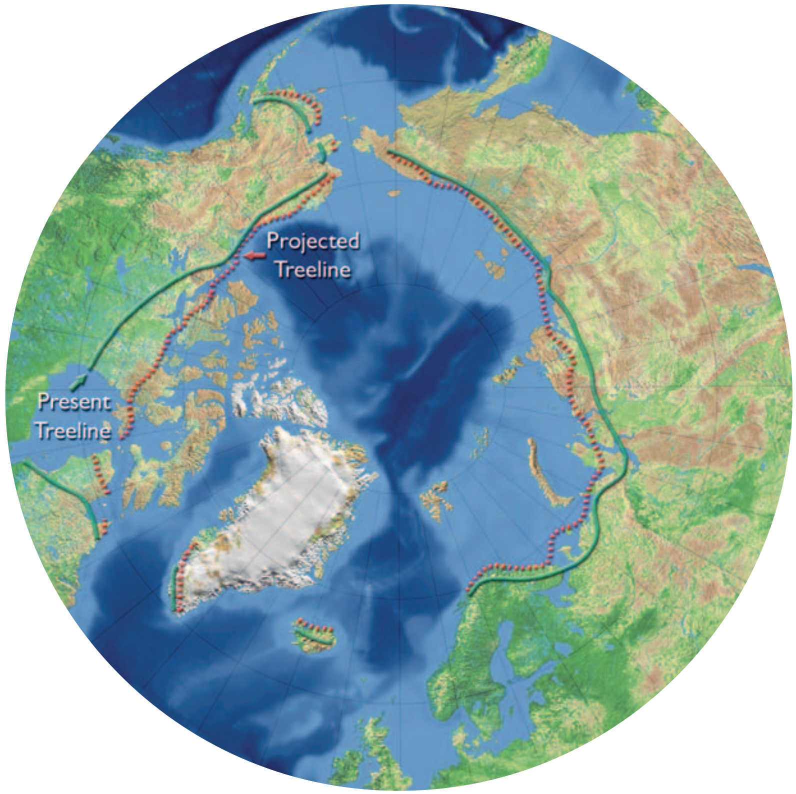
IMPACTS OF A WARMING ARCTIC

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

Northward Shifting Treeline



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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.

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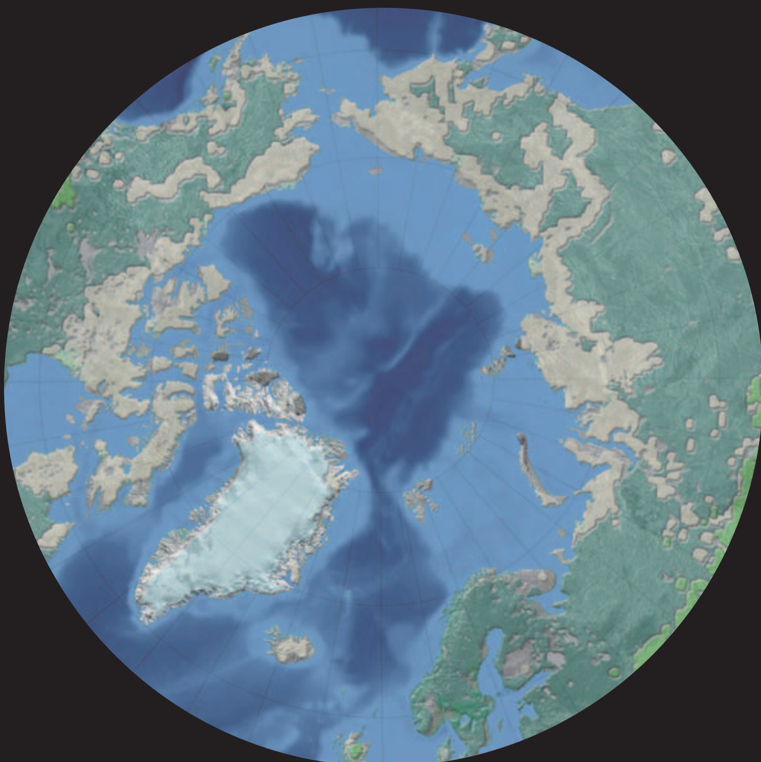
Current Arctic Vegetation



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

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

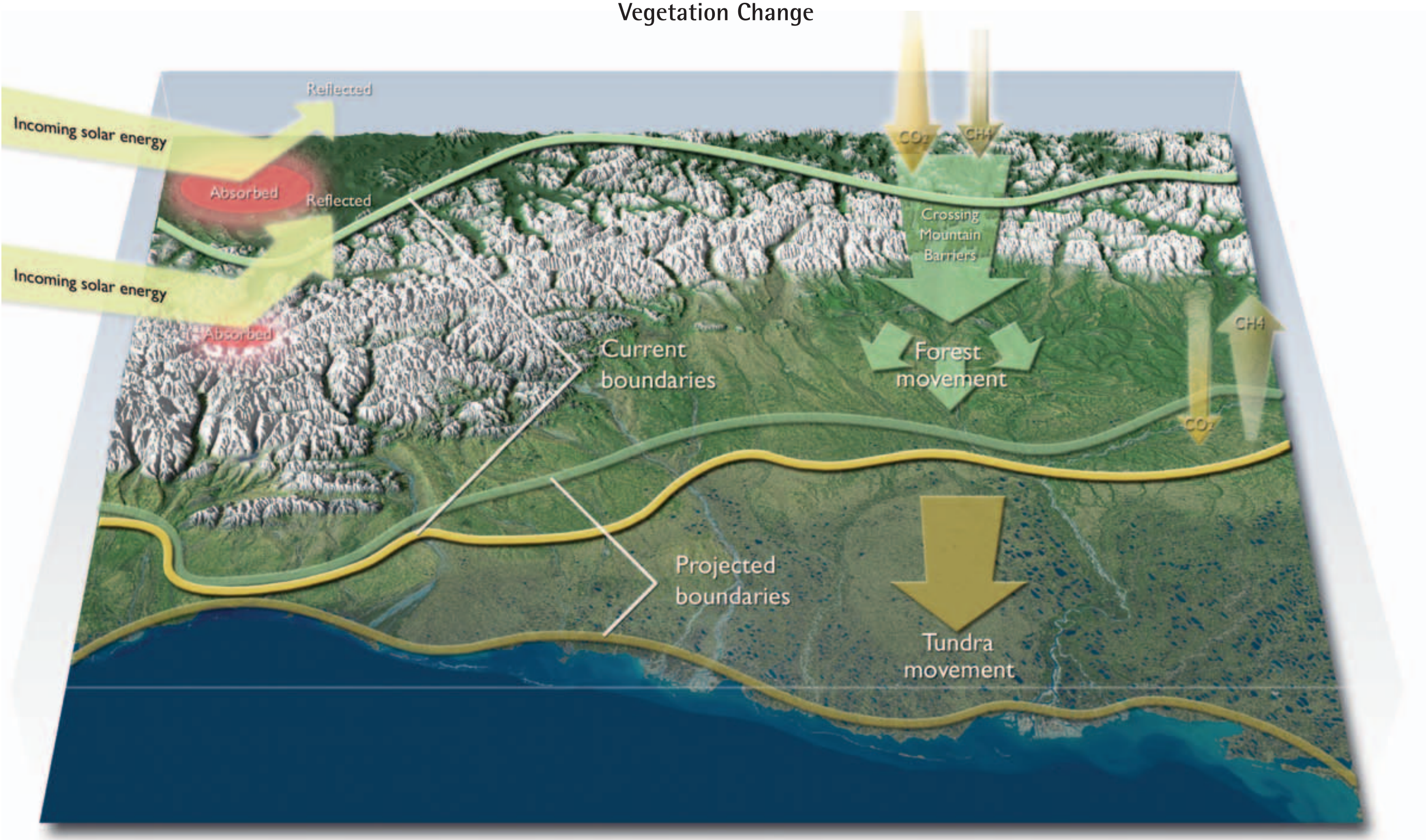
Projected Vegetation, 2090-2100

- 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.

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

Vegetation Change



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

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.

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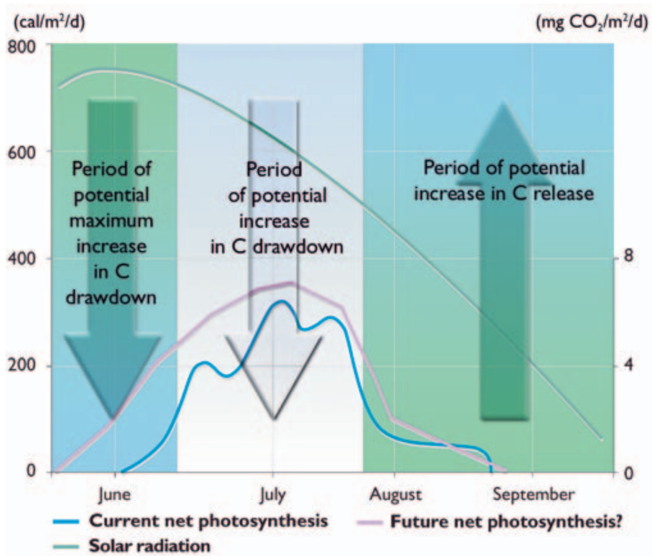
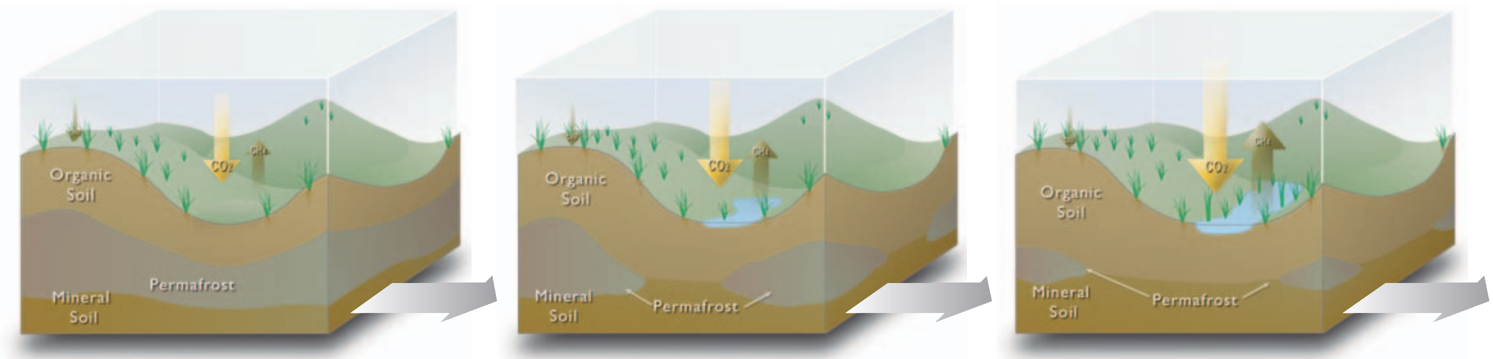
Seasonal Switch from Carbon Sink to Carbon Source



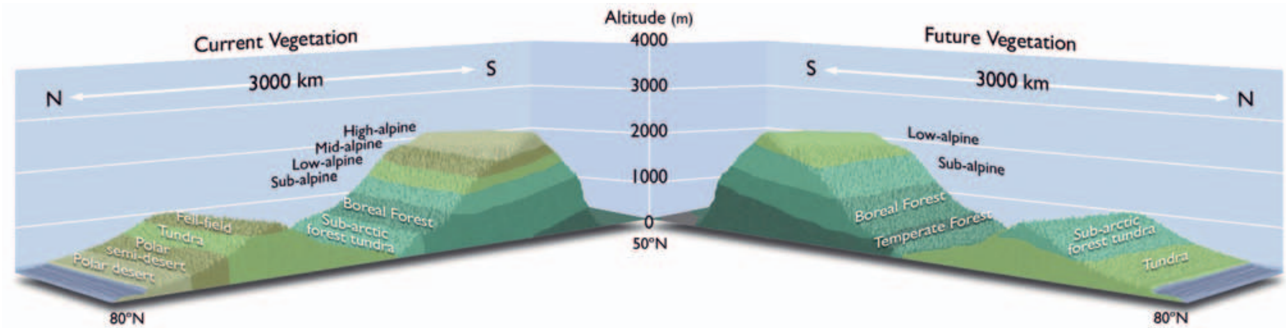
3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

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.

Vegetation Zone Shift



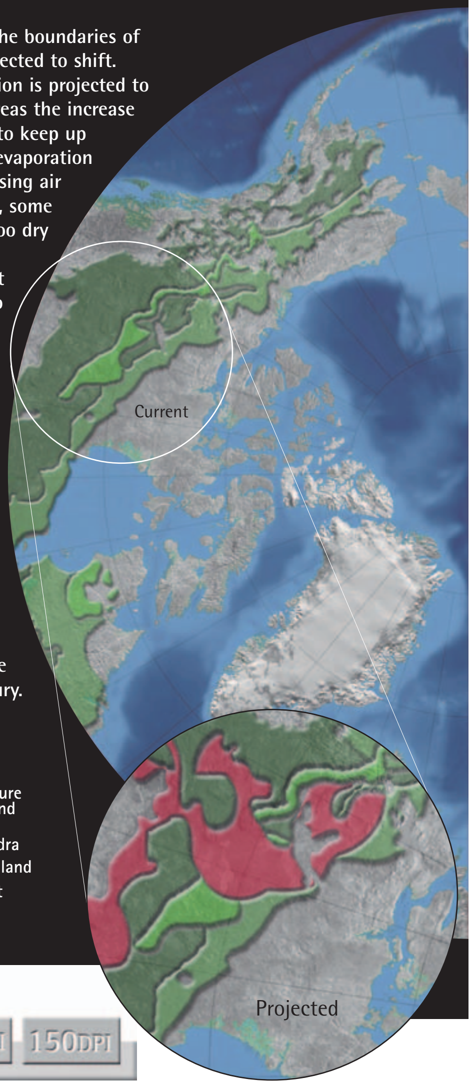
This schematic illustrates the projected upslope and northward displacement of vegetation zones in the Arctic as a result of future warming. Note the difference in altitude of vegetation boundaries on north and south facing slopes. The altitudinal and latitudinal zones are analogous, but not identical.

IMPACTS OF A WARMING ARCTIC

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

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

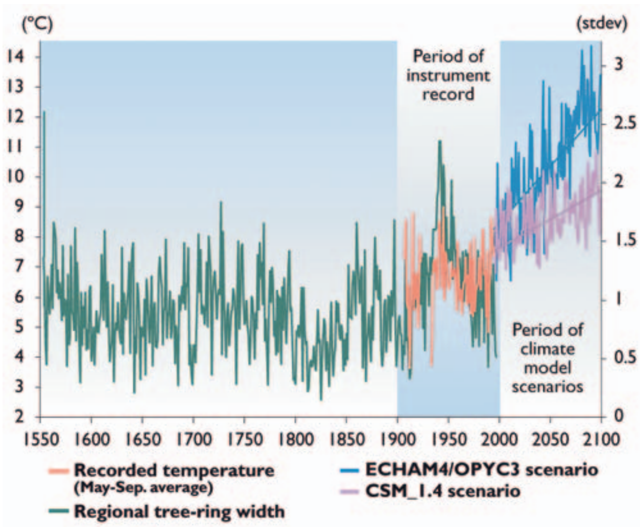
As climate warms, the boundaries of forest types are expected to shift. Although precipitation is projected to increase, in some areas the increase will be insufficient to keep up with the increased evaporation that accompanies rising air temperatures. Thus, some areas will become too dry to support 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

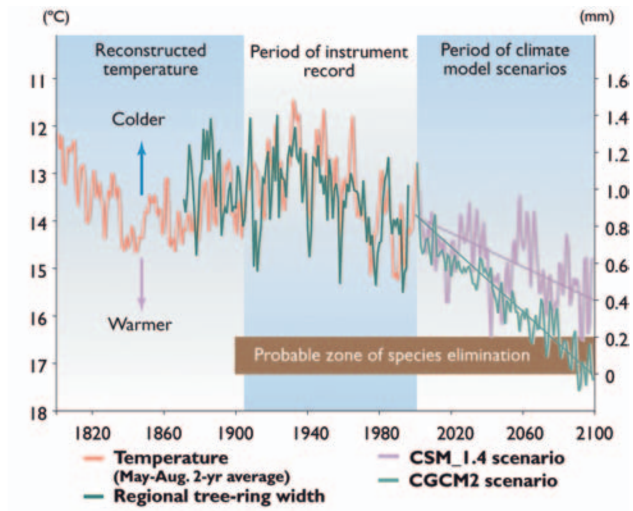
This map of forest types in Eurasia illustrates how climate affects forest distribution. In the colder northern part of the region, there is a southward displacement of forest types compared to the western part. As climate warms, some areas that are currently sparsely vegetated are expected to become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

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.

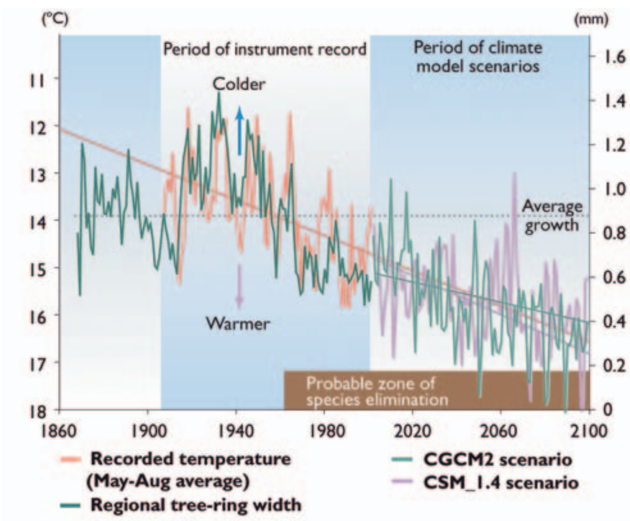
White Spruce Response to Warming



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.

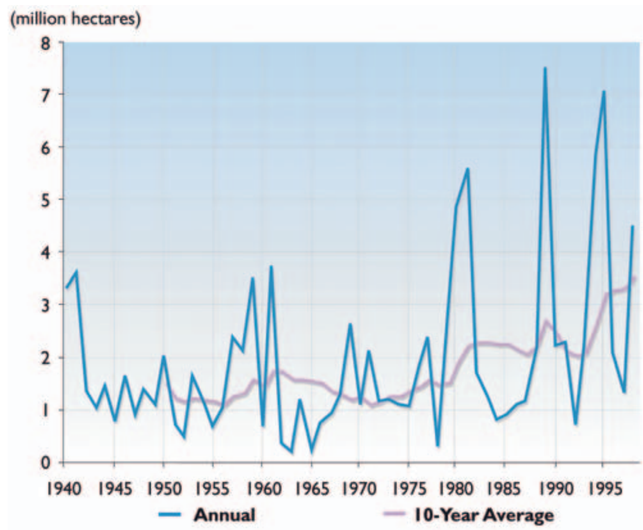
3 Arctic vegetation zones are very likely to shift, causing wide-ranging impacts.

Black Spruce Response to Warming



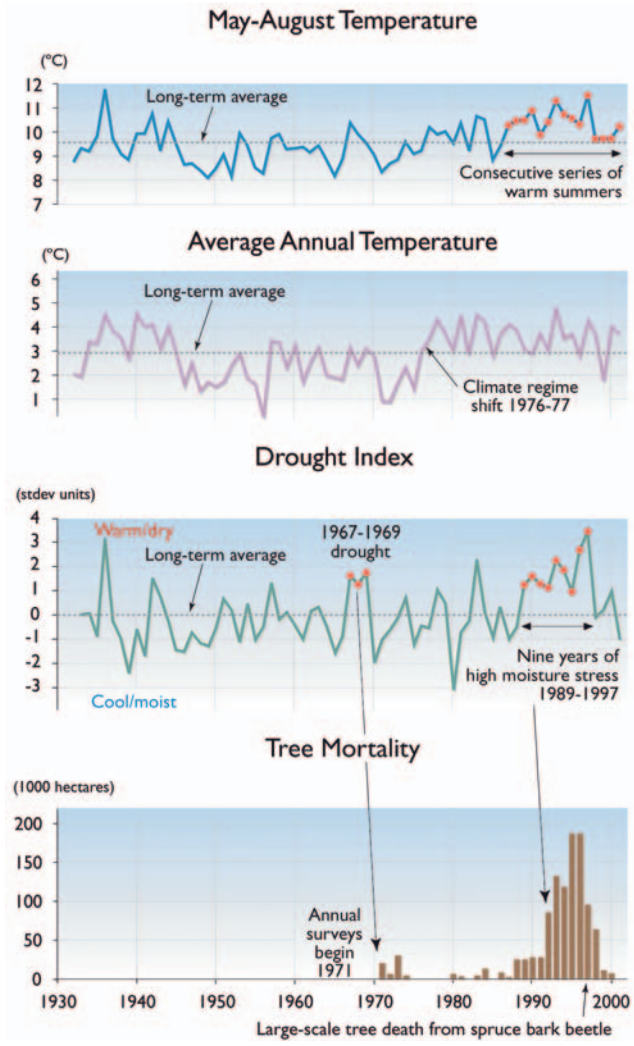
The graph shows the relationship of summer temperatures at Fairbanks, Alaska and relative growth of black spruce, historically and for two future warming scenarios. Average summer temperature is an excellent predictor of black spruce growth, with warm years resulting in strongly reduced growth. By 2100,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

Boreal Forest Burned in North America

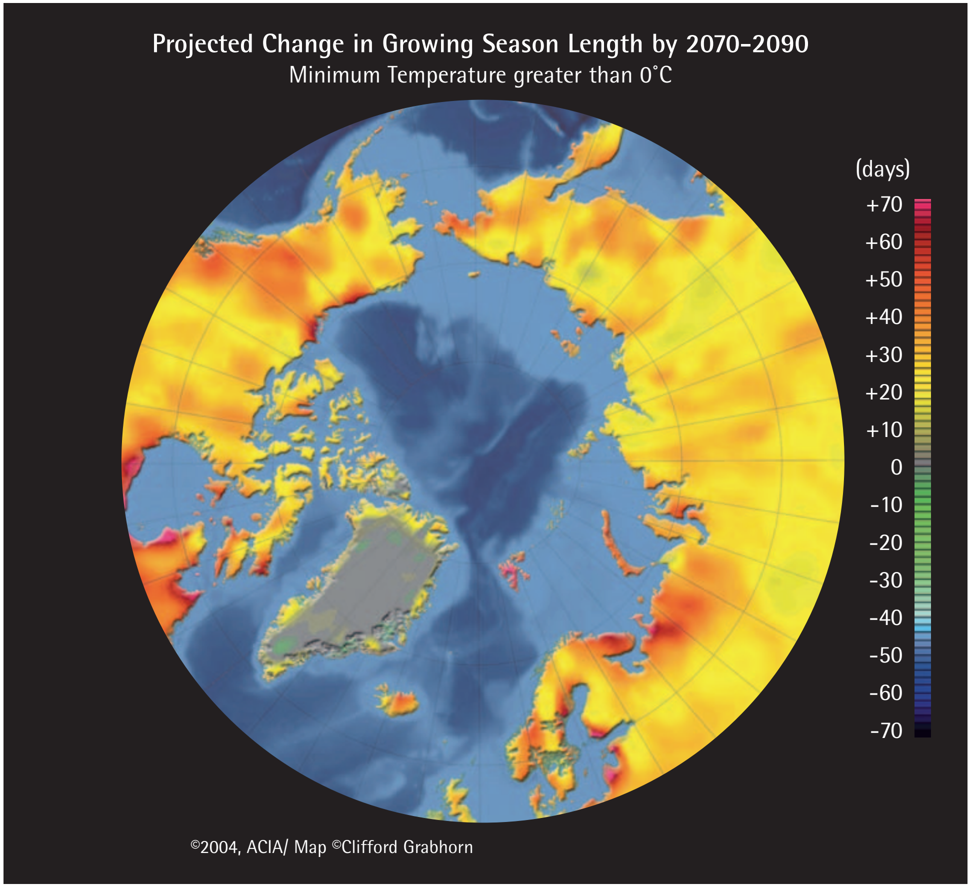


The graph shows the area of North American boreal forest that burned each year, in millions of hectares. The average area burned has more than doubled since 1970, coinciding with climatic warming in the region.

Spruce Bark Beetle Outbreaks
Southern Kenai Peninsula



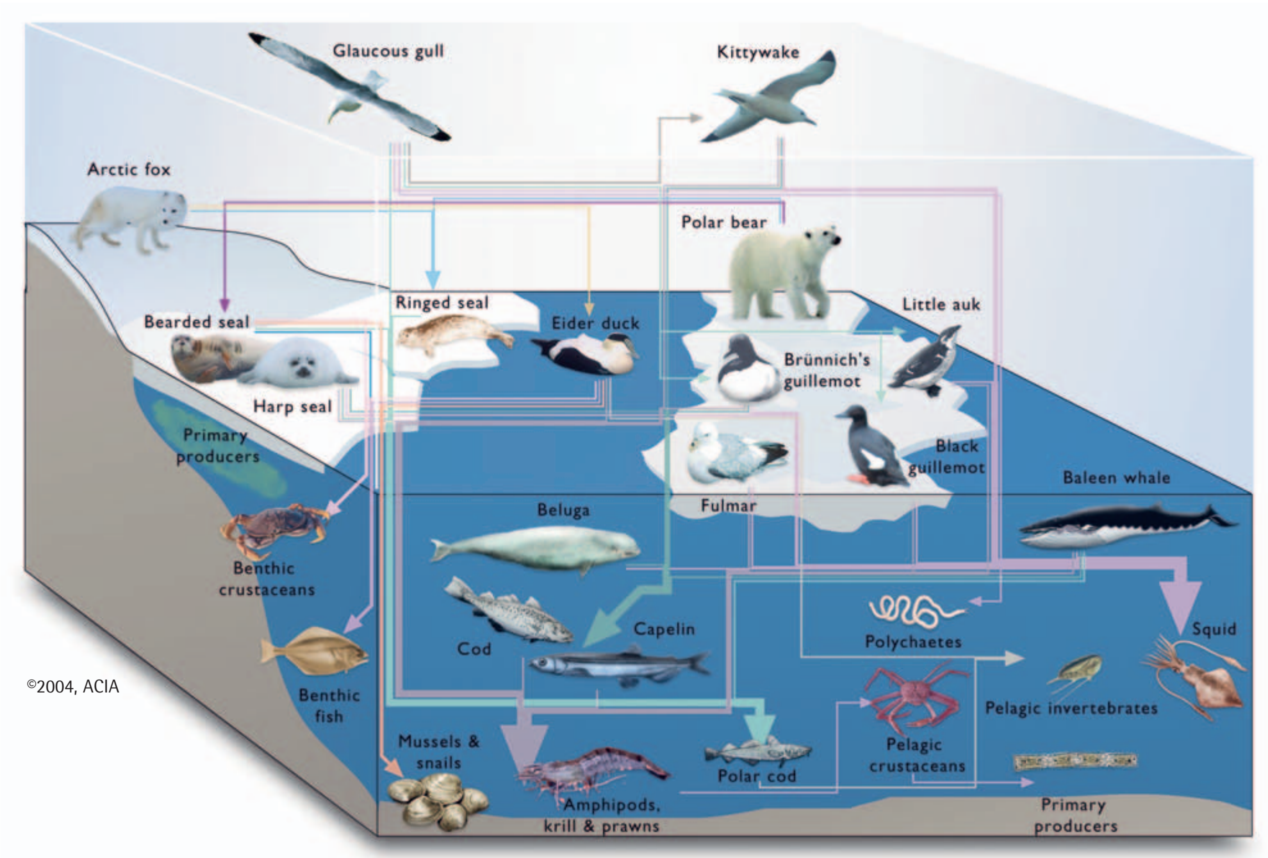
The relationship of the spruce bark beetle to climate involves three factors, including two direct controls on insect populations and an indirect control on tree resistance. First, two successive cold winters depress the survival rate of the bark beetle to a level low enough that there is little outbreak 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.



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.

4 Animal species' diversity, ranges, and distrubution will change.

Arctic Marine Food Web



Research in the Beaufort Sea suggests that ice algae at the base of the marine food web may have already been profoundly affected by warming over the last few decades.

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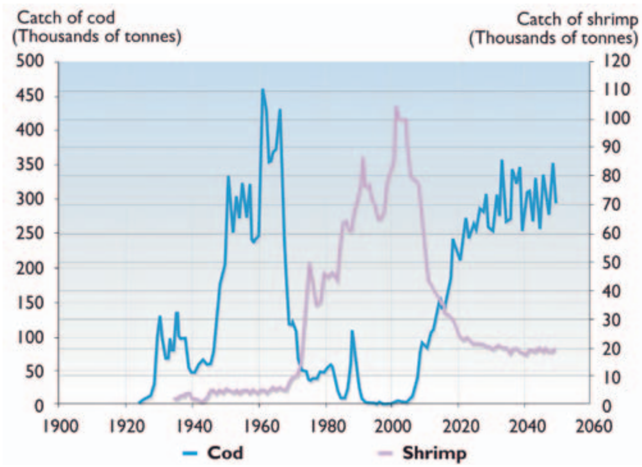
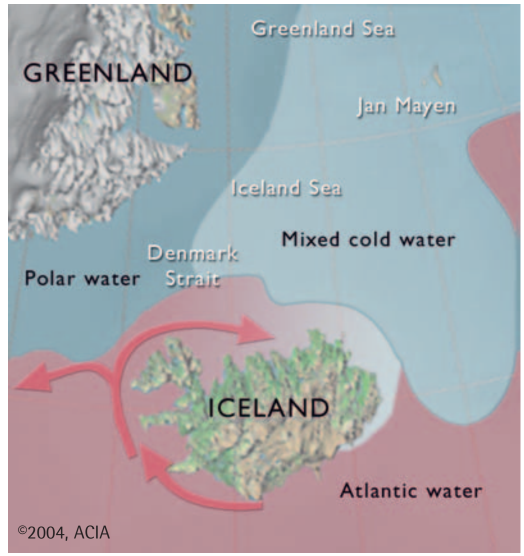
Observed and Projected Harvests



Past and potential future development of cod and shrimp harvest off Greenland with climate change.

Mixing Waters and Fish Drift Routes

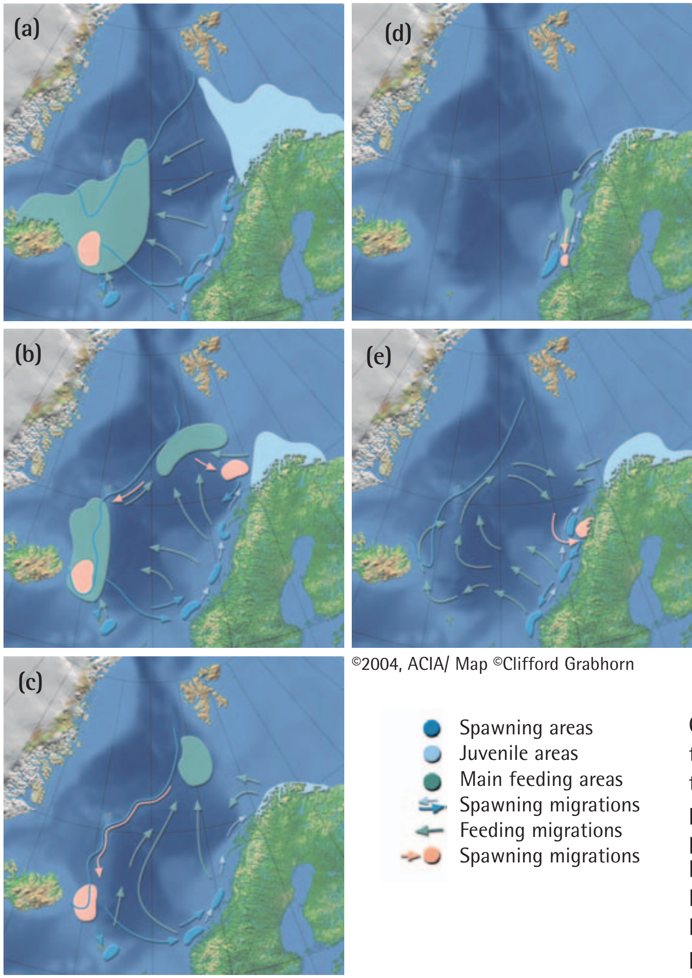


The main water masses in the Iceland-East Greenland-Jan Mayen areas. The red arrows indicate the main drift routes of larvae and fish less than one year old.

IMPACTS OF A WARMING ARCTIC

4 Animal species' diversity, ranges, and distrubution will change.

Historic Changes in Migration Routes



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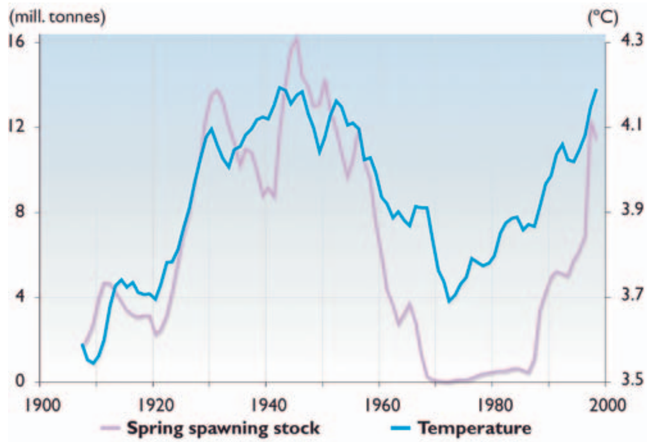
Changes of migration routes (left), and feeding and wintering areas of Norwegian spring spawning herring during the latter half of the 20th century. (a) Normal migration pattern during the warm period before 1965. (b-c) After a pulse of sea ice and freshwater from the Arctic sent cold, low-salinity water into the East Greenland and the East Icelandic currents, until the stock collapsed in 1968. (d) During years of low stock abundance (1972-1986). (e) The present day migration pattern.

Herring Spawning Stock and Temperature



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Norwegian spring spawning herring stocks increased greatly during the warming period of the 1920s-1930s and then declined rapidly beginning in the late 1950s. Overfishing was the primary cause of the collapse of the population, although climatic cooling was probably a contributing factor.

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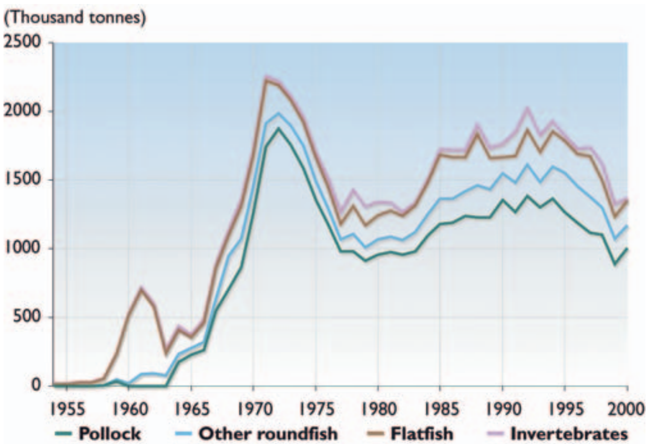
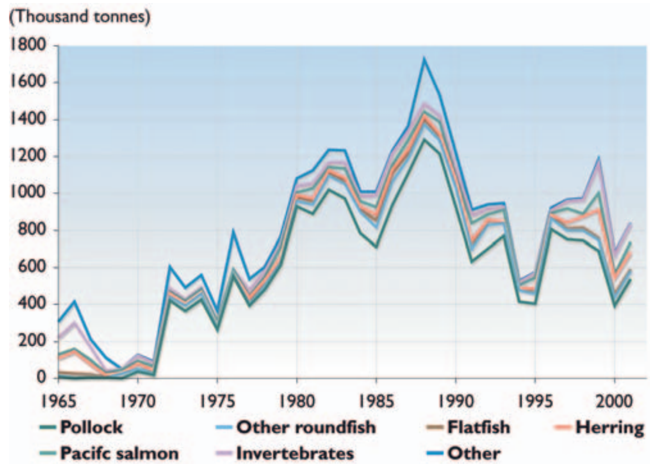
4 Animal species' diversity, ranges, and distrubution will change.

Eastern Bering Sea Catch, 1954-2000



Western Bering Sea Catch, 1965-2001



In the Bering Sea, rapid climate change is already apparent, and its impacts significant. The Bering Sea is experiencing a major warming in bottom water temperature that is forcing cold-water species of fish and mammals northward and/or into decline. The first concern of Bering Sea fisheries management is thus likely to be managing for the ecosystem reorganization that is and will continue to be taking place as a result of climate change.

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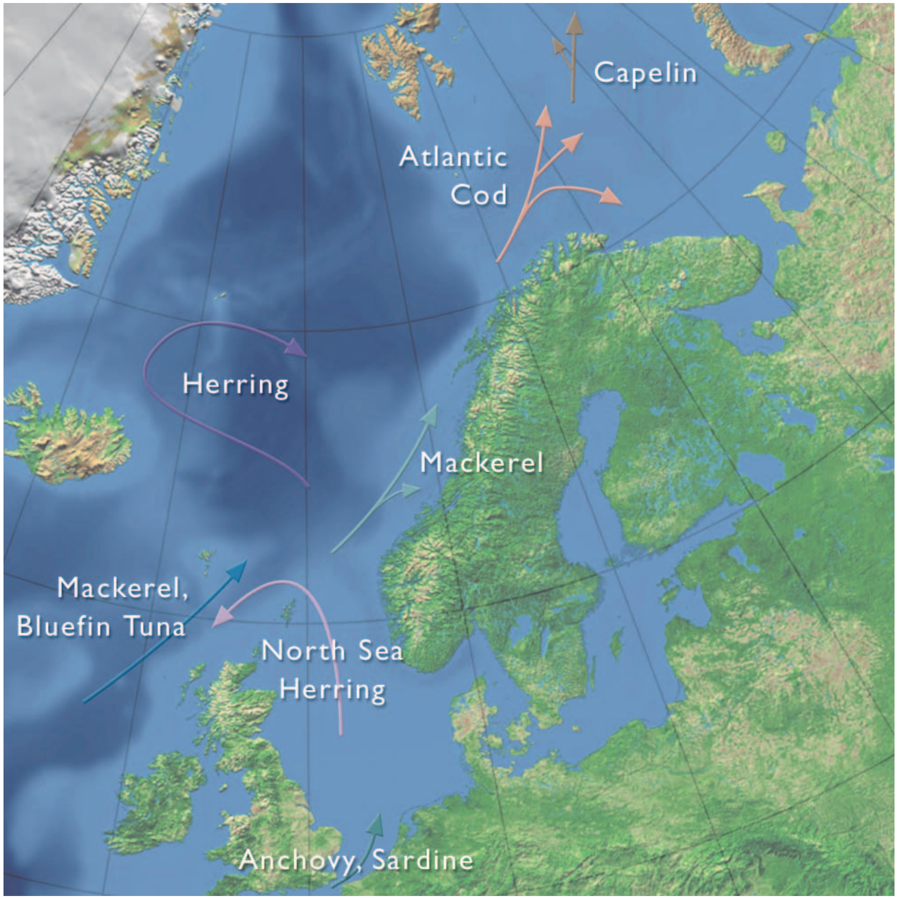
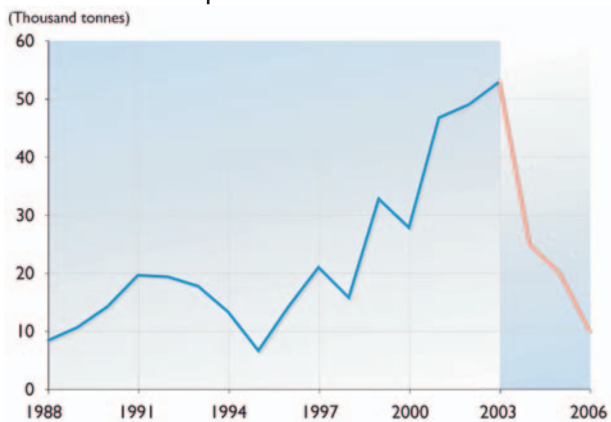
Possible Changes in Fish Distribution



Possible changes in the distribution of selected fish species the Norwegian and Barents Seas resulting from an increase in ocean temperature of 1 to 2˚C.

Possible Changes in Faroe Island Aquaculture Production

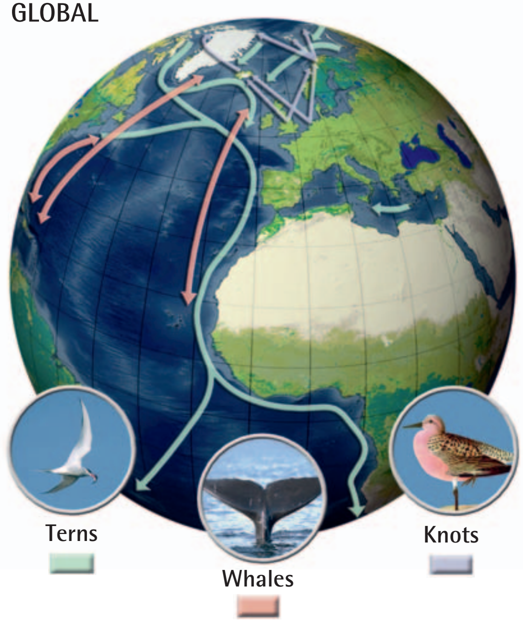


The production of farmed Atlantic salmon and rainbow trout 1988-2003. The red line is a projection for 2004-2006. The projected decrease reflects problems caused by fish diseases and economic issues. Climate change adds additional uncertainties.

IMPACTS OF A WARMING ARCTIC

4 Animal species' diversity, ranges, and distrubution will change.

GLOBAL



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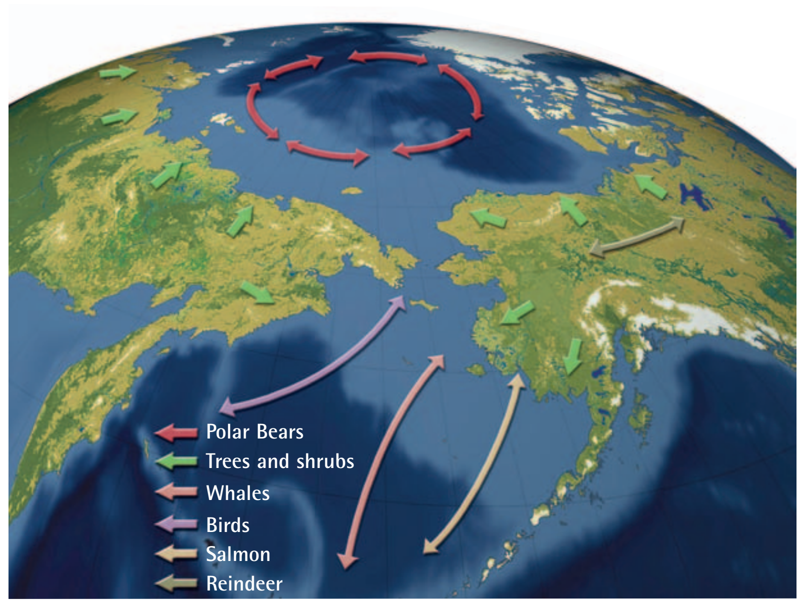
Long-distance animal migration routes are sensitive to climate-related changes such as alterations in habitat and food availability. The amplification of warming in the Arctic thus has global implications for wildlife.

REGIONAL LEVEL



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At the regional level, vegetation and the animals associated with it will shift in response to warming, thawing permafrost, and changes in soil moisture and land use. Range shifts will be limited by geographical barriers such as mountains and bodies of water. Shifts in plankton, fish, and marine mammals and seabirds, particularly those associated with the retreating ice edge, will result from changes in air and ocean temperatures and winds.

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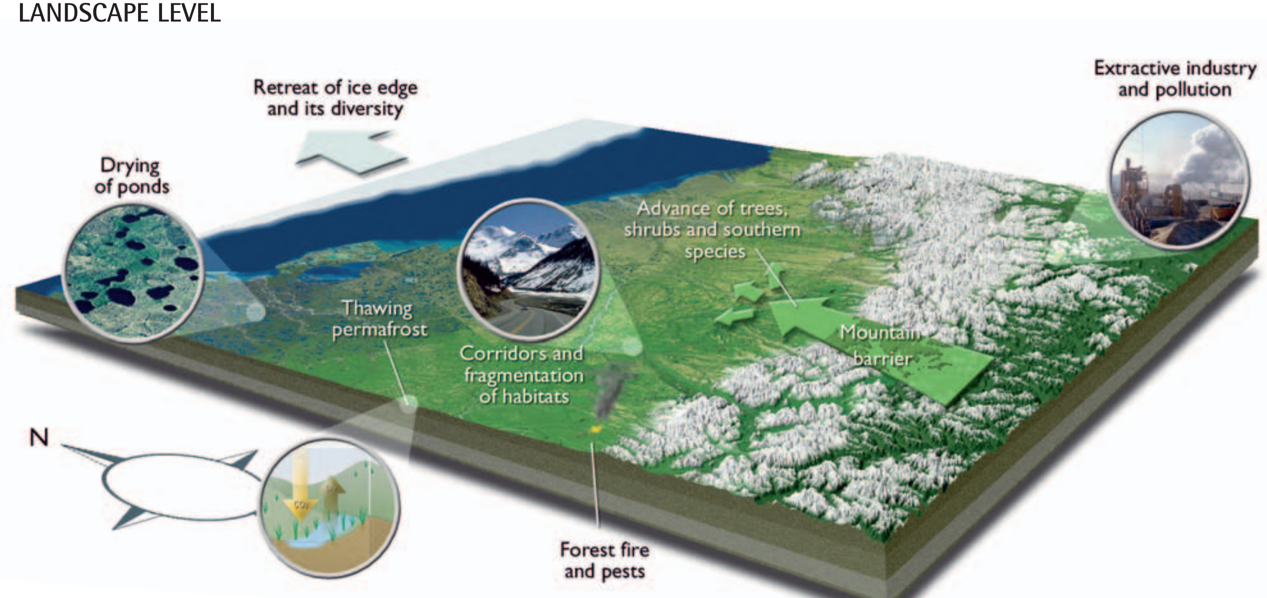
4 Animal species' diversity, ranges, and distrubution will change.

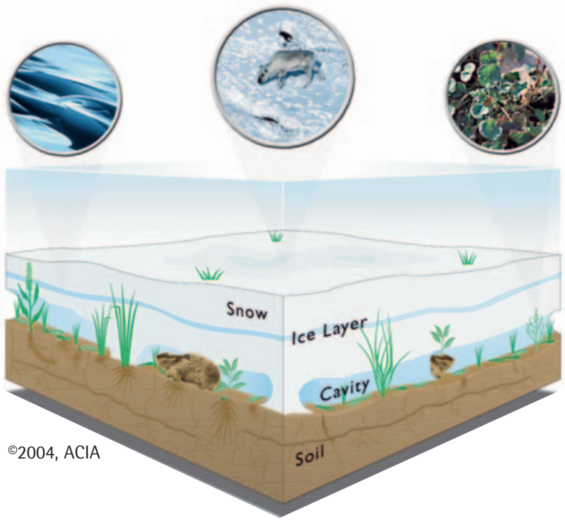
LANDSCAPE LEVEL



At the landscape level, shifts in the mosaic of soils and related plant and animal communities will be associated with warming-driven drying of shallow ponds, creation of new wet areas, land use change, habitat fragmentation, and pests and diseases. These changes will affect animals' success in reproduction, dispersal, and survival, leading to losses of northern species and range extensions of southern species.

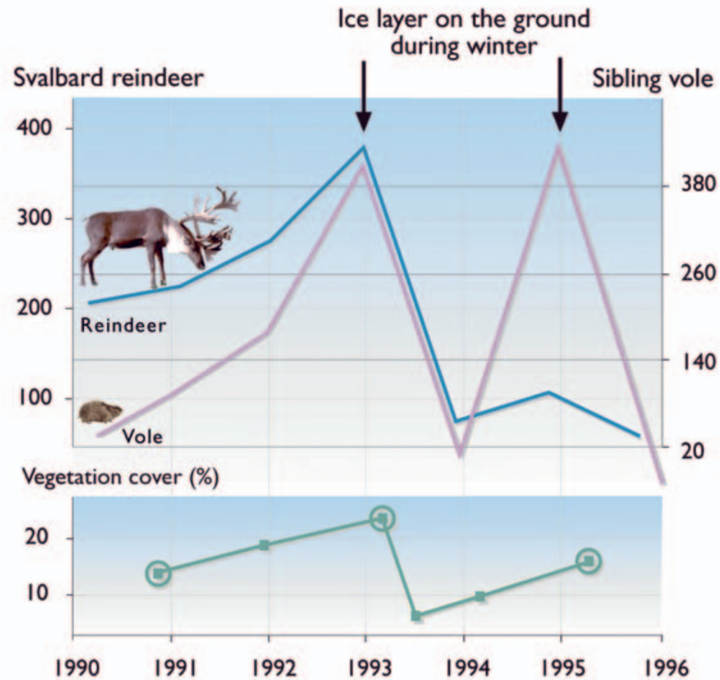
4 Animal species' diversity, ranges, and distrubution will change.

PLOT LEVEL



Changes in snow conditions, ice layers, the cavity beneath the snow, summer temperatures, and nutrient cycling act on individual plants, animals, and soil microorganisms leading to changes in populations. It is at the level of the individual animal and plant where responses to the climate take place leading to vegetation shifts across the earth.

Cascading Impacts in a Changing Climate



Population dynamics (number of individuals in a particular area) of Svalbard reindeer and sibling voles on Svalbard, along with observed (circles) and projected (squares) changes in vegetation.

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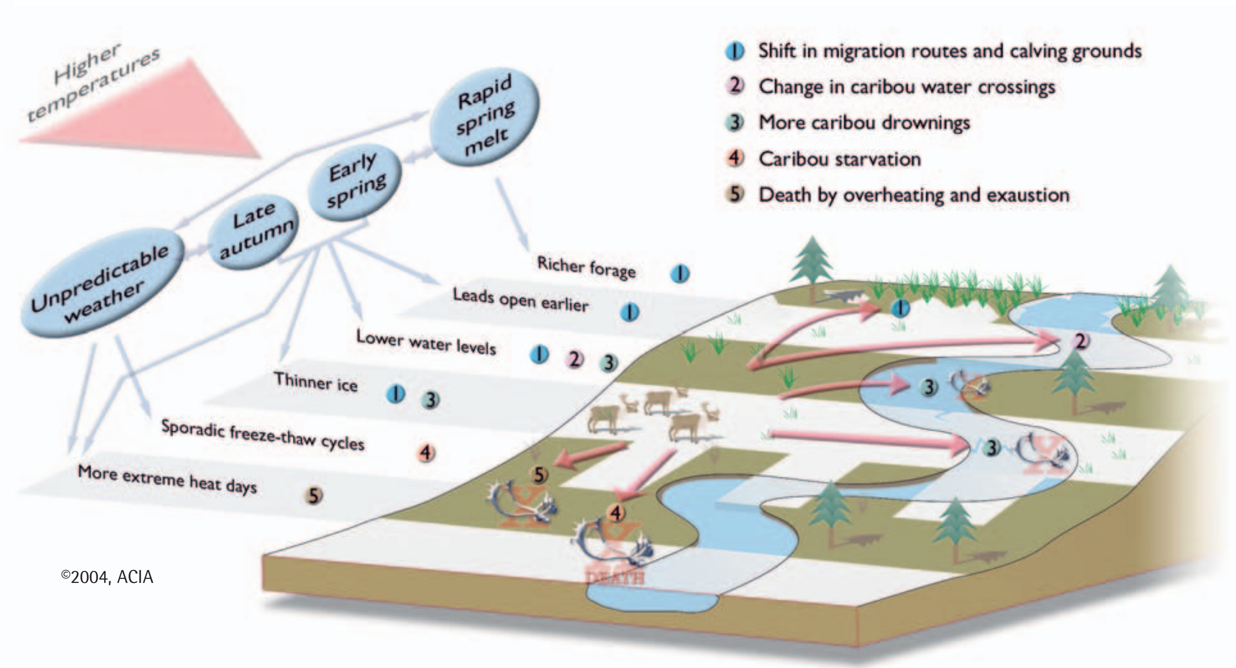
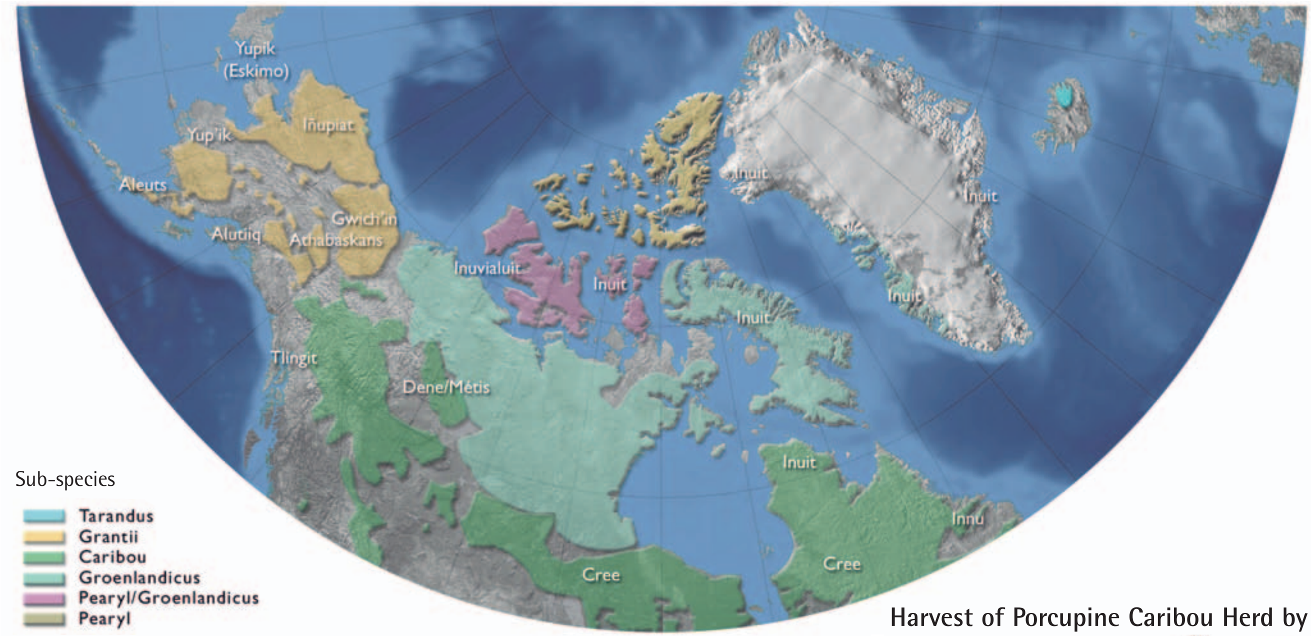
Kitikmeot Inuit Observations of Impacts of Warming on Caribou



Climate-induced changes to arctic tundra are projected to cause vegetation zones to shift significantly northward, reducing the area of tundra and the traditional forage for these herds. Freeze-thaw cycles and freezing rain are also projected to increase. These changes will have significant implications for the ability of caribou and reindeer populations to find food and raise calves. Future climate change could thus mean a potential decline in caribou and reindeer populations, threatening human nutrition for many indigenous households and a whole way of life for some arctic communities.

4 Animal species' diversity, ranges, and distrubution will change.

Caribou Ranges and Indigenous Peoples of North America



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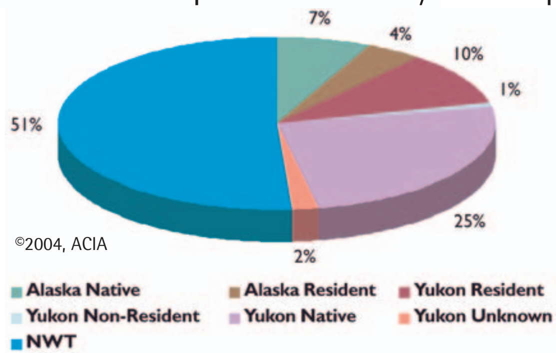
Harvest of Porcupine Caribou Herd by User Group



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This chart (right) apportions annual average harvest of the Porcupine Caribou Herd in northwestern Canada and northeastern Alaska by user group. Approximately 89% of the harvest is taken in Canada, and more than 90% of the total harvest is taken by indigenous communities.

IMPACTS OF A WARMING ARCTIC

4 Animal species' diversity, ranges, and distrubution will change.

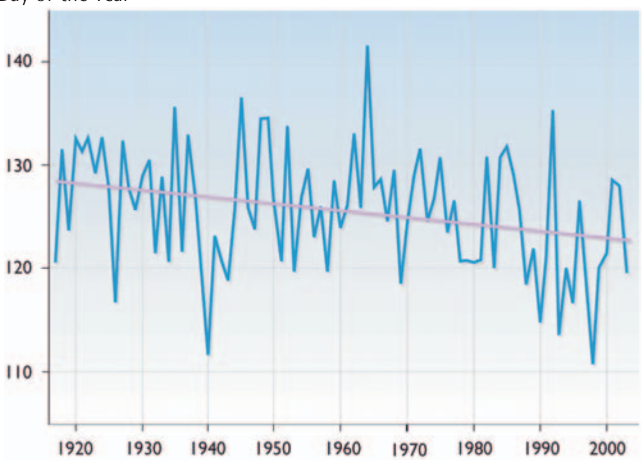
Potential Climate Change Impacts on the Porcupine Caribou Herd

Climate Change Condition	Impact on Habitat	Impact on Movement	Impact on Body Condition	Impact on Productivity	Management Implications
Earlier Snow Melt on Coastal Plain	Higher plant growth rate	Core calving grounds move further north	Cows replenish protein reserves faster	Higher probability of pregnancy	Concern over development on northern portion of present core calving area
		Less use of foothills for calving	Higher calf growth rate		
			Lower predation risk	Higher June calf survival	
Warmer, Drier Summer	Earlier peak biomass	Movement out of Alaska earlier in season	Increased harassment resulting in lower body condition	Lower probability of pregnancy	Protection of insect relief areas important
	Plants harden earlier	More use of coastal zone while in Alaska			
	Reduction in mosquito breeding sites	More dependence on insect relief areas, especially from mid- to late July			
	Significant increase in oestrid activity				
	Greater frequency of fire on winter range				
	Fewer "mushroom" years				
Warmer, Wetter Autumn	More frequent icing conditions	Caribou abandon ranges with severe surface icing	Unknown	Unknown	Protection of low snow regions
Warmer, Wetter Winter	Deeper denser snow	Increased use of low snow regions	Greater over-winter weight loss	Maternal bond broken earlier	
		Later to leave winter range			
Warmer Spring	More freeze / thaw days, snow forms ice layers	Move to windswept slopes	Accelerated weight loss in spring	Higher wolf predation due to use of windswept slopes	Concern over timing and location of spring migration in relation to harvest
	Faster spring melt	Faster spring migration			Lower productivity due to high spring mortality
Overall Effect	Calving range improves, summer, autumn and winter ranges probably lower quality	Seasonal distribution less predictable, timing less predictable	Improved June condition but later summer reduced condition, more rapid weight loss in winter and early spring	High pregnancy rates but overall lower survival and recruitment; Shift mortality later in year (late winter, spring); Herd more likely to decline	Need to assess habitat protection in relation to climate trends
	Extremes (such as very deep snow or very late melt) hard to adapt to				Need to factor climate change impacts on harvest levels
					Need to communicate impacts of climate on harvest patterns and timing
					Need to set up monitoring programs

4 Animal species' diversity, ranges, and distrubution will change.

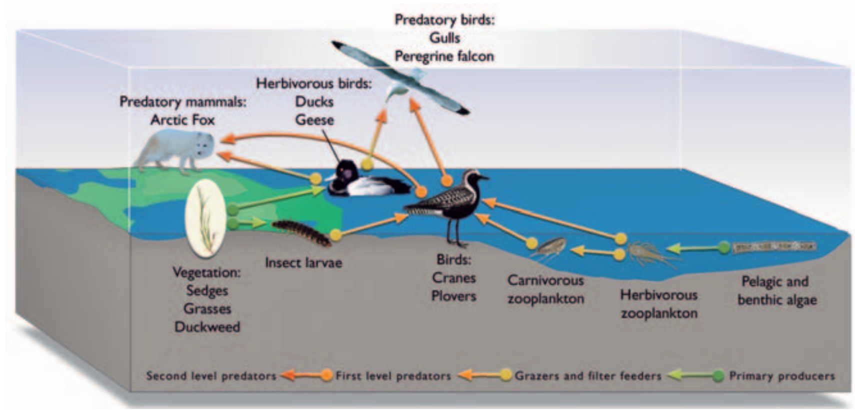
Tanana River Ice Break-up Dates

Day of the Year



The graph shows the ice break-up dates for the Tanana River at Nenana, Alaska over the last 80 years. Though there is considerable variability from year to year, there is a trend toward earlier break-up by over a week.

Freshwater Food Web



Warming is very likely to accelerate rates of contaminant transfer to the Arctic and increased precipitation is very likely to increase the amount of persistent organic pollutants and mercury that are deposited in the region. Increasing contaminant levels in arctic lakes will accumulate in fish and other animals, becoming magnified as they are transferred up the food chain.

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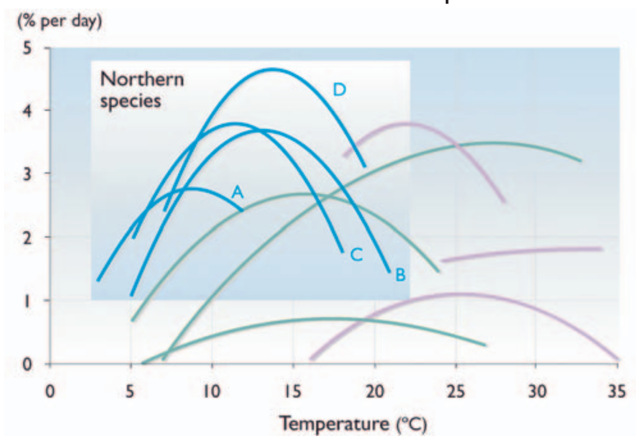
Fish Growth Rate and Temperature



These growth curves (in percent per day) for various fish species illustrate that growth typically increases with rising temperature up to a certain point and then declines as temperature continues to rise. Northern species (A. Arctic char, B. lake cisco, C. lake trout, and D. brook trout - all in blue) are grouped toward the lower temperatures on the left, and have a more peaked curve, indicating only narrow and typically low temperature ranges over which optimal growth is achieved. This suggests that their ability to adapt to a warming climate is likely to be quite limited. The unlabeled growth curves are for various lower latitude species.