August 1991

Global Change in the High Plains of North America

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GLOBAL CHANGE IN THE HIGH PLAINS OF NORTH AMERICA

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Abstract. *The High Plains of North America extends from Canada to northern Mexico. This grassland region is subject to prolonged drought, herbivory, and wildfire. Organisms that are indigenous to the High Plains are adapted to these environmental factors. Periodic droughts occur at inexact, but few year, intervals. The grazing by free ranging bison, the indigenous large herbivore, has been replaced by grazing of fenced domestic stock. Fire regimes throughout human occupation of the region have been greatly influenced by human activities. Cultivation of wheat and corn also is carried out in the region.*

Predicted climate changes in this region are increased temperature and reduced effective precipitation. Paleontological records document past climate changes from which certain predictions may be made about the effects of current models of Global Change. Ecological studies at the ecosystem, community, species, and population levels are defensible. Land use modifications should be undertaken immediately to minimize deleterious effects of Global Warming.

Key Words: fire ecology, global change, grasslands, Great Plains, herbivory, vegetation.

The Great Plains, located near the center of the North American continent, is mentioned frequently in models of global change. This region, where evapotranspiration exceeds precipitation for much of the growing season, experiences drought periodically. Grazing by large herbivores and fire have also been common phenomena in both historic and prehistoric times. Most predictive models of global change suggest that the central United States could experience both an increase in temperature and a decrease in effective precipitation. Common ecological wisdom links the ecological consequences of grazing, drought, and fire patterns to temperature and precipitation. In this paper we will discuss the potential effects global change may have on the vegetation of the western region of the Great Plains, the High Plains. We also will discuss approaches to ecological research relevant to these predictions. We define the High Plains as that area of the Great Plains of North America lying west of 100° W longitude. This meridian is a major biological demarcation, and in many ways may have more biological significance than the border between the Plains and the Rocky Mountain foothills (C. Bock et al. 1977). The High Plains includes parts of Saskatchewan and Alberta in Canada, North Dakota, South Dakota, Montana, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, Texas, and Arizona in the US, and Chihuahua, Coahuila, and Sonora in Mexico (Fig. 1).

Three models of global climate change have received special attention from the US Environmental Protection Agency. These are the models of the Goddard Institute for Space Studies (GISS; Hansen et al. 1988), of the Geophysical Fluid Dynamics Laboration (GFDL; Wetherald and Manable 1988), and of the Oregon State University (OSU; Schlesinger and Zhao 1988). There is more agreement between the GISS and GFDL models, and these have received rather more attention from US scientists than the OSU model. We are unequipped to evaluate the detailed strengths and weaknesses of the models, but we follow Smith and Tirpak (1988) in accepting these three as useful working hypotheses. All three model the climate for a doubled CO_2 content, compared to the present, by the year 2050. The model results indicate an average warming of 3.3° C (OSU), 4.5° C (GISS), or 4.9° C (GFDL). The GISS model predicts that winter temperatures are likely to increase more than summer temperatures, while the other two predict the opposite, that summer temperatures will increase more than winter temperatures. The GISS model predicts that annual precipitation rate will be decreased by 0.22 mm/day/year; GFDL predicts a decrease of 0.12 mm/day/year; and the OSU model predicts a slight increase in annual precipitation. However, all three predict a reduction of effective precipitation for vegetation.

Biotic and Abiotic Features of the High Plains

History: Grasslands of the central United States originated at least by the late Tertiary (Thomasson 1985). Since that time trees have invaded and retreated from the Great Plains region several times (Axelrod 1985). Axelrod (1985) suggests that the grasslands were maintained throughout this period primarily by fire and grazing, and that the woodlands when present were not continuous, but rather they formed a savannah. At the

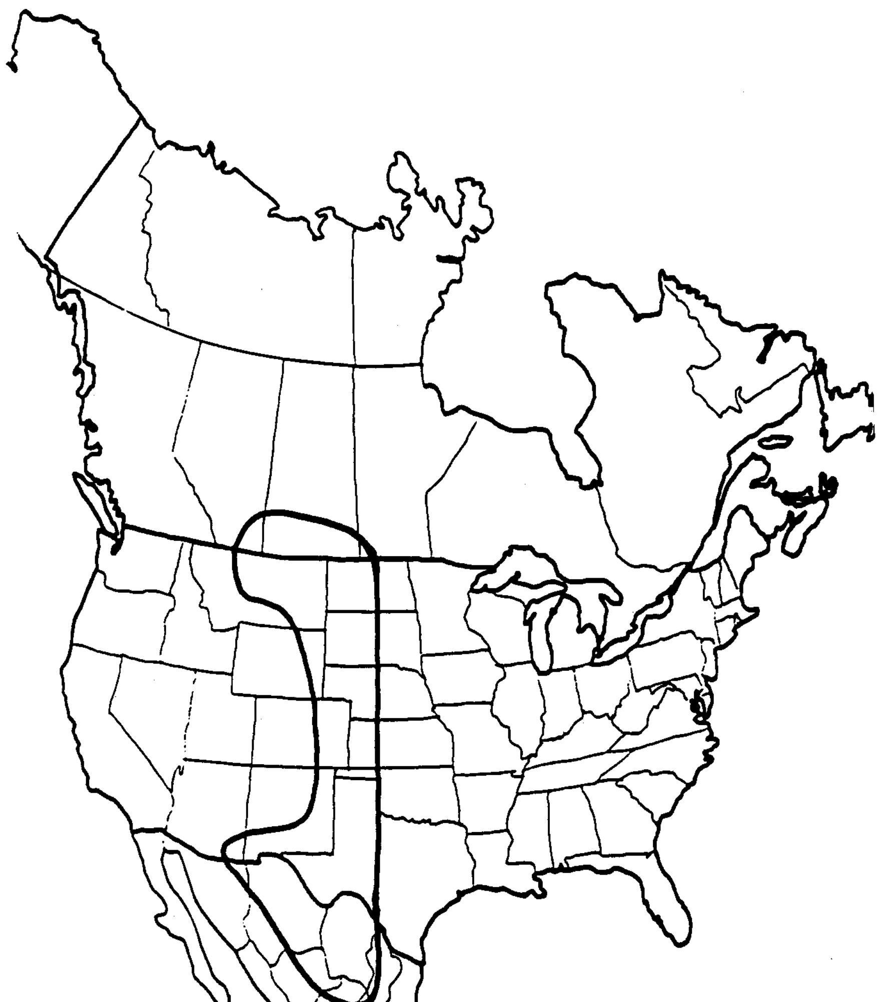

Figure 1. The High Plains of North America.

end of the Pleistocene, grassland species spread rapidly, replacing the dying and probably often-burned forests. Today, the relict Ice Age flora exists in woodlands along waterways and on occasional large rocky outcrops where fire and grazing are discouraged by topography (Wells 1965; Axelrod 1985). Ryan (1991) suggested from the fossil record that mid-Holocene (6000 BP) vegetation apparently shifted in much the same way the climate change models predict it may shift by 2050.

Periodic drought, herbivory, and fire impact the High Plains in significant ways (Risser et al. 1981; Estes et al. 1982). Indigenous and naturalized species are likely to have passed through an evolutionary sieve that selected against those species that could not withstand or avoid these forces. Drought, grazing, and fire, all are capable of initiating plant succession, although humans can modify within limits the effects of these disturbances (Luken 1990). Plants growing on rocky outcrops or islands in larger rivers, such as the Platte, may escape the effects of drought, grazing, and fire because they are isolated by fire- and animal-proof barriers. In the case of island sites, the water table can remain high throughout the year so that the effects of short-term drought may be avoided.

In several regions of the world, including parts of the southwestern United States and northern Mexico, the southern Mediterranean, and large areas south of the Sahara, grasslands have been replaced by desert. Some authors have attributed these shifts in vegetation to shifts towards warmer, drier climatic regimes, while others point to crop cultivation and overgrazing during periods of drought as primary factors for grassland desertification (Johnson 1947; Hurt 1981).

Agriculture and Drought: Since settlement of the High Plains in the late 1800s, agriculture and cattle have occupied much of the landscape. The cultivation of crops, especially the growing of wheat and corn, in this region takes place in "one of the most marginal agricultural regions in the United States" (Smith and Tirpak 1988, p. 77). The High Plains, where evapotranspiration exceeds precipitation for much of the growing season (US Geological Survey 1970), is always on the verge of a multiple-year drought. Dendrochronological studies show a span of approximately 38 years between five-year (or longer) droughts "and a drought of 10 or more years came every 55.6 years" (Hurt 1981, p. 3). The specter of one of these, the Dust Bowl of the 1930s, has had considerable impact on legislation aimed at ameliorating the effects of that event and preventing the reoccurrence of such impacts. That drought led to severe erosion and economic deprivations, the effects of which are still felt today (Johnson 1947; Hurt 1981; Lewis 1989). Following the Dust Bowl, people were encouraged to change from cultivation of crops to cattle ranching through public education and economic incentives. Near the end of the Dust Bowl, the US government gained control over 736,451 acres of High Plains at a cost of $3.56 an acre, and leased these lands back to the local population (Lewis 1989). But a comparison of land use on the High Plains in 1936 and in 1986, shows that total agricultural acreage has remained unchanged, even though certain parcels have changed in use (Lewis 1989). Lewis (1989, p. 171) suggested that the threat of a drought today is even more serious than it was in Dust Bowl time because of continuing overgrazing by domestic cattle, continuing cultivation of grasslands, and a dwindling groundwater supply.

Grazing: Grazing animals remain an important component in most of the world's grasslands. Intensities of grazing generally are greater in grasslands than in other sorts of terrestrial ecosystems (Detling 1988). Historically, many of the large native herbivores were more abundant on the Great Plains than elsewhere in North America (Mack and Thompson 1982). A grazing megafauna was part of the High Plains long before the introduction of modern horses, sheep, and cattle (Pohl 1987). Stebbins (1981) and Mack and Thompson (1982) discussed how grazing by the indigenous megafauna over geologic time preadapted the morphological and reproductive traits of High Plains plants to withstand the impact of grazing by modern domestic stock. Many of the High Plains native grasses resist destruction due to feeding and other activities of large domestic herbivores, unlike the native species in other areas such as the Great Basin where a grazing megafauna was absent during the Holocene (Mack and Thompson 1982). Some workers have found that grazing by domestic animals tends to increase similarity of (homogenize) grassland vegetation (e.g., Sala et al. 1986; Belsky 1987); however, this does not appear to be the case in the Great Plains (Collins et al. 1987). Grazing by domestic animals appears almost always to increase the amount of bare ground and herbaceous and woody dicots while reducing grass cover (c. Bock et al. 1984, J. Bock and C. Bock 1989, 1989; Lewis 1989).

Fire and Plants: Evidence from pre-human geologic records (Axelrod 1985) and from prehistoric and historic periods (Pyne 1982, chapter 2) shows that fires have been a natural event in North American grasslands. Fires today may be less frequent in the High Plains in comparison with presettlement times due to contemporary reductions in burnable herbaceous and shrubby vegetation. These reductions are due to widespread, intensive grazing by domestic stock, mining, agriculture, paving, suburbanization, and other changes brought about by human activities in the High Plains. Prior to human colonization, fires in North American grasslands were most commonly caused by lightning (Komarek 1967; Pyne 1982), and virtually all natural wildfires on the High Plains today are caused by lightning. The effects of grassland fires depend upon a multiplicity of factors, including amount of fuel available, fuel moisture, ambient temperature and humidity, place and frequency of lightning strikes, wind characteristics, and time since last fire (Kozlowski and Ahlgren 1974; Wright and Bailey 1982). These factors vary from day to day and year to year. Nevertheless, it is possible to define a fire season for a geographic area by using historic records for dates and severity of previous lightning fires. The fire season for the High Plains, allowing for geographical variations, is from February through October in the south, and from May through September in the north.

Well established grassland plants almost never are killed in a grassland fire because of their reproductive and morphological characteristics (Mutch 1970; J. Bock et al. 1976; C. Bock and Bock 1978; J. Bock and Bock 1984; Gibson and Hulbert 1987), including the propensity for efficient vegetative reproduction from growing points located at or just below the soil surface (Knapp and Hulbert 1986). Carlquist (1975) suggested that this fire-adapted morphology may have evolved with the ancestors of the modern species, as contemporary members of the older flowering plant families possess fire-adapted vascular tissue. Van Wilgen et al. (1990) suggested that grassland plants often are structured in ways that enhance their flammability in comparison with plants from adjacent, wooded ecosystems.

In an unburned grassland, remnants of vegetation from previous years, the standing dead plants, remain. The amount of preburn dead vegetation helps to determine the nature of a post-fire grassland (Moe et al. 1990). Although nitrogen and carbon compounds present in dead vegetation are removed, grassland fires can add to the mineral content of the soil and circulate minerals that otherwise might be in short supply (Viro 1974; Boerner 1982). This mineral ash can also favor selected soil microbial populations that enhance plant nutrient release from the soil for post-fire plant growth (Ahlgren 1974; Malanson 1987). Another encouragement to post-fire growth comes from the soil surface itself which often is darkened by ash and burned plant stubble. This lower albedo of the land surface encourages early season warming of soil, thereby encouraging early season plant growth.

Changes may occur in the plant composition of grassland communities following fire. In minimally disturbed areas in the High Plains, these changes are more likely to be shifts in ratios among species within the communities rather than extirpation and colonization of taxa (J. Bock et al. 1976; Collins 1987; Biondini et al. 1989).

Fire and People: Fires from anthropogenic sources can occur at almost any time of year (Vogl 1974). There is strong evidence that the first people of the High Plains, as with people today, set many grassland fires either by intent or by accident (Pyne 1982). Native Americans used fire for varied purposes, including clearing of woody vegetation to increase feeding land for desired grazing species, defense and offense in war, and reduction of nuisance organisms such as mosquitos, flies, and poisonous snakes. There is anecdotal evidence that Native Americans made little effort to extinguish old camp fires before moving to a new campsite (Stewart 1956). No doubt, early European colonists in the High Plains used fire in some of these same ways. Modern day agrarians of the High Plains frequently burn grasslands to improve range and crop lands, even though most High Plains states have air pollution laws that forbid open burning for any purpose. Certain woody species invade grasslands when the natural fire regime has been suppressed, thereby creating a shrub-grassland. Such invasions also may follow overgrazing or other interruptions in vegetation cover (Vogl 1974, pp. 162-68; J. Bock and Bock 1989).

Where populations of indigenous species of a High Plains grassland persist, the pattern of post-fire succession can be somewhat predictable, although there can be great variation in the responses of individual taxa. Native short-lived plants (colonizing species) invade the burned site immediately after the burn, but within a relatively short time, they are replaced by the regrowth of longer lived indigenous species. In the High Plains grassland of southeastern Arizona, the short-lived annuals that appear in great numbers following fire in tall bunchgrass stands of *Sporobolus wrightii* (sacaton) are indigenous to the same area as the sacaton (C. Bock and Bock 1978). The return to the tall bunchgrass stands in this instance is accomplished within three post-fire growing seasons. This pattern of rapid vegetation recovery is seen throughout the Great Plains (e.g., Gibson and Hulbert 1987; J. Bock and Bock 1989; Collins 1989; Biondini et al. 1989) and elsewhere (Belsky 1987; Tsyuzaki 1987). Fire, along with drought and herbivory, create a mosaic of vegetation patterns on the High Plains. Human manipulations modify this mosaic to a considerable extent today.

Fire and Fauna: The changes that fire brings to vegetation are accompanied by faunal shifts (Komarek 1969; Ahlgren 1974; Bendell 1974; Erwin and Stasiak 1979; C. Bock and Bock 1978, 1983, 1988; J. Bock and Bock 1989; Moe et al. 1990). Grazing species are greatly influenced by the appearance of a lush, fire-induced grassland. The fire removes the dead vegetation that was present before the fire and produces an early growing food source important to all High Plains grazers, including the most conspicuous one on the High Plains, the American bison (*Bison bison*). For example, bison have been observed to migrate several kilometers to burning sites in Wind Cave National Park, South Dakota. As grassland fire approaches, the grazing herds move en masse at less than full speed away from the burns or, more commonly, across the fire lines onto the burned grasslands. Immediately after the fires pass, bison frequently are observed licking the barely cooled charcoal. When the grasslands commence regrowth after the fire, bison feed preferentially on the burned sites, ignoring nearby unburned grassland for the first post-fire growing season. This interest dampens by the second growing season, and the bison use other sites for grazing (J. Bock and Bock 1989).

As with grassland vegetation, fire can cause dramatic changes to the grassland fauna, but these changes also are short-lived for the most part. In the High Plains and in other grasslands, measurable changes in post-fire vegetation, fauna, and physical environment largely have disappeared after three to seven post-fire growing seasons (Ahlgren 1974; Viro 1974; J. Bock et al. 1976; C. Bock and Bock 1978, 1983; J. Bock and Bock 1984; Petraitis et al. 1989).

Ecological Study of the High Plains Biota in Relation to Climatic Change

Potential Contributions to Global Change Models from Population Ecologists: A generally accepted definition for "ecology" is "the study of the natural environment and of the relations of organisms to each other and to their surroundings" (Ricklefs 1990, p. 807). Plants and animals as individuals possess specific ranges of environmental tolerances that, if exceeded, will bring about reproductive failure or death, disallowing the organism to contribute genes to future generations of its kind.

In many important discussions of the potential effects of global change, the organisms of a given ecosystem or vegetation type are treated as a unit. For example, anticipated changes are discussed in terms of alpine, forest, grassland, or marsh boundaries changing as a unit. Schneider (1990, p. 33) states that "Forests probably could not sustain the much faster migration required by the projected warming." However, it is essential to remember that environmental perturbations will call forth responses not at the ecosystem level, but rather at the level of the individual species, species populations, and individual organisms. As Graham and Grimm (1990, p. 289) stated, "In montane regions, studies show that intact vegetation zones do not move up and down the slopes in response to vegetation change, but that taxa migrate individually, some more than others." This behavior is true as well for other vegetation types including grasslands. Graham and Grimm further comment (1990, p. 292), "The individualistic concept is also important in modeling the response of whole communities to future environmental change. The paleo-biological record suggests that merely shifting the location of entire ecosystems is unrealistic. Instead, the ecological requirements of individual species must be incorporated into models."

The reason that responses to climatic change vary among species is that each population (gene pool), species, and indeed each individual organism has a range of environmental tolerances that must not be violated if the taxon is to persist in its location. For a given kind of plant or animal, environmental tolerance varies with different stages in an organism's life history. For example, immature life stages often have different environmental tolerances than those of reproductively mature individuals (Woodward and Diament 1991).

Following environmental perturbations, biological succession occurs. That is, the assemblages of plants and animals in the disturbed site adjust to the modified environment. Significant advances have been made in our understanding of succession in recent years (e.g., Gray et al. 1987). Early in this century, it was assumed that patterns of succession were highly predictable. More recent work has shown that chance plays a major role in the determination of biotic communities whether or not the climate is stable (Woodward 1987). We assume that climatic changes such as those proposed in the global change models will produce biotic responses that cannot be predicted with surety. However, the study of individual species should be an essential part of predictive models. Some researchers have expressed concern that the rapid change in climatic conditions in the popular models will exceed the ability of plants and animals to adapt genetically (evolutionarily) to such change, leading to wholesale extinctions and extirpations. However, work by evolutionary ecologists and population geneticists shows that we frequently have overestimated the time required for phyletic response to environmental change (Mettler et al. 1988). Holocene paleontological records add further documentation to the rapidity of organismal response to environmental changes.

Records of Past Climatic Changes

A most important source of information about what to expect from proposed climatic changes is the paleontological record of past climatic changes and their biotic effects. Species respond to rapid change by evolving or not evolving (Holt 1990). If the species do not evolve and the changes exceed their tolerance limits, they may change their patterns of distribution and abundance or go extinct. If they evolve in response to climate, again they may show demographic adjustments.

Both plants and animal taxa have been documented as having unique, rather than community, responses to climatic change. Also, one group of organisms may change while another assemblage or species does not. For example, Harrington's mountain goat persisted through vegetation change at the end of the last Ice Age (Mead et al. 1986). Smaller animals responded individualistically: the northern pocket gopher moved west, the least shrew shifted towards the east, and the collared lemming moved north (Graham and Grimm 1990). Birds also may have shown individualistic responses, but generalizations are difficult due to the paucity of the fossil record. Reptiles and amphibians did not shift among vegetation regions during this period. Populations of amphibians around the world are declining at present (Blaustein and Wake 1990). The exact cause of the decline is not agreed upon, although its global nature suggests an atmospheric change is involved. Acid rain has been widely implicated. It may be difficult in future to attribute extinctions and declines in taxa to climate change in temperature and precipitation patterns rather than other products of atmospheric global pollution.

Graham and Grimm (1990, pp. 290-91) commented that the new assemblages of organisms that followed warming at the end of the Ice Age are not analogs of the assemblages that existed during glaciation. Many organisms that once lived together are now separated geographically, and new associations of taxa now exist. These distinctions are attributed in part to selection forced by environmental extremes rather than means. Also, some organisms come equipped with rapid means of migration under inclement conditions. For example, flying animals and wind dispersed seeds have an advantage for rapid migration over those organisms with more cumbersome propagules. It is important to keep in mind that large scale migrations leading to the establishment of new assemblages of plants and animals likely require centuries to take place, not just a few years (Woodward 1987).

Global Climatic Change Models and the High Plains

Models for the High Plains: In his model of climate change Mitchell (1989) predicted a temperature increase of 2° to 4° C in the Great Plains, in the near future. Associated with this temperature increase is a predicted decrease in precipitation, particularly in the southern High Plains (Wilson and Mitchell 1987), and a decrease in available soil moisture (Schlesinger and Mitchell 1987). A substantial increase in amount of temperate grasslands in western North America has been predicted under such a climate change scenario, with replacement of northern boreal forest by grassland (Emanuel et al. 1985). Concomitant changes in North American agriculture also are predicted (Adams et al. 1990).

Global Change and Agriculture in the High Plains: Cereal fields constitute the largest human maintained temperate ecosystem in the world, with approximately 700 million ha under cultivation (Sugdon and Rands 1990, p. 205). The High Plains grain fields are not highly productive: "Despite the adoption of conservation tillage techniques, drought-resistant cultivars, and risk management programs, some analysts argue that the region remains particularly vulnerable to climate-induced reductions in crop yields and might manifest the first impacts of climate change" (Smith and Tirpak 1988, p. 7-7). Crop failures due to drought and disease are well known to most High Plains farmers, and the margin between profit and loss is almost always narrow (Sugden and Rands 1990). In eastern Colorado, wheat and corn crops have been known to fail four years out of five for one or more decades. In such cases, the vegetative plant material is salvaged as hay or silage, but the grain is discounted, or the land is converted into pasture for domestic stock. Schneider speculated (1990, p. 34) that the grain belts might move north by several hundred kilometers once southern lands were no longer suited to current crops. Although this shift sounds reasonable, it is simplistic. Many genetic and ecological problems must be solved before such crop relocations can succeed. Genetic adjustments must be made for new photoperiods, precipitation patterns, pests and diseases, and soil arability and fertility. Most boreal forest soils are chemically and structurally unsuited to Great Plains crops.

Global Change and Fire in the High Plains: The increase in temperature and decrease in moisture could increase fire frequency and intensity based upon models used at present to predict fire behavior (Wright and Bailey 1982; Engle et al. 1989). Under an altered climate of warmer ambient temperatures, reduced precipitation accompanied by more dry lightning storms, and lowered fuel moisture, we predict that fires could be more frequent, larger, and more intense in vegetated portions of the High Plains. However, it also is likely that if this new climatic regime continues, fires will decrease to present levels or to lower frequencies and intensities. The factors that encourage fires, increased drought and temperature, also act to decrease primary production, thereby reducing fuels for fires. The long-term consequences of global warming as defined by models such as that of Mitchell (1989) will be a reduction, rather than an increase, in fire frequency and extent. This is seen today in Old World deserts that once were grasslands, but today support no fires due to the paucity of vegetation cover.

Climatic change is not new to the world. Previous comparable or even more dramatic climatic shifts have been documented through paleobotanic reconstructions of past vegetation (Davis 1986; Budyko et al. 1987;

Robinson 1989). Paleontologists have described previous periods in the earth's history when fires were more common than today (Berner and Canfield 1989; Robinson 1989). Robinson (1989) described times during the Tertiary when O_2 levels were much higher than at present. He assumed fires were much more common then in mesic as well as grassland vegetation, because of these elevated oxygen levels, and he implicates fire in the origin of the angiosperms. This interpretation fits Carlquist's (1975) finding that the most ancient flowering plant families extant today in mesic (rarely burned) habitats show vascular tissue types commonly associated with fire resistance.

Accommodating Global Climatic Change

The High Plains grasslands prior to settlement existed as a mosaic of biotic communities shaped by intermittent wildfires, passing herds of bison, and roaming bands of humans. Today, remnants of the fauna and many of the plant species have persisted, albeit in a greatly reduced extent. These species for the most part have survived past periods of climatic change comparable to those predicted for the near future. Two unique aspects to the predicted changes are that the change is unidirectional and it is human induced. In the past, incidences of decreased precipitation and increased temperature have been part of cyclic phenomena that reversed themselves through geologic time. Directional natural selection vectors at levels such as the proposed changes in temperature and available moisture in the past have led to phyletic evolutionary changes (Mettler et al. 1988). However, if the directional changes persist, it is not unreasonable to anticipate extinctions and extirpations of a catastrophic nature could occur.

Because human activities have set in motion the potential for global climate change, it behooves us to modify our behaviors in ways that can alleviate the anthropogenic causes for climate change. However, if the models of global change are accurate and if we continue wholesale human disruptions to the High Plains such as tilling of the grasslands, overstocking, and other activities that destroy the sods, we can reach a point of no return. Desertification already has been the fate of many of the earth's grasslands. Human activities that act to enhance the effects of global warming should be curtailed on the High Plains. The measures we suggest are those that tend to maintain biological diversity and slow denudation of the grasslands, which global change will encourage. Appropriate laws and public policies exist, but they have not been well followed. First, grazing of domestic animals on public lands (representing the tragedy of the commons) should be greatly curtailed and lease rates made to reflect economic and ecological reality. Second, the laws against plowing unbroken sod should be enforced, because plowing is another nonprofitable enterprise both economically and ecologically. Third, ecological monitoring should be carried out using information from federal, state, and educational sources already at hand as baseline data.

The technology being encouraged by national and international programs at present is to monitor global change by remote sensing of vegetation from hundreds of kilometers above the earth (Harris et al. 1990). Geographical information systems (GIS) technology facilitates integration of remotely-sensed data with ground-based data and rectification of scales (Haslett 1990). The information gathered in this way is both innovative and useful in terms of keeping track of global climate patterns and vegetation changes at the biome scale. Vegetation mapping has thereby been enhanced (e.g., Fuentes et al. 1991) as has monitoring of productivity (e.g., Adams et al. 1990). However, this scale is ineffectual for monitoring the health of the components, the plants and animals, of an ecosystem such as the High Plains. For the High Plains, a second sort of monitoring must be instituted as well. Cairns (1990) stressed that monitoring carried out by evolutionary ecologists not be data gathering for its own sake, but be used as a "quality control." "My discussion here assumes three major goals for global climate/ecosystem monitoring: (1) to maintain balanced biological communities, (2) to protect both structural and functional integrity of ecosystems, and (3) to protect biodiversity" (Cairns 1990, p. 72).

Authors differ as to how sensitive vegetation is to climatic change (Lewin 1985; Neilson 1986). There are approximately 1500 species of higher plants on the High Plains, of which perhaps 80% are indigenous. Unfortunately, we know little about the tolerance limits of most of them and the associated fauna. We need to ascertain these limits for indigenous plants and animals, and to pay special attention to those with both the lowest and highest tolerance levels for the proposed direction of change. In the former case, these species are the most likely to disappear, and the more we know about their characteristics, the more likely we will be able to conserve these genetic resources. In the latter case, highly tolerant plants may be our natural legacy, and we should understand their potential much more thoroughly than we do in order to help our species to coexist with the "new biota."

The precepts of ecology should be an integral part of our preparations for coexistence with global warming. A three pronged approach is called for, to include remote sensing, on the ground ecological, genetic, and evolutionary studies, and application of sound ecological principles to land use. Otherwise, many valuable High Plains species may be lost.

Acknowledgments

We gratefully acknowledge support for our work from the US Forest Service, the National Park Service, the Charles A. Lindbergh Foundation, the National Geographic Society, and the National Science Foundation(BSR-8604931, BSR-8613038, and BSR-8703512). We also express thanks to our colleagues from the University of Colorado and the National Audubon Society.

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