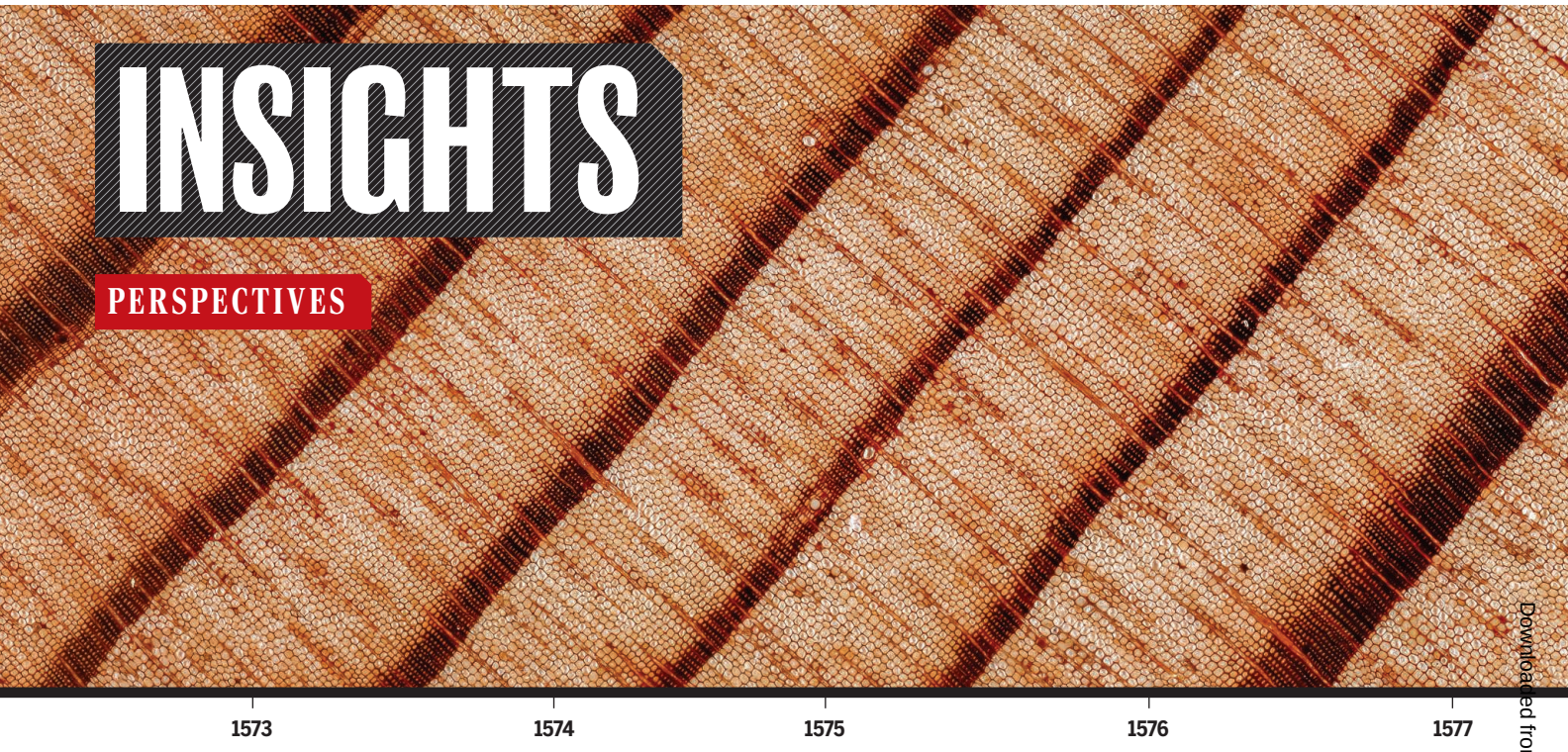

CLIMATE

Anthropogenic megadrought

Human-driven climate warming worsens an otherwise moderate drought

By **David W. Stahle**

Historical documents from the Spanish Entrada on the northern frontier of New Spain (now the U.S. Southwest) include anecdotal evidence for unusual aridity in the late 16th century (*1*). However, a quantitative record of the 16th-century megadrought has only recently been obtained from hundreds of exactly dated and moisture-sensitive tree-ring chronologies developed across Canada, the United States, and Mexico. On page 314 of this issue, Williams *et al.* (*2*) provide a new assessment of proxy climate data from the U.S. Southwest. They determine that the 16th-century megadrought was the worst multidecadal drought episode in the Southwest over the past 1200 years, and that the second-worst event occurred from 2000 to 2018 over southwestern North America (SWNA) and may be ongoing. The study also pinpoints substantial anthropogenic (human) contribution to the severity of the current drought.

The 16th-century megadrought affected much of North America but was most severe and sustained over the southwestern United States and northern Mexico. Williams *et al.* define megadrought precisely, but in simpler terms, megadroughts are dry spells more severe and sustained than any witnessed during the 20th-century period of instrumental observations. The instrumental record for the United States shows that the droughts of the 1930s and 1950s were the most severe, widespread, and long-lasting soil-moisture droughts of the 20th century (*3*). The episode of dryness over the Southwest that commenced during the early 2000s has now eclipsed even the Dust Bowl (1930s) and southern Great Plains (1950s) droughts in duration and intensity (*2*).

The southwestern megadroughts of the medieval era caused fierce wildfires, ecosystem changes, and subsistence crises among ancient societies (*4*–*6*). Indeed, the disruption of agriculture and social order by intense drought appears to have dictated the cultural time horizons of southwestern prehistory (*6*). For example, the 16th-century megadrought is implicated in the abandonment of the Salinas Pueblos (New Mexico) and likely aggravated the indigenous hemorrhagic fevers that killed half of the native population of Mexico that remained after the Spanish conquest (*7*).

Scientists have not yet deciphered the climate boundary conditions or low-frequency ocean-atmospheric dynamics capable of producing megadroughts. Nor do they understand why the frequent droughts of the medieval period abated over North America after 1600 CE, at least until very recently. Because megadroughts are rare events not represented in the modern instrumental record, proxy paleoclimate data and model simulations often are used to investigate these prolonged and widespread droughts.

Climate modeling experiments have revealed that stochastic atmospheric variability and land-surface feedbacks (the flux of energy and moisture from the surface) are sufficient to produce megadroughts in long simulations (*8*). These drought drivers must surely have played a role in some of the real-world decadal droughts of the past. Paleoclimate investigations also have identified forcing of southwestern megadroughts by persistent anomalies in tropical Pacific sea surface temperature (SST) and changes in radiation balance caused by increased solar activity, reduced volcanic activity, or both (*9*, *10*).

In a noteworthy example of global-scale climate coherence, the 16th-century mega-

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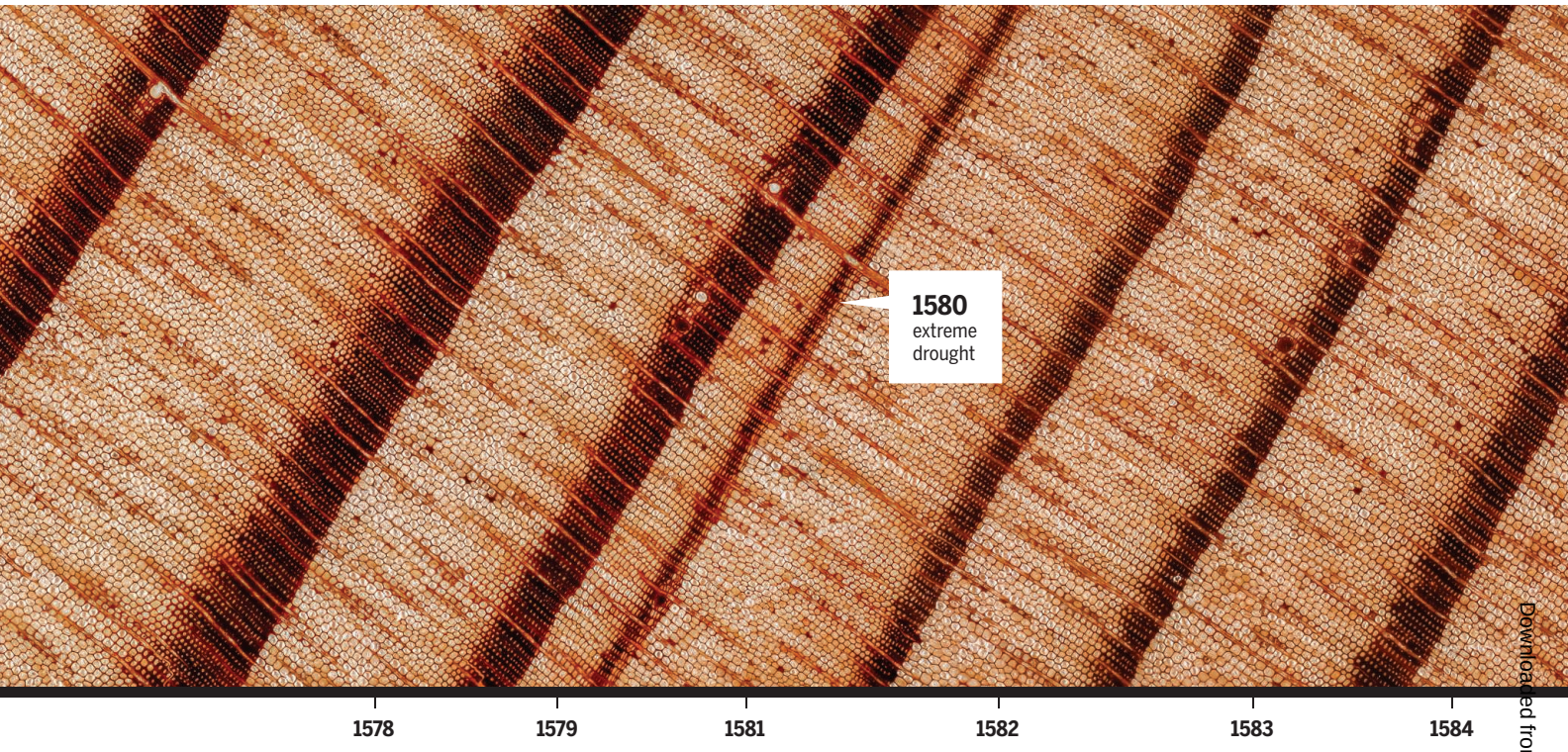

This annual tree-ring sequence reveals reduced growth of a Douglas fir in California during the late 16th-century megadrought.

drought over North America occurred simultaneously with a multidecadal pluvial in paleolake levels and gridded soil-moisture reconstructions for Australia and New Zealand. Such widely separated and opposing long-term moisture conditions are consistent with cold La Niña–like conditions in the El Niño–Southern Oscillation (ENSO): climate-altering, quasi-periodic variations in tropical Pacific SSTs (*11*).

The simultaneous co-occurrence of medieval megadroughts in the mid-latitudes of North and South America also has been reported (*12*) and is based on the Paleo Hydrodynamics Data Assimilation (PHYDA) reconstruction. This co-occurrence of decadal droughts over southwestern North America and Patagonia is statistically significant and is linked with prolonged La Niña–like SST anomalies across the tropical Pacific in the PHYDA reconstructions (*12*). Multidecadal modulation has been observed in instrumental measurements, proxies, and some models of the intensity, frequency, and large-scale teleconnection patterns of ENSO (*13*). The low-frequency activity of ENSO remains a leading candidate for the forcing of megadroughts over the Americas.

Williams *et al.* add anthropogenic forcing to the list of factors capable of transforming a garden-variety dry spell into a full-blown multiyear megadrought. The study combines hydrological modeling, new 1200-year tree-ring reconstructions of summer soil moisture, and a careful statistical evaluation of the issues that influence the uncertainty of comparison between modern and prehistoric droughts. The data demonstrate that the 2000–2018 SWNA drought was the second driest 19-year period since 800 CE. The derived reconstruction represents a nearly seamless evaluation of anthropogenic influence on soil moisture in the U.S. Southwest during the early 21st century, placed in the context of the past 1200 years. The sobering conclusion is that 47% of the severity in the current megadrought can be attributed to anthropogenic climate warming. In the absence of this anthropogenic contribution to warmer regional temperatures, the 2000–2018 interval would have been just another episode of reduced precipitation, low soil moisture, and poor tree growth in the U.S. Southwest during the past millennium. Instead, the artificially increased temperature, lower relative humidity, and rising vapor-pressure deficits have killed millions of western trees (*14*) and helped to make the early 21st century the second most severe and sustained period of megadrought in 1200 years.

Megadroughts cause sufficient environmental and socioeconomic hardship without the unwanted anthropogenic amplification documented by Williams and colleagues. Climate models predict that conditions might worsen by the mid-21st century, when average vapor-pressure deficits over the Southwest could be comparable to the most severe drought episodes of the past millennium (*15*). Meanwhile, declines in wildlife populations and the overappropriation of water resources might have made nature and society less resilient to heat waves, water shortages, and wildfires. Fortunately, reasonable policy options exist to begin muting anthropogenic climate change. These include a number of "no-regrets strategies" to promote energy efficiency and innovation, create jobs, grow investments, and help solve the energy and climate crises. ■

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