CLIMATE CHANGE

Is Global Warming Causing More, Larger Wildfires?

Steven W. Running

Higher spring and summer temperatures and earlier snowmelt are extending the wildfire season and increasing the intensity of wildfires in the western United States.

On 3 April 2006, the U.S. weekly news magazine *Time* ran a report on global warming with the cover title "Be worried, be very worried." Similar coverage of global warming has emerged in other general-interest magazines in recent months, triggered by scientific studies that are finding evidence for adverse impacts of global warming occurring today, not merely projected for future decades. These adverse impacts—from higher probabilities of category 4 and 5 hurricanes (*1*, *2*) to higher rates of sea-level rise (*3*)—are found not in some distant unpopulated region, but rather right in our own back yards.

On page 940 of this issue, Westerling *et al.* (*4*) come to a similarly discomforting conclusion for wildfires. They show that warmer temperatures appear to be increasing the duration and intensity of the wildfire season in the western United States. Since 1986, longer, warmer summers have resulted in a fourfold increase of major wildfires and a sixfold increase in the area of forest burned, compared to the period from 1970 to 1986. A similar increase in wildfire activity has been reported in Canada from 1920 to 1999 (*5*).

Westerling *et al.* used the most comprehensive data set of wildfire occurrences yet compiled for the western United States to analyze the geographic location, seasonal timing, and regional climatology of the 1166 recorded wildfires with an extent of more than 400 ha. They found that the length of the active wildfire season (when fires are actually burning) in the western United States has increased by 78 days, and that the average burn duration of large fires has increased from 7.5 to 37.1 days. Based on comparisons with climatic indices that use daily weather records to estimate land surface dryness, Westerling *et al.* attribute this increase in wildfire activity to an increase in spring and summer temperatures by ~0.9°C and a 1- to 4-week earlier melting of mountain snowpacks. Snow-dominated forests at elevations of ~2100 m show the greatest increase in wildfire activity.

The hydrology of the western United States is dominated by snow; 75% of annual streamflow comes from snowpack. Snowpacks keep fire danger low in these arid forests until the spring melt period ends. Once snowmelt is complete, the forests can become combustible within 1 month because of low humidities and sparse summer rainfall. Most wildfires in the western United States are caused by lightning and human carelessness, and therefore forest dryness and hot, dry, windy weather are the necessary and increasingly common ingredients for wildfire activity for most of the summer. Snowpacks are now melting 1 to 4 weeks earlier than they did 50 years ago, and streamflows thus also peak earlier (*6*, *7*).

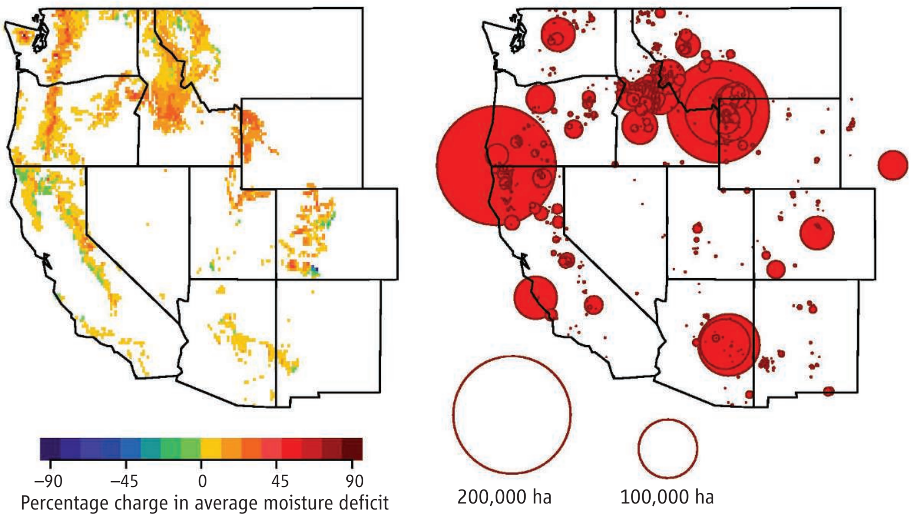
Westerling *et al.* found that, in the 34 years studied, years with early snowmelt (and hence a longer dry summer period) had five times as many wildfires as years with late snowmelt. High-elevation forests between 1680 and 2690 m that previously were protected from wildfire by late snowpacks are becoming increasingly vulnerable. Thus, four critical factors—earlier snowmelt, higher summer temperatures, longer fire season, and expanded vulnerable area of high-elevation forests—are combining to produce the observed increase in wildfire activity.

The fires in Yellowstone Park in 1988 (see the first figure) seemed to inaugurate this new era of major wildfires in the western United States. The fires lasted more than 3 months, burning 600,000 ha of forest, and—despite the investment of $120 million and deployment of 25,000 firefighters—were only extinguished when snow began to fall in mid-September (*8*).

Too close for comfort. Wildfire is seen approaching Old Faithful Village, Yellowstone National Park, in 1988.

CREDIT: (TOP) NPS PHOTO

The Yellowstone fires exemplify a common statistic of wildfires: Less than 5% of all wildfires account for more than 95% of the area burned. A small fraction of fires get very large and become uncontrollable despite human efforts to suppress them, regardless of money expended. Such efforts can cost more than $20 million per day, and seasonal expenditures by governmental agencies in recent years have reached $1.7 billion.



Less moisture—more fires. Between 1970 and 2003, spring and summer moisture availability declined in many forests in the western United States (**left**). During the same time span, most wildfires exceeding 1000 ha in burned area occurred in these regions of reduced moisture availability (**right**). [Data from (*4*)]

The author is with the Numerical Terradynamic Simulation Group, University of Montana, Missoula, MT 59812, USA. E-mail: swr@ntsg.umt.edu

Fire is an important process for recycling dead biomass in the arid west, where natural decomposition rates are extremely slow (historical repeat photography has shown untreated wooden fenceposts still intact after 100 years). However, this benefit is balanced by the annual damages in the western United States from wildfires that have exceeded $1.0 billion in 6 of the past 15 years (*9*).

In 2002, the U.S. Departments of Agriculture and the Interior embarked on a controversial new land management policy called "Healthy Forests," whose stated objective is to clean out dead and dying trees in the west to reduce the risk of wildfires. This initiative blames increasing wildfire activity in the western United States solely on increasing stand density and the buildup of dead fuel as a result of fire exclusion policies; it does not acknowledge any role of changing climate in recent wildfire trends. In contrast, the analysis of Westerling *et al.* suggests that observed increased wildfire activity is at least partially the result of a longer wildfire season acting over a larger forested area. This increased wildfire trend correlates with observed higher temperatures and reduced moisture availability (see the second figure).

As part of the upcoming 4th Assessment of the Intergovernmental Panel on Climate Change (IPCC) (*10*), seven general circulation models have run future climate simulations for several different carbon emissions scenarios. These simulations unanimously project June to August temperature increases of 2° to 5°C by 2040 to 2069 for western North America. The simulations also project precipitation decreases of up to 15% for that time period (*11*). Even assuming the most optimistic result of no change in precipitation, a June to August temperature increase of 3°C would be roughly three times the spring-summer temperature increase that Westerling *et al.* have linked to the current trends. Wildfire burn areas in Canada are expected to increase by 74 to 118% in the next century (*12*), and similar increases seem likely for the western United States.

Wildfires add an estimated 3.5×10^{15} g to atmospheric carbon emissions each year, or roughly 40% of fossil fuel carbon emissions (*13*). If climate change is increasing wildfire, as Westerling *et al.* suggest, these new sources of carbon emissions will accelerate the buildup of greenhouse gases and could provide a feed-forward acceleration of global warming.

References and Notes

1. P. J. Webster *et al.*, *Science* **309**, 1844 (2005).
2. K. Emmanuel *et al.*, *Nature* **436**, 686 (2005).
3. E. Rignot, P. Kanagaratnam, *Science* **311**, 986 (2006).
4. A. L. Westerling, H. G. Hidalgo, D. R. Cayan, T. W. Swetnam, *Science* **313**, 940 (2006); published online 6 July 2006 (10.1126/science.1128834).
5. N. P. Gillett *et al.*, *Geophys. Res. Lett.* **31**, L18211 (2004).
6. P. W. Mote *et al.*, *Bull. Am. Meteorol. Soc.* **86**, 39 (2005).
7. I. T. Stewart *et al.*, *J. Clim.* **18**, 1136 (2005).
8. See www.nps.gov/yell/nature/fire/index.htm.
9. See www.ncdc.noaa.gov/img/reports/billion/billion2005.pdf.
10. See www.ipcc-wg2.org/authors/index.html.
11. K. Rousteenoja *et al.*, *Finn. Environ. Inst.* #644 (2003); see www.ymparisto.fi/download.asp?content id=25835&lan=EN.
12. M. D. Flannigan *et al.*, *Clim. Change* **72**, 1 (2005).
13. G. R. van der Werf *et al.*, *Science* **303**, 73 (2004).

Published online 6 July 2006;
10.1126/science.1130370

NEUROSCIENCE

No More Cortical Neurons for You

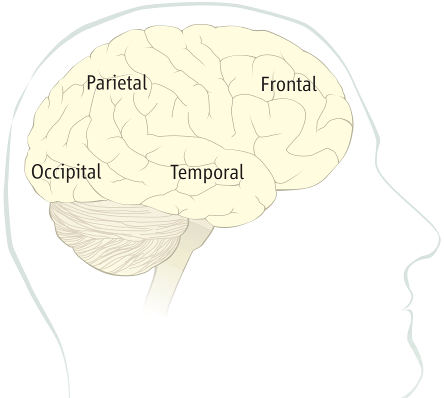
Pasko Rakic

Are new neurons born in the cortex of the adult human brain? An advanced method of cell birth dating appears to answer this contentious question in the negative.

The cerebral cortex is the seat of human intelligence, language, and creativity. This may be why the question of whether new cortical neurons are generated during a person's life span is so fascinating. In particular, whether the human neocortex (see the figure) receives new neurons during adulthood has remained highly controversial. In a recent issue of the *Proceedings of the National Academy of Sciences U.S.A.*, Bhardwaj *et al.* (*1*) add to the evidence that establishes the absence of neurogenesis in this region of the adult human brain. They accomplish this by using an advanced approach based on the carbon-14 (^{14}C) assay for determining the age of cells in the human body.

Over the past 120 years, numerous histological, silver impregnation, and electron microscopic studies have not displayed morphological evidence of new neurons in adult mammalian cortical tissue. More indirect methods, such as radiolabeling the replication of genomic DNA during cell division, have indicated that the cerebral cortex in all mammals so far examined, including rodents and nonhuman primates, is generated during a well-defined developmental period (*2–4*). On the other hand, it was reported that a large number of neurons stream daily from proliferative layers near the cerebral ventricle to the overlaying neocortex in adult nonhuman primates (*5*), raising speculation that new neurons are continuously added to the adult human cerebral cortex. However, this finding could not be confirmed in either the primate (*6*, *7*) or rodent cortex (*8*, *9*), making this issue controversial (*9*, *10*).

The author is in the Department of Neurobiology, Yale University School of Medicine, New Haven, CT 06520–8001, USA. E-mail: pasko.rakic@yale.edu



The adult human brain. The surface of the human neocortex is about 10 times as large as that of a macaque monkey and 1000 times as large as that of a mouse. The neocortex consists of the frontal, parietal, temporal, and occipital lobes. It can be further subdivided into structurally and functionally distinct areas that mediate our most important mental capacities.

CREDIT: P. HUEY/*SCIENCE*

The innovative study by Bhardwaj *et al.* demonstrates with advanced methodology—^{14}C dating of cell births—that no new neurons are added to the human neocortex after birth. The authors take advantage of a transiently sharp increase in the level of the radioactive carbon isotope, ^{14}C, in Earth's atmosphere during the era of aboveground testing of nuclear weapons between the mid-1950s and the time of the nuclear Test Ban Treaty in 1963. In the years following these events, the level of ^{14}C in the atmosphere declined to preexisting low background levels. The authors acquired cortical tissue from the autopsies of seven individuals born in Sweden between 1933 and 1973, and examined the level of ^{14}C in individual cells by accelerator mass spectrometry. The presence of ^{14}C in genomic DNA indicates that cells passed through their last cell division