Climate Change, Fire & Natural Vegetation: Implications for Wilderness Areas

by Kevin C. Ryan

Emissions from industrial processes, burning of fossil fuels, and slash-and-burn agriculture in the tropics are increasing the concentrations of greenhouse gasses in the atmosphere. Chief among these is carbon dioxide, but water vapor, ozone, methane, nitrous oxide, and various chlorofluorocarbons (CFCs) are also important. This "greenhouse effect" is expected to alter global circulation patterns and significantly change regional climate.

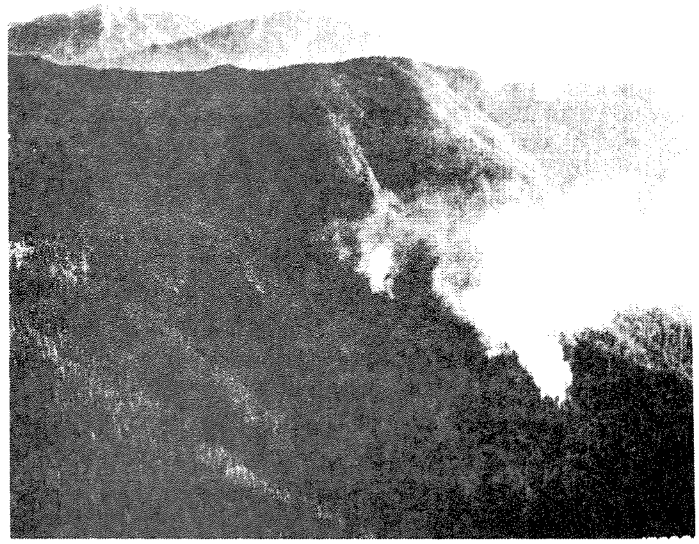
If global warming occurs, the increase in carbon dioxide and changes in climate will alter growth and competitive interactions of plant communities. As a result the structure and species composition of ecosystems will change. Superimposed on the relationship between climate and vegetation are interactions between climate and wildland fire and between vegetation and fire regimes. Climate change will directly affect the frequency and severity of weather favorable to fire. Changes in plant communities will affect fire regimes indirectly, by altering the physical and chemical properties of fuels. Fire is a major source of mortality in many communities. It creates gaps for new species. As a result, changes in fire regimes will modify the rate at which communities respond to climatic change.

The purpose of this paper is to stimulate further thought and research into the potential effects of global climate change on vegetation and fire, and to stimulate discussion on how wilderness vegetation and fire should be managed in the face of probable climate change.

Climate Change

Evidence now is undeniable that the global average concentration of carbon dioxide in the atmosphere is increasing. It is expected to double by the middle of the next century. Doubling carbon dioxide is expected to result in approximately a 4 °C mean global temperature rise, with possibly 7 to 11 percent increases in global mean precipitation and evaporation. Strong seasonal precipitation patterns including summer drought are suspected for mid-latitude continental climates. Maritime climates may be wetter, but it is uncertain if increases in precipitation will be adequate to compensate for higher temperatures.

There is much uncertainty as to the magnitude of effects of increased carbon dioxide on global climate. However, considerable climate change is possible in western wilderness areas. For example, one possible scenario is for summer and winter temperatures to be 4 °C and 6 °C higher, respectively, throughout much of the Rocky Mountain region, with the growing season extended by 1 to 2 months depending on latitude and altitude. Average annual precipitation could increase or decrease as much as 20%, and little summer rain is expected. Increased carbon dioxide and temperature, and altered precipitation patterns, would affect the survival and growth of individual plants, the distribution of species, and the composition and fire relations of communities.



Climate change will affect the ecological consequences of wildfire. (Photo: Wilderness Institute)

Climate Change and Fire

A detailed discussion of fire weather is beyond the scope of this paper, but it should be apparent that significant climate change would affect the frequency and severity of conditions suitable for the ignition and spread of fires. Loosely packed fine dead fuels, such as foliage litter, are the primary fuels responsible for fire spread. The moisture content of these fuels changes rapidly as relative humidity changes. If climate change alters humidities, then the ignition and spread of fires will be affected. If the growing season is extended and summer precipitation is lacking, the length and severity of the fire season should increase. Wind is also a major factor in determining how fast fires spread. If the frequency of high winds changes, the potential for large fires will also change. Lightning is a major source of ignitions. Increased temperature, precipitation, and evaporation will change thunderstorm patterns and, hence, the likelihood of lightning-caused fires. Drought also has a significant impact on the fire potential of a region. If the frequency and duration of drought change, the ecological consequences of fires will also be affected.

Climate and Vegetation

Climate is a major determinant of vegetation distribution on a regional scale. Although the physiological basis for the distribution of plants is not well known, strong correlations exist between moisture and temperature and plant communities. Climate-controlled similarities between vegetation structure and species composition occur along both altitudinal and latitudinal gradients. Changes occur along these gradients so that every 500 m increase in altitude is roughly proportional to a 275 km increase in latitude (Hopkins Bioclimatic Law). Given time to establish an equilibrium following an average annual temperature increase of 5 °C, vegetation zones in the Rocky Mountains can be expected to shift about 900 m up mountain slopes or 500 km farther north.

Changes of this magnitude have occurred in the past. The middle Holocene (4000 to 8000 Y.B.P.) or Altithermal period appears to have been dryer throughout most of the interior United States, but wetter at high latitudes and possibly in the maritime-influenced climate zone of the Northern Rocky Mountains. Moisture does not appear to have been limiting at higher elevations. In the western United States, massive species migrations occurred during this warm period. Many species, including several conifers, moved northward 500 to 600 km. Species also migrated to higher elevations. During the height of the period, montane conifers such as western larch, grand fir, and Douglas-fir occupied elevation zones presently occupied by subalpine or alpine species in the Rockies. For example, the Douglas-fir zone was approximately 500 m higher in the Northern Rocky Mountains than today. Communities of subalpine species such as Engelmann spruce, subalpine fir, and whitebark pine were, apparently, much less extensive than today, occurring only in the higher mountain ranges. Species composition of many communities were apparently different than we find them today, indicating that communities do not migrate as entities but as assemblages of individuals.

The species migrations during the Altithermal period are generally consistent with those expected to result from global warming. There are, however, several differences between the projected greenhouse effect and the Altithermal period. First, the warming during the Altithermal period cannot be attributed to doubled carbon dioxide. Increases in atmospheric carbon dioxide will affect numerous biogeochemical processes independent of the temperature and moisture effects. For example, it is estimated that about half of the carbon dioxide released into the atmosphere by fossil fuel burning has been reabsorbed by the oceans and terrestrial biosphere. If terrestrial ecosystems absorb additional carbon, plant growth could increase. If biological decomposition does not similarly increase then more biomass will be available for burning.

Second, the greenhouse-induced temperature change is expected to occur 10 to 20 times faster than changes occurred during the Altithermal period. Under conditions of rapid change, the length of time necessary to complete life cycles and colonize new areas will exert major influences on species migrations. Third, the influence of man on vegetation and fire during the Altithermal period was, no doubt, quite different from today. Finally, carbon dioxide is expected to double by the middle of the next century. However, in the absence of major changes in fossil fuel consumption, resource processing, and agriculture, carbon dioxide concentrations may continue growing.

Regional climate dominates the zonation of vegetation, but microclimate, soils, life cycle processes (such as germination and growth), and ecological interactions such as competition, herbivory, and fire strongly affect the external morphology and physiological ecology of communities within vegetation zones. All of these can be expected to change in response to changes induced by greenhouse gasses.

Greenhouse changes will affect numerous biochemical processes that will alter ecological relationships. Photosynthesis, respiration, decomposition, and nutrient cycling will all be affected. For example, substantial increases in water use efficiency (ratio of the amount of carbon dioxide assimilated during photosynthesis to the amount of water transpired) may result from increased carbon dioxide. As a result, plant growth may accelerate greatly. However, the loss of carbon during respiration should increase with temperature, thus potentially reducing the effect of increased water use efficiency. If increased carbon dioxide alters carbon-to-nitrogen ratios of plants, then decomposition, nutrient cycling, and insect and disease resistance will be altered.

Studies have not addressed inter and intraspecific interactions that affect growth rates, allocation (how a plant's growth is distributed among leaves, roots, fruiting, etc.), and community relationships. However, given the complexity of species traits, it is unreasonable to expect current community relationships to remain unchanged in the future. For example, temperature, moisture, and photoperiod exert strong controls over phenology and growth. Species are adapted to a range of seasonal patterns. Significant changes in climate can lead to asynchronous development, which can lead to reproductive failure and growth losses. Height growth and foliage biomass have been shown to increase at elevated carbon dioxide levels. If canopy structure changes, the light available for understory plants will be altered. Studies show that elevated carbon dioxide partially compensates for low light. Thus, the effect on the competitive relationships between overstory and understory species is uncertain. Water use efficiency varies by species, and some species respond to elevated carbon dioxide by increasing root-to-shoot ratios. Thus competition for water and nutrients will change.

The species composition of a community is determined by the successive birth and death of the individual community members. How fast vegetation responds to changing climate depends on species' life histories and rates with which suitable regeneration gaps are created. Fire is a major source of mortality. It creates gaps that new individuals colonize. Thus, changes in fire may greatly accelerate vegetation's response to changing climate.

Vegetation and Fire

The amount, chemistry, and size distribution of fuels will change as species, growth patterns, and decomposition change. For example, high temperatures, drought, and nutrient shortages may lead to stress-induced mortality and early leaf senescence, thus accelerating fuel accumulation. An increase in carbon-to-nitrogen ratios could also adversely affect decomposition and modify the role of fire as an agent of decomposition and nutrient cycling. Climate changes will also alter the moisture and combustion properties of fuels. Each type of fuel has its own drying rate, and its moisture content varies according to site moisture history. Each type of fuel also has characteristic physical and chemical properties that affect flammability. Changes in flammability will alter the site's fire potential.

Fire exerts selective pressure at the individual plant and community levels. The amount and type of fuel burned directly affect chemical releases to the site and atmosphere as well as the temperature and duration of the fire. Most temperate communities have evolved with periodic fire as a natural physical phenomenon. These communities contain species with adaptations and life cycles that lead to predictable responses to fire. Any change in fire regime (the frequency, severity, and seasonal timing of fire) is likely to favor some species, leading to shifts in community structure and species composition. For example, most species present before fire are present afterward, but recovery of community composition is not complete. The initial community originates from three groups: individuals that survive the fire, those that regenerate from on-site seed, or off-site colonizers. Differential heating and differential susceptibility of plant tissues strongly affect the survival of individual plants. Individuals vary in their resistance to fire injury based on species and age factors such as bark thickness and canopy height. Survival and growth vary with the type and degree of tissue injury and plant vigor. Also, fire alters the physical and chemical environment so that not all species can successfully compete. Thus, fire affects how site productivity is allocated among species. The relative abundance of species will be affected by changes in one or more components of the fire regime.

If climate change alters the frequency of favorable burning conditions or lightning patterns, fire frequency can be expected to change. If fire frequency changes, the species comprising secondary succession will change. For example, short fire cycles favor species that endure fire by juvenile sprouting, evade fire by storing seed in the soil, are off-site invaders, or have short life cycles. Intermediate fire cycles favor species that resist fires when mature or evade fire by storing seed in the canopy, but sprouting and invasion by off-site colonizers also occur. Long fire cycles favor species that typically have little fire resistance. Such species are severely injured by fire and regenerate predominantly by seed. If fires reoccur before sexual maturity, such species can be lost from the site. Then, the rate of reseeding will depend largely on the proximity of off-site seed.

The length and timing of the fire season may be different in an altered climate. If the length of fire seasons is extended, fires may burn larger areas. Also, the timing of the fires with respect to vegetation phenology may change the ecological consequences of such fires. For example, less than half of the 800,0000 hectares burned in the Central and Northern Rocky Mountain area in 1988 burned during the typical fire season period. Nearly half the area was burned on a few windy days during the 2 weeks after the usual on-set of fall rains. Major fires also occurred in June and early July. These were earlier than is typical. Where surface fires burned, mortality to pines was substantially higher than would have occurred after buds were fully developed.

The relative abundance of species may also shift because a species is not adapted to the climate-altered site. Some species may regenerate but will be unable to successfully complete their life cycle given new climate and fire regimes. For example, redstem ceanothus, a valuable wildlife forage species, and similar species that rely almost exclusively on seed stored in the soil, sometimes for centuries, could be eliminated from sites by regeneration failure resulting from new climatic extremes. If changes in climate and fire regimes lead to extensive species losses on a site, then migration of species from off-site will be accelerated. Species with wide ecological amplitude should be favored over those with narrow habitat requirements. Regeneration strategies best suited to unstable conditions should also be favored.

Given changes in initial species composition and climatic regimes, secondary succession will change. Classical succession suggests that when a community suffers a major disturbance, the site is occupied by a community of pioneering plants and then undergoes a sequence of change in structure and species composition as it slowly converges toward a climate-determined community type. A dominant feature of succession under relatively stable climate is the consistence with which sites converge to a similar community with time. Historical paths and convergence should not be expected to be repeated in a rapidly changing climate. Thus, future community composition is highly uncertain.

Given changes in climate, soils, nutrients, and fire, many natural populations will not be able to compete and successfully complete their life cycles on their current sites. They will become locally rare or extinct unless they are able to colonize new areas. In general, climatic change may be expected to result in improved habitat conditions at the cooler-wetter limits of a species' range and poorer conditions at its warmer-dryer limits. However, many Rocky Mountain communities exist as "habitat islands" isolated by ridges or valleys or surrounded by cultivation and urban areas. These form effective barriers against species migrations. The rate of climatic change may be much more rapid than species' ability to migrate.

Some species, particularly those that predominantly reproduce vegetatively or from seeds stored in the soil, are not highly mobile. Thus, while they may regenerate prolificly following site disturbance, they are less likely to take advantage of climate-induced disturbance off site. These species will be slow to migrate to new areas that are within their ecological amplitude. Given the altitudinal shift in life zones, numerous alpine species will become locally rare or endangered because there is no higher zone into which they can migrate. Similarly, subalpine species such as whitebark pine will be lost from all but the higher mountain ranges. Poor soil development will retard the migration of subalpine species into the former alpine zone, but montane species will migrate freely to higher elevations. If high temperatures and moisture stress severely limit productivity, it could be critical to the continued existence of low elevation forests in the region. The advance of dry woodland and steppe species into these forests will be slowed by their lack of shade tolerance but they will readily invade disturbed sites (such as burned areas).

Understanding the potential impacts of climate change on vegetation and fire will require a level of integration not previously attempted in ecosystem studies. There is still considerable uncertainty as to how far and how fast climate will change. The autecology of the various species is poorly known so it is not possible to make quantitative determinations of how various species will respond. Because future climate and vegetation are uncertain, it is not possible to quantify changes in fire potential. Considerable research is needed before we can confidently predict the magnitude of climate change, its effects on vegetation and fire, and interactions with the climate system. Given the complexity of the problem, it is unreasonable to expect significantly better information in the near future. However, given the magnitude of the potential changes we need to begin to address greenhouse effects on wilderness management.

Management of Parks, Wilderness, and Natural Areas

Natural vegetation has evolved with climate and, to varying degrees, fire as driving forces. The three are interrelated. Any change in one will affect the others. If predicted climate change occurs, major shifts in vegetation zones and community composition will occur in wilderness areas. Regional climates, vegetation patterns, and fire regimes are dynamic. The major difference in the projected changes is their rate, which is apparently unprecedented in recent geological time. These changes can be expected to be destabilizing so that, in the absence of disturbance, existing communities will gradually deteriorate and, following fire, will never completely recover. Climate change will alter the frequency, severity, and timing of fire. Fire-caused mortality will create sites for establishment of new individuals, leading to accelerated species transformations. These transformations will alter fuel properties, further modifying fire potential. Given changes in climate and fire regimes, many species currently in a community will no longer be suited to the site. The expected rate and magnitude of changes raise questions for the continued integrity, vitality, and stability of wilderness ecosystems.

The prospect of rapid change raises several philosophical questions. How should wilderness areas be managed in light of the potential for climate induced changes in fire regimes and vegetation distribution? Should they be managed to preserve natural processes or to preserve the resources they contain? Is it appropriate to take positive steps to mitigate the effects of climate change or should we let natural processes prevail and accept whatever change comes along? For example, is there a role for artificial regeneration to facilitate species migrations, or do we accept local extinctions as part of natural process? Should managers suppress fire to minimize vegetation change or use prescribed fire in an attempt to control the rate of change? In short, will wilderness areas remain "untrammeled by man" in an anthropogenically induced climate change? The question may no longer be what are the limits of acceptable change, but how do we manage inevitable change?

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Wilderness Institute

Montana Forest & Range Experiment Station

Wilderness & Wildfire

Misc. Pub. No. 50
Compiled and edited by Tom Walsh
June 1989

School of Forestry
University of Montana