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Defying Predictions: How Increased CO2 and Innovation Are Mitigating Effects of Drought on U.S. Crops and Forest Productivity

Susan J. Crockford, PhD

Contrary to predictions that changes in climate are going to cause forest, cropland, and rangeland productivity to decline over time, recent data show that the known fertilizing effect of additional carbon dioxide (CO2)—which is literally food for plants—has offset many of the predicted adverse effects by enhancing drought tolerance and plant growth. From record harvests for virtually all crops in recent years and a flat, long-term trend in forest fires, real observations show that innovations in crop genetics, pest control, and water management, in addition to modifications of timber harvest and fire-suppression practices, are mitigating the predicted adverse effects of increased greenhouse gases and ensuring the future productivity of these ecosystems.

The benefits we derive from healthy and productive ecosystems are critical to economic prosperity. Important ecological goods and services include the market commodities that originate from forest habitats, such as food, fuel, timber, and fresh water, but they also include the food from croplands and rangelands as well as the recreational and esthetic value that undeveloped landscapes provide. Any and all threats to these ecological goods and services, including those that may come from future increases in global temperature caused by our use of fossil fuels, must therefore be taken seriously.[1]

In forest, cropland, and rangeland ecosystems, increased risk to plant species of all kinds is perceived to come from predicted increases in summer heat waves and associated drought conditions. While it is known that increased carbon dioxide (CO_2) levels have already caused better growth rates and improved water management in virtually all plant types (including trees, food crops, and rangeland grasses), some models predict that these benefits will be overwhelmed in the future by drought conditions of unprecedented severity.[2]

Predictions of increased risk of forest fires due to climate change have also been advanced. An abundance of drought-killed and pest-killed trees is often blamed for causing larger and more intense fires in recent years, and computer models predict that these events could get worse over time as global temperatures increase.[3]

This *Special Report* examines the evidence surrounding these claims. Historical context is critical here as are the often-ignored potential for other human causes and the beneficial effects of human innovation. Extreme weather conditions with devastating effects—driven in part by completely natural, long-term climate cycles, short-term El Niño Southern Oscillation events, and decadal-level cycles in solar radiation—are nothing new to U.S. ecosystems. At issue is whether a slight rise in global temperature caused by greenhouse gas emissions might worsen such natural events and, if so, whether the most adverse effects can be alleviated.[4]

Farms and Croplands

Croplands in the southern Great Plains (Kansas, Oklahoma and Texas) are expected to be most at risk of the worst adverse effects of high temperatures and drought conditions caused by future increases in CO_2 emissions from the burning of fossil fuels. However, historic records and proxy data indicate that droughts are nothing new to U.S. ecosystems. Moreover, the natural responses of plants as well as human innovation—including improved irrigation methods and regulations, strategic use of fertilizers, and the never-ending development of resilient crop varieties—will likely continue to offset any potentially harmful effects of climate change on crop yield and quality as they have since the 1930s.[5]

Drought and Water Management. Droughts that adversely affect ecosystems are periods with abnormally low soil moisture due to increased evaporation and decreased precipitation, which the Intergovernmental Panel on Climate Change (IPCC) calls "agricultural and ecological drought."[6] Proxy evidence from tree rings over the past 2,000 years compared to historical records indicates that drought conditions much more severe than those that plagued parts of the contiguous U.S. in the 1930s, 1950s, and early 2000s—lasting three decades or more—occurred in the late 1200s and late 1500s as a result of natural climatic variation and that 1930s-like drought conditions have occurred repeatedly over the past 400 years.[7]

The IPCC expects with "medium to high confidence" that extreme heat and severe droughts will occur more frequently over the next seven decades and that demand for limited water supplies in the western U.S. in particular could adversely impact agricultural operations. Irrigation of crops, especially the hay and corn used to feed cattle and pigs, puts the heaviest demand on water supplies, while domestic and commercial users draw significantly less. In the western U.S., from Wyoming to California, water from the Colorado River drainage is the most fought-over because it is critical to so many stakeholders; shortages in 2022 drove tempers especially high. However, future innovations in irrigation systems and the availability of more drought-tolerant and heat-tolerant crop varieties could reduce this usage considerably.[8]

While it remains to be seen whether more frequent and severe droughts will put even more pressure on water supplies in the western U.S. than has been seen historically, it has been pointed out that state-imposed and federally imposed water laws often hinder conservation measures and limit the ability to move water to where it is most needed. Effective water management has been an issue in the western U.S. at least since the early 1900s, and the fact that the numbers of people and domestic livestock on the landscape have increased markedly over the past 100 years is almost certainly a bigger part of the problem than is human-caused climate change. However, at least twice over the past 400–1,000 years, wild bison herds in the tens of millions and perhaps as many Native Americans vied for dwindling water supplies when catastrophic drought events occurred—a reminder that such competition is nothing new. Thoughtful water policy has considerable potential to offset future scarcities, whether naturally caused or human-caused.[9]

Range Shifts and Crop Yields. The IPCC predicts with "high confidence" that future human-caused climate change will shift the ranges in North America where crucial food crops can be grown, which it says may intensify some harvest losses.[10] Such range shifts have already been documented in Canada where a growing season that is two to five weeks longer relative to 1950 is already benefitting Alberta and Saskatchewan farmers, enabling them to grow fast-maturing varieties of corn and soybeans profitably where they could not have done so in the past.[11]

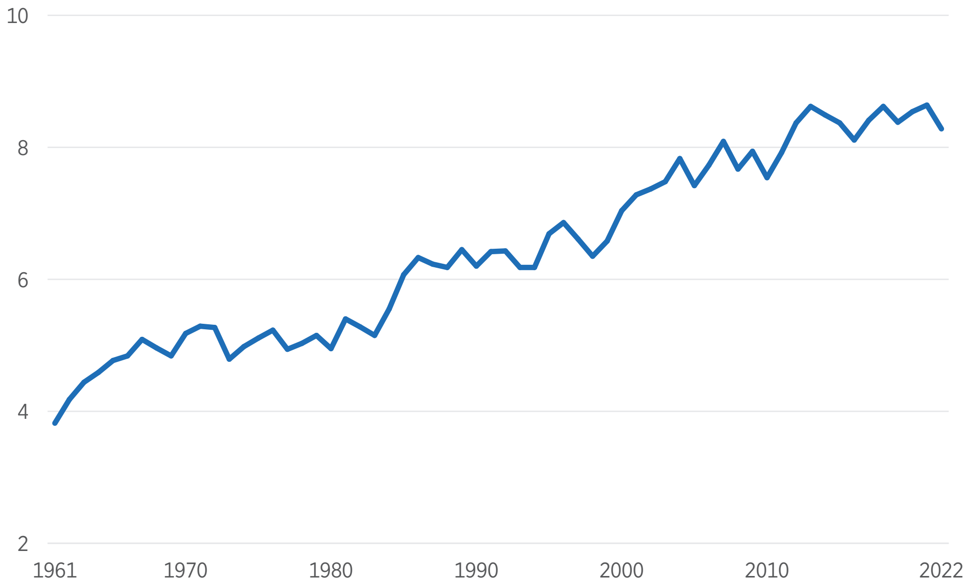
In the U.S., drought and heat waves rather than range shifts are the main climate-associated concerns: It is predicted that lack of soil moisture and daytime temperatures that are much higher than usual could stress even heat-loving crops like corn, potentially reducing their yield at harvest.[12]

So far, however, the warming experienced in recent decades either has improved harvest yields because of higher minimum temperatures (warmer nights) or has had no overall effect. In the Midwest, the severe drought of 2012 reduced yields for corn by only 13 percent compared to 2011 and soybeans by 3 percent. By contrast, in the southeastern U.S., an increased

CHART 1

U.S. Rice Crop Yields

IN TONNES PER HECTARE



SOURCE: Global Change Data Lab, Our World in Data, "Rice: Yield," https://ourworldindata.org/explorers/crop-yields?facet=none&country=~USA&hideControls=false&Crop=Rice&Metric=Actual+yield (accessed September 17, 2024).

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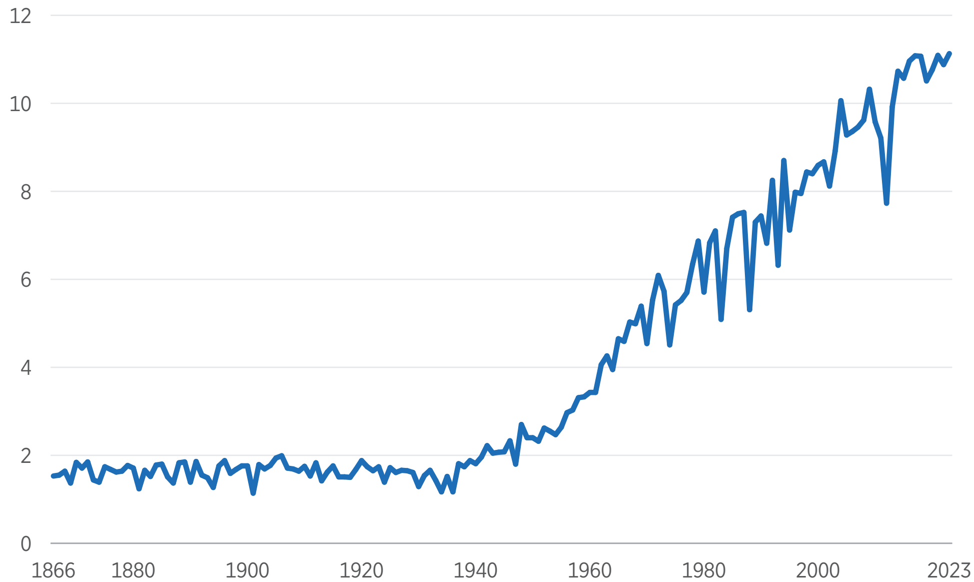
average temperature of 1 degree Celsius between 1980 and 2020 significantly *improved* corn and rice yields and had no effect on wheat. Altogether, across the U.S., major crop yields have continued to increase since the 1960s despite continually increasing CO_2 emissions and recent drought conditions.[13] (See Chart 1 and Chart 2.)

In another example, a study published in October 2023 used computer models to predict that by 2050, drought and high temperatures could somewhat reduce crop yields for European hops used in the fast-growing beer market. Media outlets promoted this as a threat to future beer drinking, but the largest producers of hops worldwide are in the U.S., where yields have been increasing steadily since 2012 despite (and perhaps because of) steadily increasing global CO_2 levels. Virtually all U.S. hops are grown in the Pacific Northwest, and 2021 was a bumper year. Yields in 2022 were slightly lower because of cold spring weather unrelated to climate change.[14]

CHART 2

U.S. Corn Crop Yields

IN TONNES PER HECTARE



SOURCE: Global Change Data Lab, Our World in Data, "Corn: Yield," https://ourworldindata.org/explorers/crop-yields?facet=none&hideControls=false&Crop=Corn+%28maize%29&Metric=Actual+yield&country=~USA (accessed September 17, 2024).

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In contrast to the pessimistic predictions offered by academics, the people who actually grow hops have forecasted a modest boost in U.S. hops production over the next decade and a significant increase in European production. Such forecasts make sense because modern farmers do not sit around waiting for adverse conditions to decimate their yields: Since the 1930s, farmers increasingly have turned to innovations in irrigation, fertilizers, crop rotation, and especially genetics, which produce all kinds of crops that are resistant to disease, drought, and high temperatures. (See Chart 2.) Climate-based models do not take future agricultural innovations like these into account. The reality is that increased crop resilience due to human innovation is likely to intensify in future decades because hundreds of years of experience have taught farmers everywhere that unforeseen adverse weather and disease can be expected at any time, and they had better take what steps they can beforehand to mitigate the damage.[15]

Another aspect of crop futures that is seldom taken into account in predictive models is the fertilizing effect of CO_2, which is literally food for plants. Higher atmospheric concentration of CO_2 makes plants grow faster and boosts their efficient use of available water. In the future, this will at least partially offset the adverse effects of higher than usual daytime temperatures and drought conditions that might occur, especially when accompanied by innovative crop management measures and the use of genetically improved crop varieties.[16]

Rangelands

Rangelands are grasslands, shrublands, and woodlands that are used for grazing domestic livestock, whether on private or public land, and currently represent about 42 percent of the total area of the U.S. Rangelands are also used by a variety of wild species including economically important stocks of elk (*Cervus elaphus canadensis*); moose (*Alces alces*); and deer (*Odocoileus spp*).[17]

In the contiguous U.S., ecologically distinct rangelands are found east of the Rocky Mountains on the Great Plains and west of the Rockies in the dry Southwest, including the shrublands of California. Different effects of human-caused climate change are predicted depending on the region, although much uncertainty is involved. In the Southwest, the possibility of adverse effects from more intense or frequent drought events in the future is a big worry; in the northern Great Plains, predictions of longer and warmer growing seasons are good news because this should result in increased habitat and forage for wild and domestic species.[18]

In other words, greater future CO_2 emissions could affect the quality and aerial extent of wildlife habitat and forage on rangeland as well as the economic viability of these ecosystems for raising domestic livestock. Because both directly positive and negative consequences of global warming are anticipated, a few examples of more indirect repercussions—from invasive weeds and soil erosion—may help to explain why the perceived adverse effects on ecosystem goods and services from rangelands are not likely to be realized in future decades.[19]

Invasive Plant Species (Weeds). An increase in the abundance of invasive weeds and grasses is forecasted to become a critical problem in future decades for rangelands across the contiguous U.S. Most invasive weeds and grasses are not native to North America: Some weed species were introduced by early settlers, and others were brought in either accidentally or intentionally.[20] As a consequence, most weeds have no natural enemies that would normally keep their abundance within bounds.

Invasive grasses and weeds are resilient species almost by definition. They are often less drought-tolerant and more fire-prone with very effective strategies for rapid growth and reproduction that may include deep or expansive roots systems, massive seed production, and self-pollination. In addition, the fertilizing effect of recent increases in global CO_2 emissions that has made trees and crops grow better unfortunately has done the same for weeds, and this situation is predicted to get worse over time as emissions increase.[21]

The superior productivity of weeds makes it difficult for native species to compete, which means that weeds can expand quickly. Drought-killed or fire-killed rangelands or those subjected to overgrazing are often subsequently invaded by weedy plants. Some of these species are poisonous, but even weeds that are simply unpalatable reduce the yield and quality of nutritious forage on rangelands. Weeds may also interfere with effective grazing when domestic livestock and wildlife avoid weed-infested areas. For these reasons, future increases in the prevalence of weeds on rangelands due to increased CO_2 emissions could have serious economic and ecological repercussions.[22]

However, invasive weeds are currently managed with a combination of mowing, selective and timely grazing, native grass reseeding, controlled burns, and the strategic application of herbicides and natural enemies (including species-specific insect and mite pests, collectively known as biocontrol agents). Most weeds can never be truly eradicated, but the expanded use of biocontrol agents and herbicides especially shows much promise for future management of weeds in the face of increased fossil fuel emissions.[23]

Soil Erosion. Soil erosion is the natural loss of soil on landscapes due to the effects of wind and water. Bare, dry soil can lose nutrients and is easily transported by strong winds; surface runoff from intensive downpours, such as occur during thunderstorms, can lead to destructive flash floods that scour landscapes and precipitate devastating landslides. Much of the damage to U.S. soils since the 1970s has come from the overgrazing of domestic livestock on rangelands, not the intensive cultivation of croplands, exacerbated by drought, that led to extreme erosion during the 1930s.[24]

In the U.S. Southwest, which is a naturally semi-arid landscape, human-caused climate change is predicted primarily to cause catastrophic flooding as a result of more frequent extreme precipitation events. Such adverse effects have the potential to destroy portions of rangeland ecosystems and their wildlife inhabitants. However, extreme weather events are locality-specific and notoriously difficult to predict accurately: The IPCC has only low confidence in the likelihood of any increased incidence of heavy precipitation.[25]

The failure to restore overgrazed rangelands with deliberate planting seems to be the primary cause of recent soil erosion and flooding events. Fortunately, the solution is relatively simple: reduced grazing intensity coupled with purposeful restoration of overgrazed habitats.[26]

Forests and Wildfire Risk

Extended periods of hot weather and drought create ideal conditions for hard-to-fight forest fires. Although climate models predict that such weather conditions generated by human-caused global warming will increase the incidence of wildfires, recent wildfires cannot be blamed exclusively (or even primarily) on global warming: Weather-driven conditions conducive to forest fires have existed for millennia as a result of naturally occurring climate cycles. For example, studies have shown that over the past 3,000 years, severe fires in the western U.S. occurred during the 1800s and the Medieval Warm Period (950–1250 AD), and some of the least destructive happened in the mid-20th century and during the Little Ice Age (1400–1700 AD).[27]

Natural climate variability clearly modified historical fire severity, but landscape changes and similar human influences—including logging and farming practices, firefighting practices, the building of railroad lines and electrical grids, domestic livestock grazing, clearing forests for farmland and settlements (including modern suburbs), deliberate agricultural burning, increased recreational use of back-country landscapes, and the intentional or accidental introduction of weedy, non-native grasses and shrubs—have affected wildlife behavior as they have changed over time, especially since the 1800s.[28]

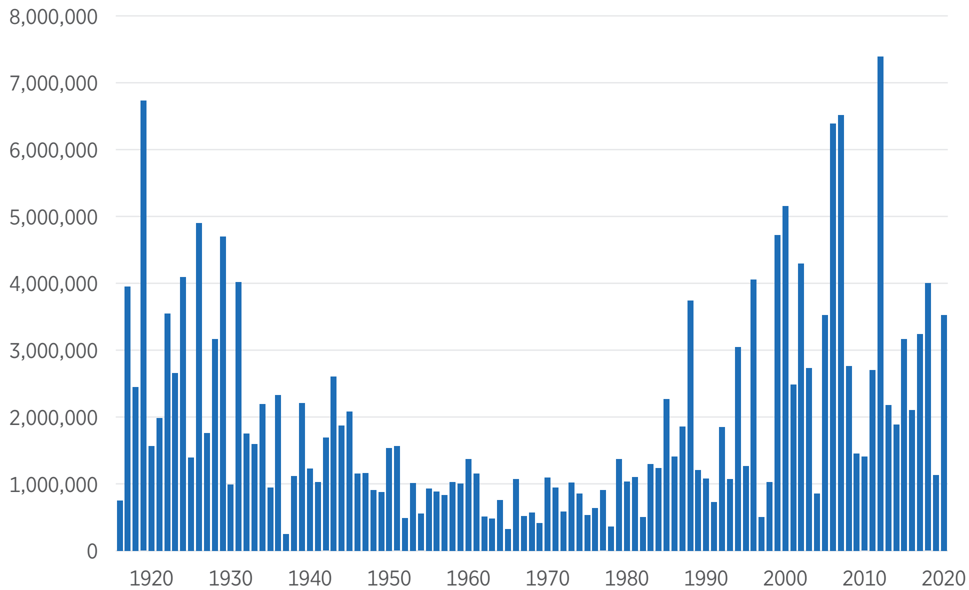
The strongest data for assessing modern forest fire severity over time in the contiguous U.S. come from the western states (Arizona, California, Colorado, Idaho, Montana, Oregon, New Mexico, Nevada, Utah, Washington, and Wyoming), where comparable records go back to 1916. (See Chart 3.) These records show that on federal and federally protected lands, fires from 1916 to the mid-1940s (excluding those caused by arson) were similar in scale to fires in the early 2000s. The most acres burned in a given year burned in 2012, but the second highest number burned in 1919, and some huge fires occurred before 1932 that were equal in size to more recent events. Overall, there is no obvious trend over time.[29]

Records show that most forest fires (including arson, unattended camp fires, discarded cigarettes, sparks from power lines or machinery, etc.) are started by people, whether intentionally or accidentally, and this has

CHART 3

Wildfires on Western U.S. Federal or Federally Protected Lands

IN ACRES BURNED EACH YEAR



SOURCE: Jon Greenberg, "No, Wildfires Weren't Bigger in the 1920s and '30s than Today," Poynter Institute, PolitiFact, October 15, 2021, https://www.politifact.com/factchecks/2021/oct/15/heartland-institute/no-wildfires-werent-bigger-1920s- and-30s-today/ (accessed September 17, 2024).

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largely been true for hundreds of years in North America.[30] For example, a huge forest fire that blazed through Maine in the fall of 1825 was variously blamed on loggers burning slash piles, settlers using fire to clear farmland, and federal agents setting fire to the hay cut by illegal loggers as fodder for their draft animals, in part because such activities were known causes of forest fires at the time.[31] By 2021, 75 percent of wildfires in Oregon and Washington State were determined to be human-caused, up from the previous 10-year average of 64 percent.[32]

Arson is a disturbing subset of human-caused wildland fires, and the deliberate intent that defines these fires can be difficult to detect and hard to prove. However, records show that arson was a serious issue in several southern U.S. states as early as the 1950s when 35 percent–50 percent of forest fires were judged to have been started deliberately.[33] More recently, one study has determined that about 86 percent of all fires in California since the 1990s have been caused by human activity; other studies put that number as high as 95 percent with perhaps 21 percent of these due to arson.[34] Because it takes so long for the judicial system to sort accidental fires from intentional ones, it will be years before we have any reliable data on whether arson fires have increased over the past decade. Nevertheless, research has shown that fires started by people are more ecologically destructive than naturally caused fires triggered by lightning because they are more likely to start on open, less-forested landscapes and on very dry days with gusty winds, which increase a fire's intensity and ability to spread quickly.[35]

Some advocates have claimed that increased numbers of pest-killed trees caused by human-caused global warming have intensified recent fires, but it appears (as explained below) that purposeful changes in human behavior have been largely responsible for worsening infestations. Recent epidemics of forest pests—including the mountain pine beetle (*Dendroctonus ponderosae*); western pine beetle (*Dendroctonus brevicomis*); spruce beetle (*Dendroctonus rufipennis*); and western spruce budworm (*Choristoneura feemani*)—have devastated large woodland tracts across the contiguous U.S. over the past 40 years, but all of the evidence points to intentional shifts in forestry and wildfire-suppression practices as primary causal factors and reduced timber harvests and increased fire suppression as having had the greatest impact on wildfire behavior since 1980.

Tree Pest Infestations. The tree pests responsible for the recent loss of forest trees in the U.S. are largely native species gone rogue. Most are host-specific, which makes them ecosystem-specific: Mountain pine beetles attack lodgepole and ponderosa pines that are widespread across western North America, and spruce beetles go after Engelmann spruce that live in more isolated, high-elevation habitats across the western U.S. The southern pine beetle (*Dendroctonus frontalis*) is native to the southeastern U.S. and attacks pitch pines and red pines.[36]

These destructive forest pests have been present in North America for millennia: Infestations are not a new phenomenon. Records show that epidemics of bark beetle infestations tend to occur every three to 15 years or so. In the past, severely cold winters capable of killing these pests have partly controlled severe infestations, which is why warmer winters due to human-caused climate change are often blamed for recent outbreaks, especially at higher altitudes and more northerly latitudes. While pest-killed trees do provide fuel for wildfires and are often said to be a major contributor to recent increases in forest fires, at least one study in the western U.S. has shown little overlap between these patches of dead trees and major, destructive fires.[37]

The evidence shows that the trees most at risk for insect infestations are slow-growing individuals living in densely packed, mature timber stands, primarily because older trees produce less of the resins that help to rebuff pests in faster-growing young trees. Because these pests thrive on old trees and in forests where trees grow close to one another, reduced or abolished logging and increased fire suppression are considered primarily responsible for the recent phenomenon of bark beetles spreading farther, more rapidly, and more destructively than they did in the past.[38]

Tree Diseases. Increases in infectious disease that afflict trees most often damage or weaken them, making them more susceptible to lethal insect infestation. While warmer winters and the stresses induced by heat and drought due to human-caused climate change have been blamed for an apparent increase in the incidence and spread of tree diseases in the U.S. in recent decades, some of the same causes of pest infestation discussed above also apply to the spread of disease. As discussed below, changes in forestry and fire-suppression practices since the 1980s almost certainly have increased the ability of tree diseases to spread more easily. And while drought can certainly make trees more susceptible to infection, most diseases need a certain level of humidity for survival and effective spread, which challenges the plausibility of predictions that we will see more adverse effects from tree diseases because of climate change over the coming decades.[39]

Changes in Forestry Practices and Wildfire Suppression. Western U.S. forests live in close association with fire. They are dominated by trees in the family Pinaceae, which includes many commercially important species of pines, cedars, firs, hemlocks, larches, and spruces, as well as the giant redwoods and sequoias of California in the family Taxodiaceae. Their normal life cycle is for portions of the forest to burn down periodically, perhaps every 100 years or so, with regrowth afterwards. This effectively eliminates the old-growth forests that are so susceptible to catastrophic pest infestations.[40]

Since the 1980s, the modern practice of suppressing low-intensity to moderate-intensity fires in such naturally fire-adapted ecosystems has been called "maladaptive actions" by the IPCC because they have unintentionally caused an increase in large-scale, high-intensity fires that adversely affect those ecosystems.[41] When left to burn naturally, small to medium-sized wildfires generate a "patchwork forest" with trees of various ages and densities, making them much more resistant to heavy pest infestation and intense firestorms. Selective logging and burning of remnant fuel left after harvest (called "slash"), where it can be done and is permitted, has much the same effect.[42]

Although the widespread suppression of low-intensity to moderate-intensity fires since the 1980s, together with severe restrictions on logging and slash burning, has been largely responsible for the recent increase in large-acreage, high-intensity fires in the western U.S., it has become apparent that better forest management would go a long way toward ameliorating this pattern.[43]

Hot, dry weather over the past two decades has been a contributing factor for increased wildfires in some regions and perhaps the primary factor in others, particularly in southern California shrublands and some steep, subalpine areas of the Rocky Mountains (Colorado and Wyoming) that have never been logged or exposed to fire-suppression activities. However, the increased incidence of accidental or deliberate human-caused ignition must also be factored in, including for remote back-country locations that may have been inaccessible in the past.[44]

Conclusion

More frequent and severe droughts generated by human-caused increases in greenhouse gases are the primary concern for future U.S. forests, croplands, and rangelands, but drought is nothing new for these ecosystems: Drought conditions more severe than the catastrophe of the 1930s have occurred at least twice in the past 1,000 years and both times were due entirely to natural climatic variation. Any future droughts predicted based on increasing CO_2 emissions seem unlikely to exceed these devastating conditions, and innovations in genetics and water management, as well as the fertilizing effects of CO_2 itself, have effectively mitigated recent drought events associated with warmer temperatures and reduced rainfall. Yields of essential food crops like corn, rice, and wheat—considered to be the most at risk of calamitous failure—have increased since the 1960s despite continued increases in CO_2. Similarly, because of improved management and biological innovation, soil erosion and invasive weeds on rangelands and croplands have been less of a problem than predicted as global temperatures have risen.

The extensive history of forest fires in the western U.S. shows that they have always increased in range and intensity when climatic conditions generated drought conditions: Recent severe fire incidents are nothing new. However, compared to the early 1900s when large tracts of forests last burned extensively, the early 21st century presents many more potential ignition triggers during times of drought. Despite this, careful analysis indicates that the apparent increase in fire severity since the 1980s is due primarily to recent restrictions on timber harvests and increased suppression of low-intensity and moderate-intensity fires rather than to increased global temperatures.

While almost all recent forest fires are ultimately human-caused, arson fires are a category apart. Blaming recent forest fires on climate change comes with a specific, unique risk. Sentiments conveyed through news and social media that recent forest fires are a frightening sign of climate change could motivate emotionally unstable activists to set fires deliberately as a way to garner media attention and send a stronger message to policymakers. Wildfires are exceptional in this regard: One individual could start several huge, destructive wildland fires without detection but cannot, for example, cause sea ice to decline or sea levels to rise.

Because a demonstrable link between recent fires and rising CO_2 levels is tenuous at best, as the evidence presented in this *Special Report* shows, climate scientists and their supporters in the media should perhaps avoid labeling forest fires as a clear signal of human-caused climate change until the evidence supporting such a position is more convincing.

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