3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Shifting Vegetation Zones

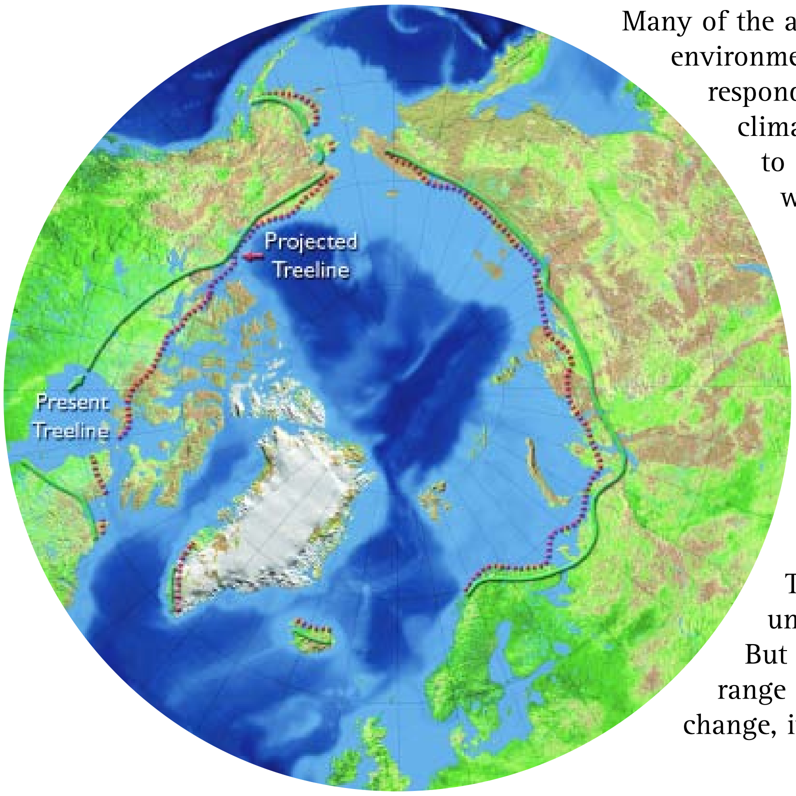
Climate-induced changes in arctic landscapes are important to local people and animals in terms of food, fuel, culture, and habitat. These changes also have the potential for global impacts because many processes related to arctic landscapes affect global climate and resources. Some changes in arctic landscapes are already underway and future changes are projected to be considerably greater.

The major arctic vegetation zones include the polar deserts, tundra, and the northern part of the boreal forest. The northern-most zone that covers most of the high arctic is the polar desert, characterized by open patches of bare ground and an absence of even the smallest woody shrubs. Although polar desert vegetation is quite sparse, musk ox and small sub-species of caribou/reindeer are found in this zone. Tundra is characterized by low shrub vegetation.

Climate change is projected to cause vegetation shifts because rising temperatures favor taller, denser vegetation.

Climate change is projected to cause vegetation shifts because rising temperatures favor taller, denser vegetation, and will thus promote the expansion of forests into the arctic tundra, and tundra into the polar deserts. The timeframe of these shifts will vary around the Arctic. Where suitable soils and other conditions exist, changes are likely to be apparent in this century. Where they do not, the changes can be expected to take longer. These vegetation changes, along with rising sea levels, are projected to shrink tundra area to its lowest extent in at least the past 21 000 years, greatly reducing the breeding area for many birds and the grazing areas for land animals that depend on the open landscape of tundra and polar desert habitats. Not only are some threatened species very likely to become extinct, some currently widespread species are projected to decline sharply.

Northward Shifting Treeline



Many of the adaptations that enable plants and animals to survive in this cold environment also limit their ability to compete with invading species responding to climate warming. The rapid rate of projected changes in climate also presents special difficulties to the ability of many species to adapt. The primary response of arctic plants and animals to warming is thus expected to be relocation. As species from the south shift their ranges northward, in some cases by as much as 1000 kilometers, they are very likely to displace some arctic species (whose northward shifts are hindered by the Arctic Ocean). Such range displacements have already begun among some bird, fish, and butterfly species. Seabirds, mosses, and lichens are among the groups expected to decline as warming increases. The Arctic is an important global storehouse of diversity for mosses and lichens, containing 600 species of mosses and 2000 species of lichens, more than anywhere else on earth.

The total number of species in the Arctic is projected to increase under a warmer climate due to the influx of species from the south. But entire communities and ecosystems do not shift intact. Rather, the range of each species shifts in response to its sensitivity to climate change, its mobility, its lifespan, and the availability of appropriate soil, moisture, and other needs. The ranges of animals can generally shift much faster than those of plants, and large migratory animals such as caribou can move much more readily than small animals such as lemmings. In addition, migratory pathways must be available, such as northward flowing rivers as conduits for fish species from the southern part of the region. Some migratory pathways may be blocked by development. All of these variations result in the break-up of current communities and ecosystems and the formation of new communities and ecosystems, with unknown consequences.

Current Arctic Vegetation

- Ice
- Polar Desert / Semi-desert
- Tundra
- Boreal Forest
- Temperate Forest

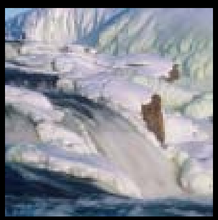
Present day natural vegetation of the Arctic and neighboring regions from floristic surveys.

Projected Vegetation, 2090-2100

- Ice
- Polar Desert / Semi-desert
- Tundra
- Boreal Forest
- Temperate Forest
- Grassland

Projected potential vegetation for 2090-2100, simulated by the LPJ Dynamic Vegetation Model driven by the Hadley2 climate model.

Ice



Polar Desert

Polar Semidesert

Wet Tundra

Tussock/Sedge/Shrub Tundra

Boreal Forest

3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Studies suggest that the increase in absorption of solar radiation will dominate over the increase in carbon storage, resulting in a net increase in warming.

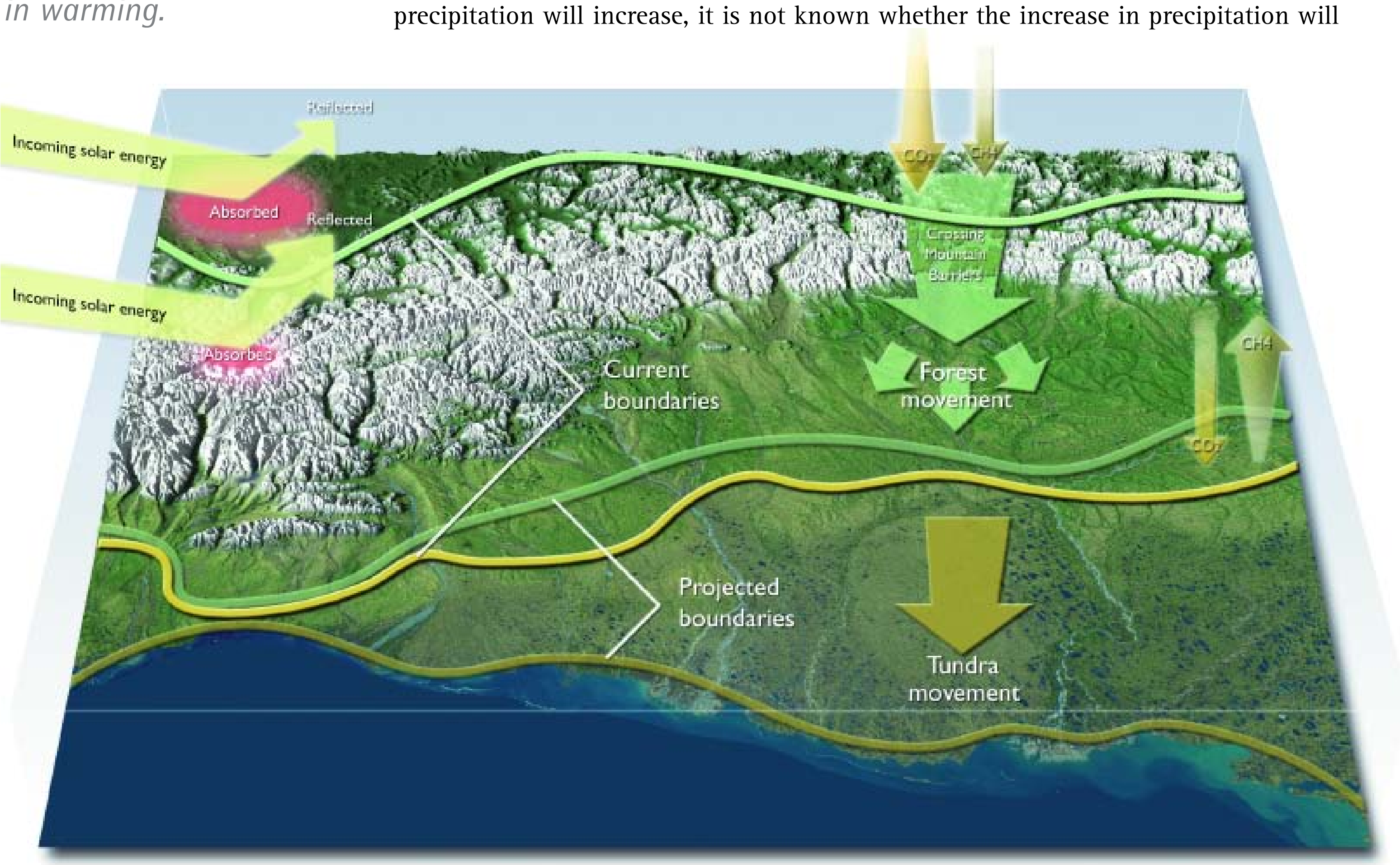
Countervailing Forces on Climate

The projected reduction in tundra and expansion of forest will cause a decrease in surface reflectivity, amplifying global warming because the newly forested areas are darker and more textured and thus will absorb more solar radiation than the lighter, smoother tundra. For example, black spruce is the least reflective of any vegetation type and is likely to be a large part of the mix of new trees in North America. In addition, expanding forests will mask highly reflective snow. The darkening of the surface that results from these changes will create a feedback loop whereby more warming will lead to more tree establishment and forest cover, which will cause more warming, and so on.

On the other hand, the expanding forest vegetation will be more biologically productive than the existing tundra vegetation, and the tundra will be more productive than the polar deserts it displaces. Model results suggest that this could increase carbon storage, slightly moderating the projected amount of warming. The net effect of these countervailing forces involves multiple competing influences that are not fully understood. However, recent studies suggest that the increase in absorption of solar radiation will dominate over the increase in carbon storage, resulting in a net increase in warming.

Desertification: A Potential "Surprise"

Because changes in climate alter many variables and their interrelationships, it is often difficult to project all of the interactive effects on the environment, especially over the long term. While there is high confidence that temperatures will rise and total annual precipitation will increase, it is not known whether the increase in precipitation will



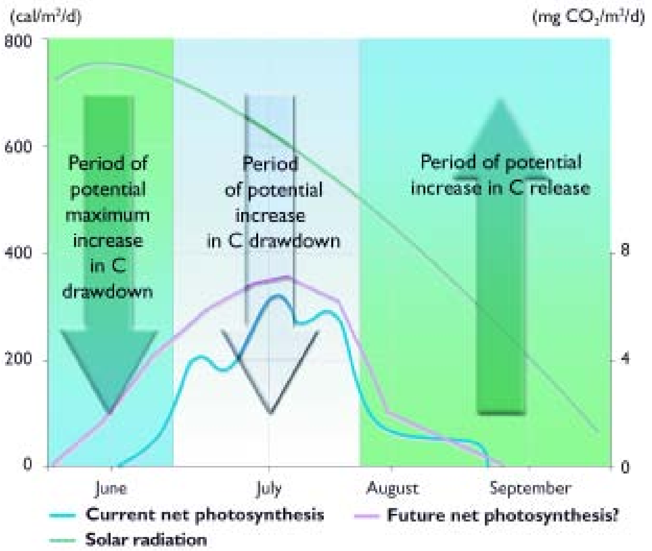
Note: The arrows depicting CO_2 and CH_4 are not drawn to scale.

keep up with the warming in all areas and for all seasons. Because the rate of evaporation increases as temperatures climb, if precipitation does not rise enough to keep up with that increase, land areas would dry out.

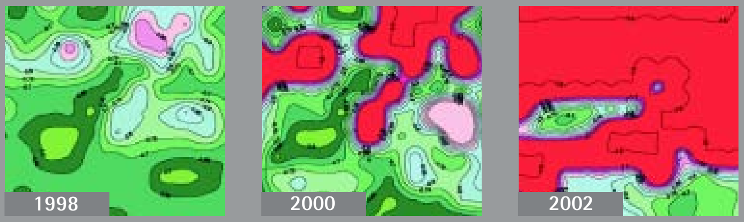
Polar desert

Another complexity is the degree of permafrost thawing and the subsequent drainage of water from the land. For example, summer thawing of the active layer of permafrost (the top layer that thaws in summer and freezes in winter) in Barrow, Alaska is now resulting in a great deal of water at the surface. However, this moisture could be lost if the depth of the active layer increases as projected. This is very likely to happen in parts of the Arctic; areas that were not glaciated 10 000 years ago and have fine-grained wind-deposited soils on top of permafrost are particularly prone to drying and erosion. Records of past climatic conditions suggest that this mechanism occurred in the cold and dry tundra-steppe areas of Siberia and Alaska. These processes are likely to lead to an initial greening, followed by desertification in some areas as warming continues.

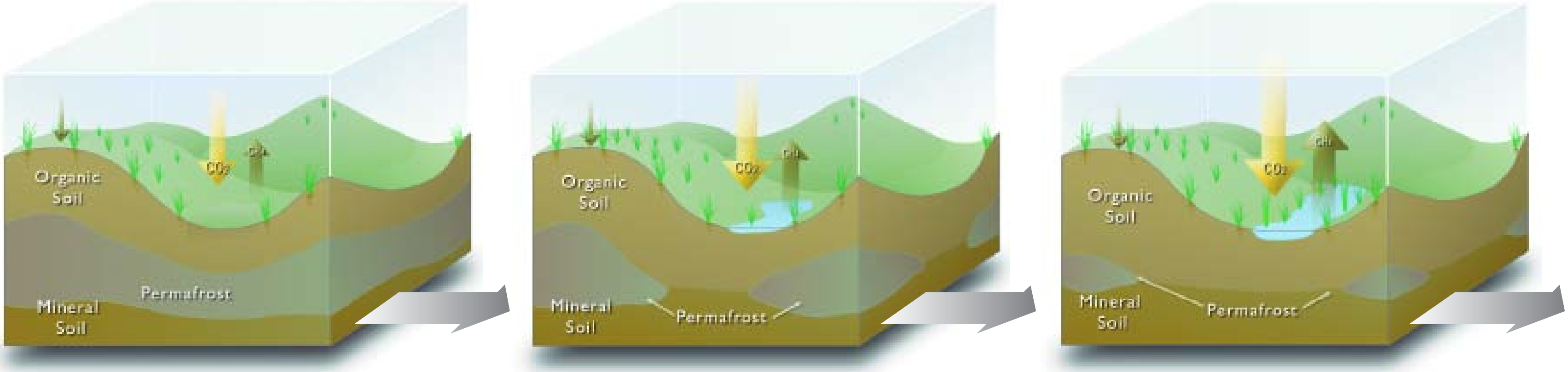
Seasonal Switch from Carbon Sink to Carbon Source



This series, from a site in northern Sweden similar to that in the photograph, shows that the layer of ground that thaws each summer is growing progressively deeper in recent years as climate has warmed. The red areas are those in which the ground thaws to a depth of 1.1 meters or more. The time series illustrates the rapid disappearance of discontinuous permafrost in this area.



Changing Landscape Dynamics with Warming



In northern Norway, Sweden, and Finland, many areas of discontinuous permafrost have small hills or mounds with wet depressions, each with characteristic vegetation (left). As climate warms, permafrost thaws and the wet areas increase in extent. The more productive vegetation captures more carbon dioxide but the greater extent of wet areas leads to greater methane emissions (middle) (this is already being observed). Eventually (right), the permafrost thaws completely, and the balance between methane emissions and carbon dioxide drawdown depends on subsequent drainage and precipitation.

3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Northern Forests

Huge areas of central and eastern Siberia and northwestern North America represent the most extensive remaining areas of natural forest on the planet. Three of the four nations with the largest areas of forest in the world are arctic nations: Russia, Canada, and the United States. Forest and woodland areas in arctic nations represent about 31% of the world's forest (all types) and the boreal forest by itself covers about 17% of the earth's land surface area. As climate continues to warm, the boreal (northern) forests are projected to shift into the arctic region as the forested area expands northward.

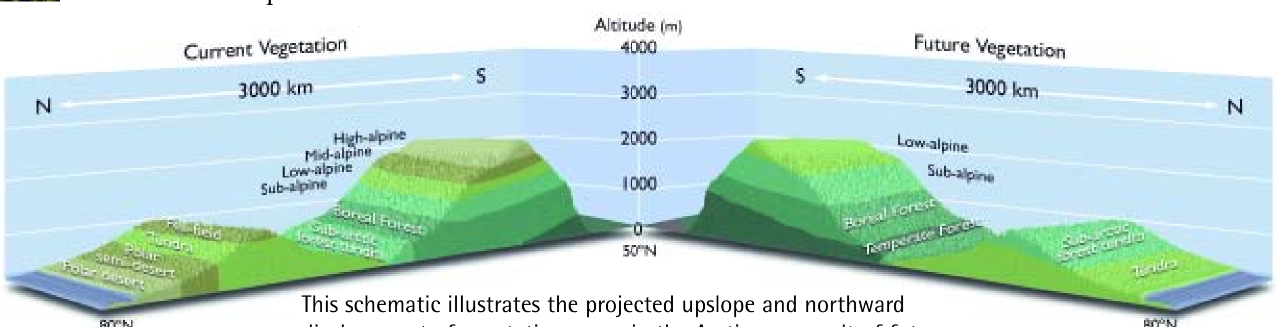
The boreal forest collects, modifies, and distributes much of the freshwater that enters the arctic basin, and climate change will modify many of these important functions.

The boreal forests are extremely important globally for their economic and environmental values. Extensive areas of the boreal forests of Finland, Sweden, and parts of Canada are intensively managed for timber production and contribute 10-30% of the export earnings of these nations. The boreal forest collects, modifies, and distributes much of the freshwater that enters the arctic basin, and climate change will modify many of these important functions. The forest is also the breeding zone for a huge influx of migratory forest birds and provides habitat for fur-bearing mammals including wolverine, wolf, and lynx, as well as larger mammals including moose and caribou, all of which significantly support northern local economies.

Many impacts of climate change are already becoming apparent in the boreal forest: reduced rates of tree growth in some species and at some sites; increased growth rates in others; larger and more extensive fires and insect outbreaks; and a range of effects due to thawing permafrost, including new wetland development and collapsing of the ground surface and the associated loss of trees.

Challenges for Tree Establishment

Recent studies in Siberia have established conclusively that trees were present across the entire Russian Arctic, all the way to the northernmost shore, during the warm period that occurred about 8000-9000 years ago, a few thousand years after the end of the last ice age. Remains of frozen trees still in place on these lands provide clear evidence that a warmer arctic climate allowed trees to grow much further north than they are now. While this and other evidence suggests that vegetation zones are very likely to shift northward over the long term, such a process rarely develops in a straightforward manner. Various factors, including disturbances such as fires and floods, can either speed up or block tree establishment for some period of time. In addition, human activities create pressures that can prevent tree establishment in new areas. For example, in some parts of Russia, treeline is actually regressing southward due to the effects of industrial pollution.



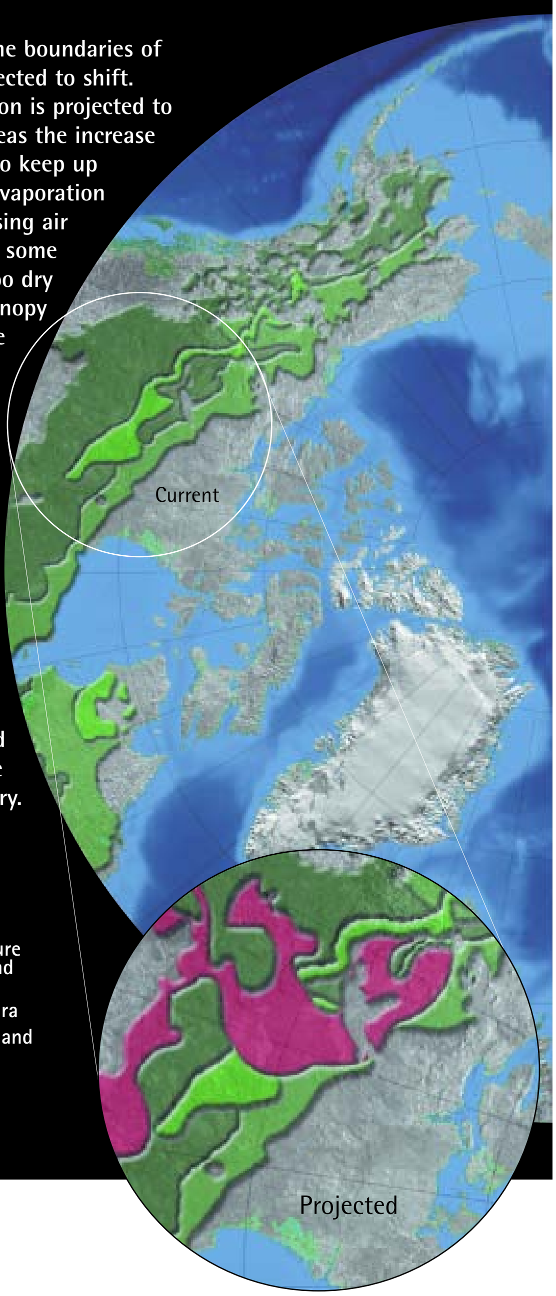
This schematic illustrates the projected upslope and northward displacement of vegetation zones in the Arctic as a result of future warming. Note the difference in altitude of vegetation boundaries on north and south facing slopes. The altitudinal and latitudinal zones are analogous, but not identical.

Though forests are generally expected to move into tundra areas, some environments that now support trees will no longer be able to, primarily due to drying. New areas are likely to have a climate suitable for growing trees, but that does not guarantee that trees will, in fact, grow there, as there are a variety of challenges for trees moving into new areas. First, there is likely to be a time lag because some conditions needed for new tree growth, such as suitable soil, may not be present and will take time to develop. In addition, the dry tundra mat is not a hospitable surface for seeds to germinate in and plants to become established on. Some types of disturbance, such as flooding in river flood plains, are likely to facilitate tree establishment in some areas. On the other hand, in western Siberia, for example, it is possible that waterlogging of trees and a subsequent southward retreat of the treeline will accompany a wetter climate.

Disturbances such as fires and floods can either speed up or block tree establishment; human activities can also create pressures that block tree establishment in new areas.

North American Forest Distribution and Projected Shifts to Aspen Woodland as Climate Warms

As climate warms, the boundaries of forest types are expected to shift. Although precipitation is projected to increase, in some areas the increase will be insufficient to keep up with the increased evaporation that accompanies rising air temperatures. Thus, some areas will become too dry to support closed canopy boreal forest and are projected to convert to a more open formation of aspen woodland, sometimes referred to as "parkland". These areas are shown in red on the map, which is derived from a model scenario under twice pre-industrial carbon dioxide concentrations, which could occur as early as the middle of this century.



Eurasian Forest Distribution

This map of forest types in Eurasia illustrates how climate affects forest distribution. In the colder northern part of the region, there is a southward displacement of forest types compared to the western part. As climate warms, some areas that are currently sparsely vegetated are expected to become more heavily vegetated, with both positive and negative consequences for the region and the world.

3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

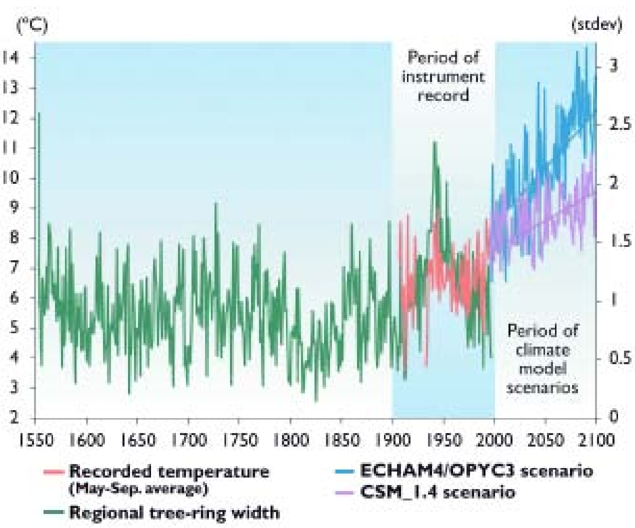
Sometimes, ecosystems display little change until they are confronted with environmental changes that exceed critical thresholds to which they are sensitive.

Response of Siberian Forests to Climate Change

A forest study conducted in Siberia from the southern edge of the Central Asian steppe (grassland) to the treeline in the north reveals some of the ways that climate controls the growth of dominant tree species, in this case, the Scots pine and Siberian larch. In the southern part of this area, drought is the major factor limiting tree growth; cool wet growing seasons produce the most growth. Further north, in the southern and middle boreal forest, warmer midsummer weather reduces growth, while extension of the growing season earlier and later is associated with increased growth. In the northern boreal forest and northern treeline, warm midsummer weather is the principal factor that increases tree growth.

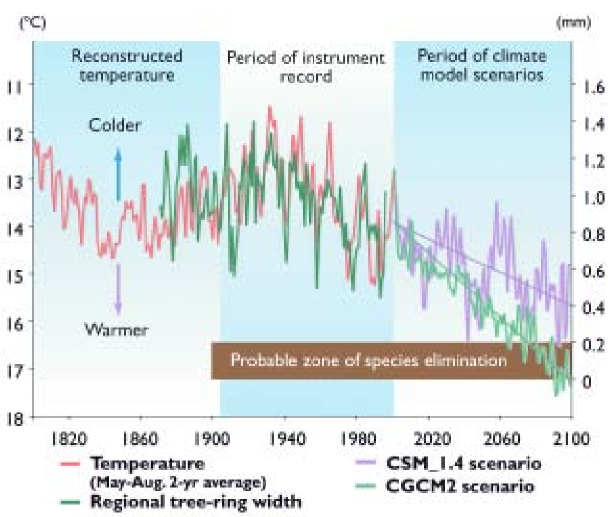
Climate change could produce two different kinds of response in the boreal forest. If the limiting environmental factors remain similar to those in the recent past, simple linear change would occur in which a forest type is replaced by its neighbor from the south. However, sometimes ecosystems display little change until they are confronted with environmental changes that exceed critical thresholds to which they are sensitive. In this case, climate change produces new kinds of ecosystems that are not present in the current landscape. Reconstructions of ancient ecosystems during past periods of climate change such as the last ice age, display such non-linear patterns of change. Potential non-linear changes might include a retreat of treeline southward in some areas. In other areas, forest tree species might not survive or might become so sparse that the tundra would directly border grassland or savanna rather than the boreal forest as it does today.

Siberian Larch and Warm Season Temperature



The graph shows the historical relationship between growth of Siberian larch and warm season temperature and two future warming scenarios in Russia's Taymir Peninsula. These trees respond positively to temperature increases. The warmer of the two scenarios above (ECHAM/OPYC3) would roughly double the growth rate and make this marginal site a productive forest. (The "site" is actually an average of four climate stations on the Taymir Peninsula.) The CSM_1.4 scenario would eliminate periods during which growth is severely limited by temperature.

White Spruce Response to Warming



The graph shows the historic and projected relationship between white spruce growth and summer temperature in central Alaska. A critical temperature threshold was crossed in 1950, after which the growth began to fall. The projection of the Canadian climate model (CGCM2) suggests that this species is likely to be eliminated in the region by the latter part of this century.

Temperature Threshold for White Spruce

White spruce is the most widespread boreal conifer (evergreen, cone-bearing) and the most valuable timber species in the North American boreal forest. It also makes up most of the slow-growing forest found near the tundra margin. In dry central Alaska and western Canada, high summer temperatures decrease the growth of white spruce due to drought. By contrast, in moist coastal and lower mountain regions, white spruce growth increases with high summer temperatures. A study at treeline in the Alaska and Brookes Ranges examined 1500 white spruce trees in both dry and moist areas and found that 42% of the trees grew less under higher summer temperatures (negative responders) while 38% grew more (positive responders).

The critical threshold of 16˚C is now frequently exceeded, strongly decreasing growth in this white spruce population. Extending the observed pattern into the future, a 4˚C rise in summer temperature would result in the elimination of these trees at treeline.

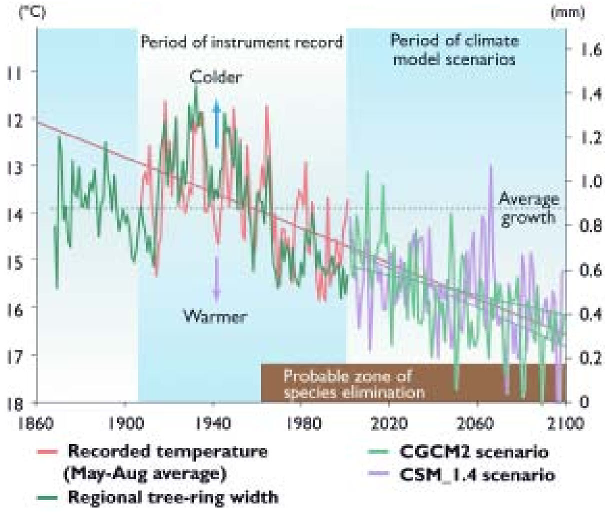
Most significantly, this study found a specific temperature threshold above which the growth of the negative responders decreased sharply. When July temperature at a near-by station rose above 16˚C, the growth of the negative responders decreased in direct proportion to the warming. Before 1950, few Julys were warmer than the threshold, so the negative response was weak. But since 1950, there have been many warm Julys, so the negative response has been very strong. Extending the observed pattern into the future, a 4˚C rise in July temperature would result in no growth, causing the elimination of these trees at treeline. (As for the positive responders, at most treeline sites in the Arctic, their positive response to warming has weakened in the late 20th century, although in Alaska their growth has increased with warming.)

Specific temperature thresholds also trigger white spruce cone production, which is timed to release large numbers of seeds only when conditions are optimal for their establishment, generally following fires. Climate change has altered the timing of both fires and cone production so that these events are no longer as closely related, which could reduce the effectiveness of white spruce reproduction.

Black Spruce, Rising Temperatures, and Thawing Permafrost

Black spruce is the dominant tree in about 55% of the boreal forest in Alaska. It is a key species because its high absorption of the sun's energy increases warming and because of its role as a flammable species that carries fire across the landscape. While black spruce is likely to be an important part of the boreal forest that would expand into tundra as a result of climate change, the species faces a number of challenges to its survival where it is currently dominant. On drier permafrost-dominated sites in interior Alaska, the growth of black spruce decreases with increasing summer temperatures. At the upper ranges of projected warming for this century, it is not likely to survive on these sites due to drought conditions. On other sites in Alaska, black spruce is negatively affected by high early spring temperatures because photosynthesis (and thus the requirement for water) begins while the ground is still frozen, causing damage due to drying of its needles. Finally, even on those permafrost sites where warming has historically increased the growth of black spruce, the trees are at risk from collapsing of the ground surface due to thawing.

Black Spruce Response to Warming



The graph shows the relationship of summer temperatures at Fairbanks, Alaska and relative growth of black spruce, historically and for two future warming scenarios. Average summer temperature is an excellent predictor of black spruce growth, with warm years resulting in strongly reduced growth. By 2100, temperatures projected by both scenarios would not allow the species to survive.

Spruce Bark Beetle

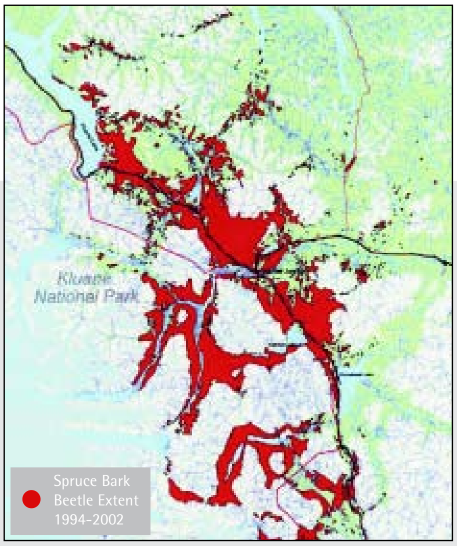
Insect Outbreaks

Increased forest disturbances due to insect outbreaks are almost certain to result from climate warming. Increasing problems with spruce bark beetles and spruce budworms in the North American Arctic provides two important examples. Large areas of forest disturbance create new opportunities for invasive species from warmer climates and/or non-native species to become established.

Spruce Bark Beetle

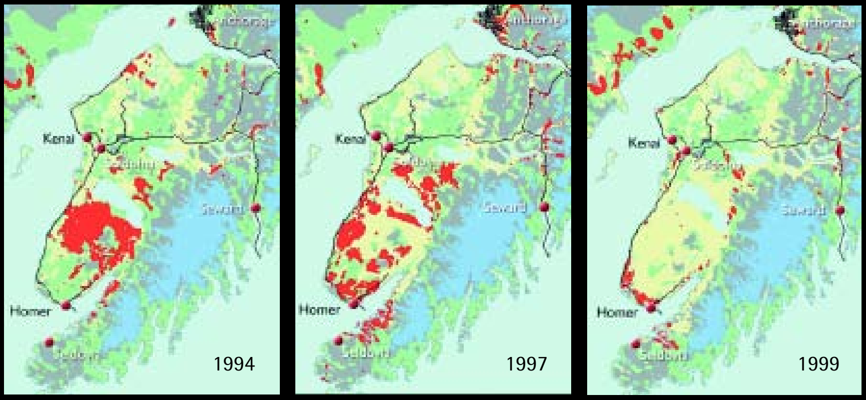
The relationship of the spruce bark beetle to climate involves three factors, including two direct controls on insect populations and an indirect control on tree resistance. First, two successive cold winters depress the survival rate of the bark beetle to a level low enough that there is little outbreak potential the following summer. However, winters have been abnormally warm for decades in the North American Arctic, so the conditions for this control have not been met for some time. Second, the bark beetle normally requires two years to complete its life cycle, but in abnormally warm summers, it can complete its life cycle in one year, dramatically increasing the population and the resulting damage. This has occurred recently in Alaska and Canada.

Spruce Beetle Infestations in the Yukon, 1994-2002



The spruce bark beetle has killed trees on about 300 000 hectares in the Alsek River corridor in Kluane National Park and in the Shakwak Valley north of Haines Junction since an outbreak was first identified in 1994. This is the largest and most intense outbreak of spruce bark beetle ever to affect Canadian trees. It is also the most northerly outbreak ever in Canada. 2002 was particularly intense, as aerial surveys recorded a 300% increase in the extent of infested areas as well as an increase in the severity of the attack.

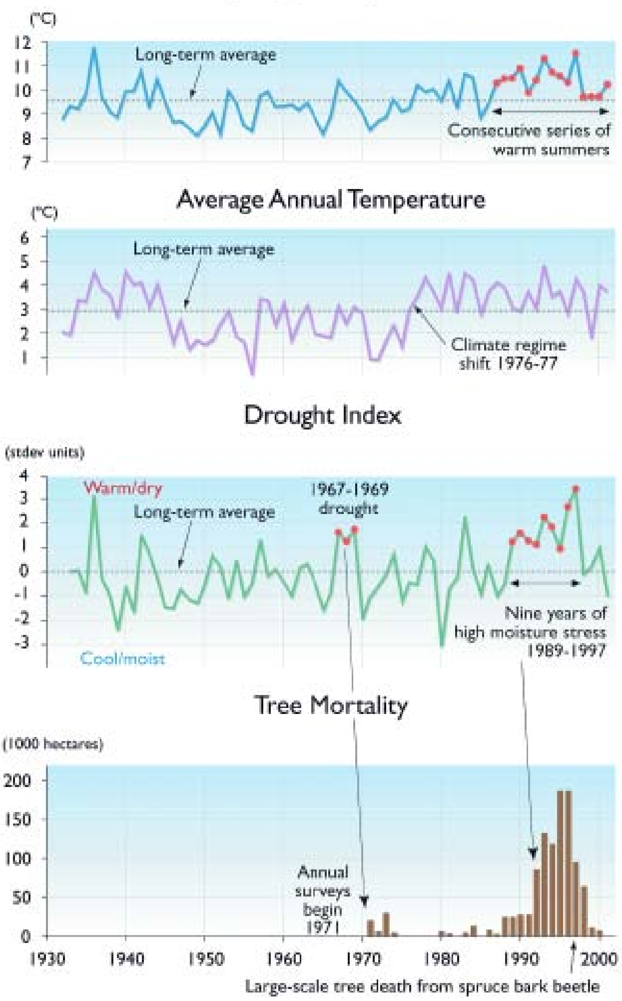
Spruce Beetle Activity Kenai Peninsula 1994-1999



During the 1990s the Kenai Peninsula in Alaska experienced the world's largest outbreak of spruce bark beetles (SBB). Since 1989, more than 1.6 million hectares of mature white spruce and Sitka/Lutz spruce forest in south-central Alaska have been affected with at least 10% to 20% tree mortality, the threshold level for aerial mapping detection.

- Tree Mortality due to SBB
- Past Tree Mortality due to SBB
- Forest
- Non-Forest
- Glacier

Spruce Bark Beetle Outbreaks
Southern Kenai Peninsula



In addition, healthy spruce trees can successfully resist moderate numbers of beetle attacks by using their pitch, under high pressure, to push back against the female beetles trying to bore into the tree to lay eggs; the beetles are generally unable to overcome the flow of pitch. However, host trees under stress due to heat and drought have reduced growth reserves, leading to reduced amounts and lower pressure of pitch, and so a reduced ability to resist beetle attacks. When entire populations of trees are stressed by regional climatic events, such as has occurred recently in Alaska and parts of Canada, spruce bark beetle success is greatly increased and large-scale tree damage and loss occurs.

Spruce Budworm

The entire range of white spruce forests in North America is considered vulnerable to outbreaks of spruce budworm under projected climate change.

Spruce Budworm

Weather is a critical factor in determining spruce budworm distribution. Sudden upsurges in budworm numbers generally follow drought and the visible effects of these outbreaks begin after hot, dry summers. Drought stresses the trees, reducing their resistance, and elevated summer temperatures increase budworm reproduction. For example, female budworms lay 50% more eggs at 25˚C than at 15˚C. Also, higher temperatures and drought can shift the timing of budworm reproduction such that their natural predators are no longer effective in limiting budworm numbers. Conversely, cold weather can stop a budworm outbreak. Budworms starve if a late spring frost kills the new shoot growth of the trees on which the larvae feed.

Thus it is to be expected that climate warming would result in the northward movement of the spruce budworm and this has already occurred. Before 1990, spruce budworm had not appeared able to reproduce in the boreal forest of central Alaska. Then, in 1990, after a series of warm summers, a sudden and major upsurge in spruce budworm numbers occurred and visible damage to the forest canopy spread over several tens of thousands of hectares of white spruce forest. Populations of spruce budworm have since persisted in this area near the Arctic Circle. The entire range of white spruce forests in North America is considered vulnerable to outbreaks of spruce budworm under projected climate change. In the Northwest Territories of Canada, for example, the northern limit of current spruce budworm outbreaks is approximately 400 kilometers south of the northern limit of its host, the white spruce. Therefore, there is potential for a northward expansion of spruce budworm to take over this remaining 400 kilometer-wide band of currently unaffected white spruce forest.

Spruce Budworm infestation in Canada.

3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

About four million hectares of boreal forest in Russia burned annually over the past three decades, and the amount more than doubled in the 1990s.

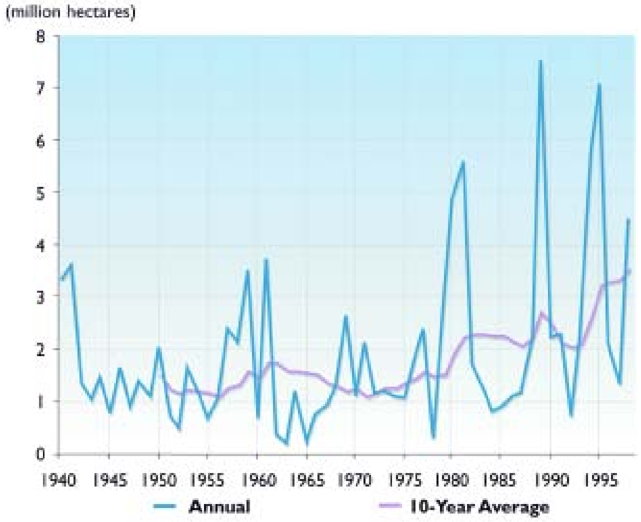
Forest Fires

Fire is another major disturbance factor in the boreal forest and it exerts pervasive ecological effects. The area burned in western North America has doubled over the past thirty years, and it is forecast to increase by as much as 80% over the next 100 years under projected climate warming. Models of forest fire in parts of Siberia suggest that a summer temperature jump from 9.8˚C to 15.3˚C would double the number of years in which there are severe fires, increase the area of forest burned annually by nearly 150%, and decrease average wood stock by 10%.

Fires in Eurasian Forests

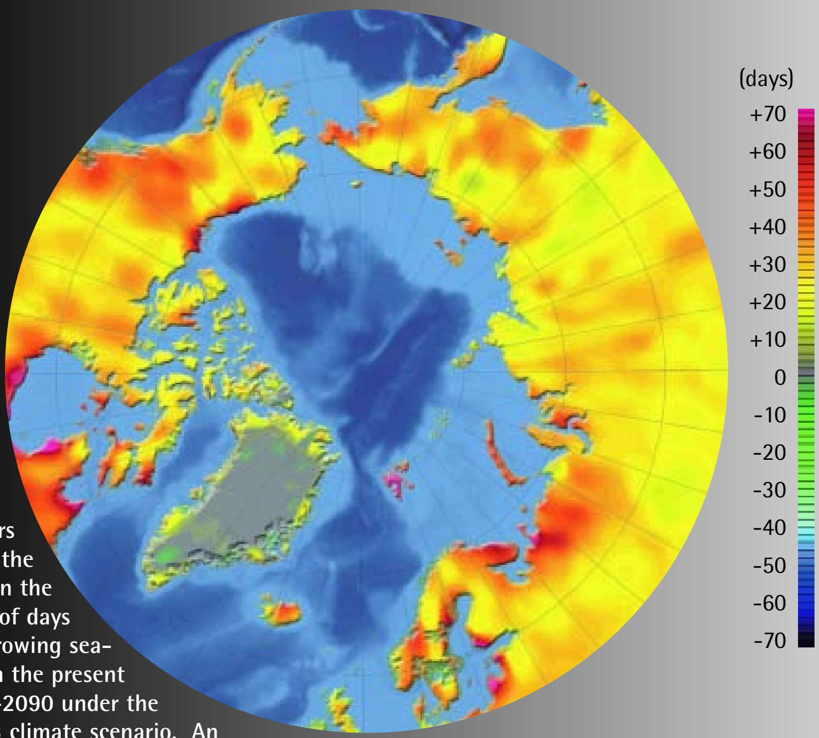
The area of boreal forest burned annually in Russia averaged four million hectares over the last three decades, and more than doubled in the 1990s. As climate continues to warm, the forest fire season will begin earlier and last longer. Projected changes in climate would greatly increase the area subjected to the types of weather that cause extreme fire danger. Under those conditions, fire spread in boreal forests of Eurasia would greatly increase if ignitions occurred. Fires are also expected to be more frequent and of higher intensity in all ecosystems, including bogged forests and peat bogs that that contain vast amounts of carbon-based forest materials such as moss, wood, and leaves. It is projected that about one billion tonnes of this organic matter will burn annually, increasing carbon emissions to the atmosphere. However, some scenarios suggest that it is possible that fire would become more frequent in some regions and less frequent in others, greatly affecting individual areas but amounting to only a small overall change in the total amount of fire.

Boreal Forest Burned in North America



The graph shows the area of North American boreal forest that burned each year, in millions of hectares. The average area burned has more than doubled since 1970, coinciding with climatic warming in the region.

Projected Change in Growing Season Length by 2070-2090
Minimum Temperature greater than 0˚C



The colors indicate the change in the number of days in the growing season from the present to 2070-2090 under the Hadley 3 climate scenario. An average of three climate model's results suggests about a 20-30 day increase in the growing season for areas north of 60˚ latitude. The growing season is defined as the number of consecutive days in which the minimum temperature is above 0˚C.

Agricultural Opportunities are Likely to Expand

Arctic agriculture is a relatively small enterprise in global terms, though some nations, such as Iceland, produce more than enough meat and dairy products to sustain their populations. Agriculture in the north consists mostly of cool-season forage crops; cool-season vegetables; small grains; raising cattle, sheep, goats, pigs, and poultry; and herding reindeer. While agriculture is limited by climate in the Arctic, especially in the cooler parts, it is also limited by the lack of infrastructure, small population base, remoteness from markets, and land ownership issues. Climatic limitations include short growing seasons (not enough time for crops to mature or to produce high yields of harvestable crops), lack of heat energy (days not warm enough during the growing season), long cold winters that can limit survival of many perennial crops, and moisture stress in some areas.

Climate warming is projected to advance the potential for commercial crop production northward throughout this century.

Key Finding #3

Climate change is projected to advance the potential for commercial crop production northward throughout this century, with some crops now suitable only for the warmer parts of the boreal region becoming suitable as far north as the Arctic Circle. Average annual yield potential is likely to increase as the climate becomes suitable for higher yielding varieties and the probability of low temperatures limiting growth is reduced. However, in warmer areas, increased warmth during the growing season may cause slight decreases in yields since higher temperatures speed development, reducing time to accumulate dry matter. Longer and warmer growing seasons are expected to increase the potential number of harvests and hence seasonal yields for perennial forage crops.

Uncertainty about winter conditions make forecasts about survival potential for crops difficult. Warmer winters could actually decrease survival of some perennial crops if winter thaws followed by cold weather become more frequent. This would be especially true in areas with little snowfall. However, longer growing seasons, especially in autumn, should result in a northward extension of conditions suitable for producing crops such as alfalfa and barley.

Water deficits are likely to increase over the next century in most of the boreal region because increases in warm-season precipitation are unlikely to keep up with increased evaporation due to higher temperatures. Unless irrigation is used, water stress is likely to negatively affect crop yields and water limitation is likely to become more important than temperature limitations for many crops in much of the region. Areas that are unlikely to experience water deficits include parts of eastern Canada, western Scandinavia, Iceland, and the Faroe Islands, which all experience fairly maritime climates.

Insects, diseases, and weeds are likely to increase throughout the Arctic with climate warming, although these problems are unlikely to offset potential yield increases or potential for new crops in most cases. However, severe outbreaks could indeed have that effect. For example, studies suggest that climate warming in Finland will increase the incidence of potato blight to the point that it will significantly decrease potato yield in that country.

Lack of infrastructure, small population (limited local markets), and long distance to large markets are likely to continue to be major factors limiting agricultural development in most of the Arctic during this century.