentrations of carbon dioxide created by wintertime exhaling of the biosphere and summertime inhaling of carbon dioxide have lengthened by 6 days since 1960. River and lake ice have been observed to freeze later and break up sooner in boreal land.

The changes predicted for the boreal ecosystem are profound. The build up of carbon dioxide could raise average global temperatures between 1.4° and 5.8°C (2.2 to 10°F) over the next century, with larger increases likely at higher latitudes. The warming temperatures will almost certainly melt the upper layers of permafrost. This permanently frozen layer of soil keeps the water table fairly close to the surface, and many boreal species have developed shallow root systems in response. Recent evidence indicates that permafrost is thawing earlier and freezing later in the year, increasing run off and drying out the soil. This drying could make the entire ecosystem more prone to fire. Finally, many species of boreal trees require a period of chilling before their buds will burst open in the spring, which ensures that new leaves will not open up before the winter is really over. If winter temperatures rise too greatly—and, in fact, models predict temperatures will rise most in the winter—this important growth cycle requirement may be lost, and species that require it might fail.



Over the past several years, the NASA-Goddard Institute for Space Studies has been producing maps of global temperature anomalies, or regions where temperatures are significantly different from climatic norms. This map shows where temperatures from December 2000-November 2001 were above and below normal. Across northern North America and Russia, where the boreal forest is located, temperatures have been significantly warmer than the average of temperatures observed between 1951 through 1980. This high-latitude warming puts northern forests under particularly strong pressure from climate change. (Image courtesy NASA-Goddard Institute for Space Studies)

Model simulations performed by the scientists of the Intergovernmental Panel on Climate Change (IPCC) indicate that alpine tundra will lose ground to boreal forest spreading northward. According to their estimates, between one- and two-thirds of the current tundra will likely be replaced by boreal migrants. But as the boreal forest is gaining ground to the north, it will probably be losing ground in the south, as warmer temperatures speed up evaporation from the warming soil. If this happens, the low-moisture-requiring grasses from the prairies of southern Canada will begin to push northward, especially in the interior of the continent, and the losses to the boreal forest at the southern ecotone (transition between two biome types) are expected to exceed gains in the north.

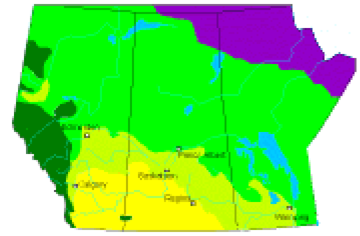
In Western Canada, some scientists are already concerned that the expected warming and drying of the climate will drastically reduce the abundance of aspen, the primary commercial hardwood species in the southern boreal forest. Insufficient moisture could produce an open aspen parkland, where stunted aspen cluster along water courses, with grasslands in between.

Dramatic differences in aspen forests growing in regions of decreasingly favorable conditions. The first image shows a stand of aspen growing in the boreal forest in Prince Albert National Park, Canada. Tree density decreases and the aspen take on an increasingly stunted appearance farther south (images 2 and 3), as moisture availability drops. These latter two images represent a plausible scenario for future aspen forests under increasing carbon dioxide concentrations. (Photographs courtesy Ted Hogg, Northern Forestry Division of the Canadian Forest Service)

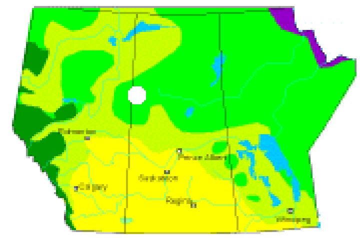
Where forests will gain or lose ground depends on the regional characteristics of their environment, including water availability and temperature, and one other crucial factor—how fast the species can migrate. This lag time between climate change and species adaptation is something many models don't take into account.

According to Hall, there are two different approaches to modeling future terrestrial environments. One kind of model, the biogeography model, begins by describing the climate conditions that support a particular biome today, and then attempts to predict where those conditions might be present in the future—coupling biology to the geography of climate. These models identify areas that ought to be suitable for certain plants and trees to colonize in the future.

These models, however, don't provide any physical insight into how these transitions might be accomplished—or whether they could be accomplished at all. An increase in global temperatures of 2 degrees Celsius (3.6 degrees Fahrenheit) could shift the ideal growing conditions for North American tree species as far as 322 kilometers (200 miles) north of their present location. If this warming occurs over the next 100 years as predicted, trees would have to migrate about 3.2 kilometers (2 miles) every year. Just over three kilometers a year may not seem like much, but even that short a distance may be unattainable for trees that reproduce by means of wind-dispersed seeds or nuts, such as oaks. Some scientists fear that even some of the faster migrators, such as jack pine, which the fossil record has shown to spread as much as 500 meters in a year, may not be fast enough to keep pace with the rapid warming expected in the



Present Climate



Possible Future Climate

- Foothills Forest
- Boreal Forest
- Aspen Parkland
- Grassland

The distribution of grasslands and boreal forests is highly dependent on moisture availability. These maps of central Canada show the present location of grasslands, aspen parkland, and boreal and foothills forests. Model simulations by Canadian Forest Service scientists indicate that under doubled atmospheric carbon dioxide levels, boreal forests will retreat and grasslands will expand. (Images courtesy Ted Hogg, Northern Forestry Division of the Canadian Forest Service) next 100 years.

The biogeography models also neglect the impacts that climate change will have on ecological factors like frequency of forest fires or insect outbreaks, both of which may amplify the impact of climate change on the forests. Mature trees can hang on for many years in less-than-optimal conditions, albeit with a major slow-down in growth. But their seedlings would be less successful. And should continued warming and drying of the boreal forests' peaty soils increase the occurrence of fire, vast areas of forest might rapidly become open to colonization by invading grasses. And while in previous eras, plants and animals may have had a seamless canvas on which to draw the map of their migration, current human disturbances of terrestrial communities—including deforestation, urbanization, and agriculture—mean that there are few large tracts of undisturbed land through which trees and plants can gradually expand their range in response to climate changes. These land use changes may leave many forest species stranded.

It is not surprising, then, that some scientists consider the biogeography models to be overly optimistic about the fate of northern forests. It's one thing to say that a spruce could find suitable habitat in far northern Canada in 100 years, and quite another to explain how it will actually get there. Hall describes a second kind of vegetation model as a process model. These models simulate a scenario in which a dying tree creates a gap in a forest canopy. Based on what is known about the variety of plants available for reseeding, their individual reproductive and physical characteristics, and the changing climate, the models try to predict what species will fill that gap.

These models, while predicting some increases in forest productivity in certain locations and for certain species, overall “suggest that large numbers of areas may no longer be able to support forests, particularly if the climate becomes drier,” according to Environmental Protection Agency reports. Of course, there’s no such thing as a perfect model. The trouble with gap or process models is that because they require detailed information about the regional conditions, so far, they have only been applied to individual stands of trees, not to an entire ecosystem at once.

According to Hall, the integration of the two approaches along with climate models into a single coupled model has become a prime objective for many researchers in the field, but without those coupled models we are a long way from completely understanding how the boreal forest will change in most global-warming scenarios. These changes have implications not just for the forest itself, but for human and other animal populations that depend on it—for timber, for habitat, and for food.

Concludes Hall, “In the last 150 years, the amount of atmospheric carbon dioxide is higher than anything we have seen in the last 450,000 years. The Earth has taken up increasingly more carbon dioxide as we have put it out. So far it appears to be sopping up about half of the 6 gigatons we put in each year from burning fossil fuels. But we don’t know how long that can continue.” If that natural cleansing is reversed by climate change—such as by the predicted dramatic losses in the extent of the boreal forest—our scientific models are currently at a loss to predict what the outcome might be.

In the meantime, Davis says, our best shot at preserving biodiversity may be to create large forest reserves at all latitudes. “We need to provide reserves that would not only allow species to migrate in response to climate change,” she says, “but that are large enough to contain a genetically diverse group of trees.” She explains: “If a reserve is large enough and spread out over a broad latitude range, you increase the likelihood that even within a single species of tree there exists a range of genetic backgrounds already uniquely adapted to the different growing conditions found in the north versus the south." This type of genetic variation, sometimes called ecotypic differentiation, increases the chance that an individual species of tree will be able to genetically adapt to changing climate. But Davis also says we may have to face the fact that many tree species may not be able to keep pace with expected rates of warming, and may simply go extinct. "It's quite sad, really," says Davis, "but starting in about mid-[21st] century, we are probably going to see vast areas of forests disappear, especially at the southern limits of the current range." The loss of the current boreal forest would have radical commercial, biological, and climatological consequences, some of which we can't even yet imagine.

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Department of Geological Sciences at Brown University
The National Center for Ecological Analysis and Synthesis
The Department of Geography at the University of Oregon.