Chapter 10
North American Tree Rings, Climatic Extremes, and Social Disasters

David W. Stahle and Jeffrey S. Dean

Abstract Tree-ring reconstructed climatic extremes contemporaneous with severe socioeconomic impacts can be identified in the modern, colonial, and precolonial eras. These events include the 1950s, Dust Bowl, mid- and late-nineteenth century Great Plains droughts, El Año del Hambre, and the seventeenth and sixteenth century droughts among the English and Spanish colonies. The new tree-ring reconstructions confirm the severe, sustained Great Drought over the Colorado Plateau in the late thirteenth century identified by A.E. Douglass and document its spatial impact across the cultural heartland of the Anasazi. The available tree-ring data also indicate a succession of severe droughts over the western United States during the Terminal Classic Period in Mesoamerica, but these droughts are located far from the centers of Mesoamerican culture and their extension into central Mexico needs to be confirmed with the new suite of millennium-long tree-ring chronologies now under development in the region. The only clear connections between climate extremes and human impacts are found during the period of written history, including the prehispanic Aztec era where codices describe the drought of One Rabbit in Mexico and other precolonial droughts. The link between reconstructed climate and societies in the prehistoric era may never be made irrefutably, but testing these hypotheses with improved climate reconstructions, better archaeological data, and modeling experiments to explore the range of potential social response have to be central goals of archaeology and high-resolution paleoclimatology.

Keywords Climate · Dendrochronology · Drought · Epidemic disease · Human impacts · Megadrought · Palmer Drought Severity Index · PDSI · North America famines

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10.1 Introduction

The impact of climate on society has been a controversial research focus from the early days of dendrochronology. A.E. Douglass (1935) noted the coincidence between tree-ring-dated climate extremes and prehistoric Anasazi activities on the Colorado Plateau, including an increase in tree-ring-dated building activity during wet years and decreased activity or complete village abandonment in dry years. 'The great drouth from 1276 to 1299 was the most severe of all those represented in this 1200-year record and undoubtedly was connected with extensive disturbances in the welfare of the Pueblo people' (Douglass 1935, p. 49). 'Pueblo III, the golden age of southwestern prehistory, took its early form in Chaco Canyon about 919 AD, reached its local climax in the late eleventh century, and probably closed with the great drouth of 1276–1299' (Douglass 1935, p. 41). The first long tree-ring chronology developed by Douglass for the American Southwest has been replicated by more than 850 tree-ring chronologies now available for North America (Cook et al. 2004), and Douglass' 'great drouth' of the late thirteenth century has been verified as one of the most severe and protracted of the past 1000 years (Grissino-Mayer et al. 1997). However, the precise role of prolonged drought in the welfare of the Anasazi and their ancient migrations remains an interesting and provocative research question.

There have been a number of more recent attempts to link paleoclimatic extremes to famine, disease, and the collapse of human societies (Keys 1999; Diamond 2005). These catastrophe scenarios have been fiercely controversial among anthropologists, historians, and social theorists, and include viewpoints involving climate determinism, Malthusian demographics, a famine-prone peasantry, and Marxist and entitlement economic theory (Arnold 1988). Elements of each viewpoint are evident in many recent famines, and a loose consensus on the causes of *modern* hunger now includes environmental hazards, food system breakdowns, and entitlement failure. The impact of climatic hazards may have been greater among simple premodern societies, but under some circumstances even modern, more complex societies can suffer extreme climatic disruption. However, the impacts of climate and other geophysical hazards do tend to be greatest among impoverished segments of societies (Ingram et al. 1981; Mutter 2005), as has been demonstrated by the effects of the southeastern Asia tsunami and hurricanes Katrina and Rita. It is anticipated that the consequences of future anthropogenic climate change will continue to be greatest among the poor (Houghton 1997).

Two of the worst famines in world history illustrate the complex environmental, socioeconomic, and political dimensions of these catastrophes. The so-called 'late Victorian famines' of 1876–1879 across India, northern China, and Brazil—when an estimated 16–31 million people perished—were initiated by a strong El Niño event and extreme drought across the Indo-Pacific realm; the human tragedy, however, appears to have been aggravated by poverty, unrestrained market forces, and incompetent government (Davis 2001). Likewise, the catastrophic Chinese famines of 1958–1961 that attended the 'Great Leap Forward'—when 16–30 million 'excess deaths' occurred—began with drought but seem to have been magnified by Mao Zedong's social experiments and failed centralization of Chinese agriculture (Davis

2001). Analyses of these and other nineteenth- and twentieth-century famines indicate that the role of climatic extremes in economic system collapse and starvation has been complex, nonlinear, and strongly subject to prevailing social and technological conditions. The climatic sensitivity of premodern agrarian societies was likely increased by simpler trade and transportation systems, smaller-scale water control systems, and the absence of immunization against disease.

The variable social impacts of climatic extremes also were evident during the major decadal moisture regimes witnessed over North America during the modern era. The Dust Bowl drought of the 1930s (Figs. 10.1 and 10.2a) included the most extreme annual to decadal moisture shortfalls measured in the United States or Canada during the instrumental period (Fye et al. 2003). The Dust Bowl drought interacted with poor land use practices to produce massive dust storms and the most famous environmentally mediated migration in American history. The social costs of environmental change in the 1930s have not been fully separated from the technological and economic changes in Great Plains agriculture during the Depression, but the drought and dust storms certainly contributed to the heavy depopulation of the hard-hit areas on the southern High Plains (Worster 1979). The impact of the Dust Bowl was also mediated by a massive federal relief effort, and President Roosevelt's New Deal Policies 'ensured that the "catastrophe" of the 1930s was a large ripple

Fig. 10.1 A 'Dust Bowl farm' north of Dalhart, Texas, photographed during the June growing season of 1938 by Dorothea Lange (Library of Congress, Prints and Photographs Division, reproduction number LC-DIG-fsa-8b32396). The decadal drought of the 1930s contributed to one of the greatest environmental and social disasters in American history. The house illustrated here was still occupied, but most in the district had been abandoned by 1938

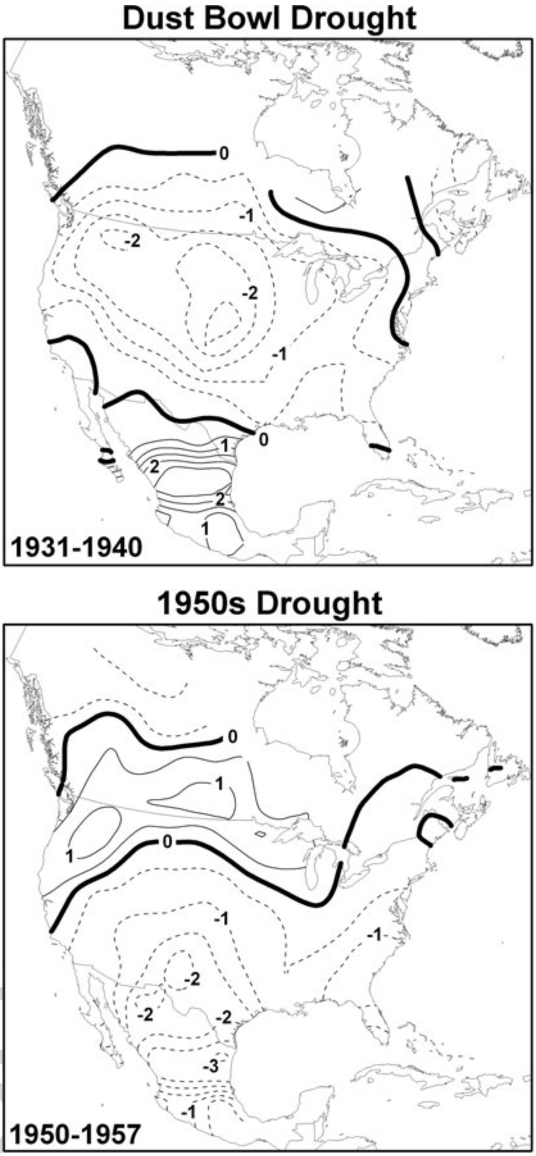


Fig. 10.2 Instrumental summer (June–July–August, JJA) Palmer Drought Severity Index averaged at each of the 286 grid points for North America (the 2.5° × 2.5° latitude/longitude grid from Cook et al. 2004, 2007) and then mapped for the Dust Bowl (**a**, 1931–1940) and 1950s (**b**, 1950–1957) droughts. The PDSI is an integration of monthly precipitation and temperature effects on available soil moisture, and it has proved to be a good model for the effects of climate on tree growth at moisture-limited sites. The 10-year average summer PDSI fell to −2.5 over the central Great Plains and reached above +2.5 over Mexico during the 1930s (a; contour interval is 0.5 PDSI units; *dashed lines* = negative PDSI and dry; *solid lines* = positive PDSI and wet). Note the changing geographical focus of decadal drought from the 1930s through the 1950s

through the national economy, rather than the tidal wave of system collapse on the entire western front of the Plains as in the 1890s' (Bowden et al. 1981).

By contrast, the severe drought of the 1950s, which impacted the southern Plains, Southwest, and Mexico (Fig. 10.2b), lasted nearly as long and impacted a region nearly as large as the Dust Bowl drought (Fig. 10.2a), but did not produce a fraction of the social consequences associated with the Dust Bowl in the United States (e.g., Warrick and Bowden 1981). Out migration from the hard-hit southern Plains was less than 10% for the 1950s, comparable to emigration during wet decades (Bowden et al. 1981). The ranching (Kelton 1984) and dry farming (Rautman 1994) economies of the Southwest were hard-hit, but the postwar economy of the United States was booming and the drought had little economic impact at the national level. The ‘Sun Belt miracle’ of Southwestern population growth and intensive water and energy demand had yet to occur. However, Mexico experienced ‘national drought’ during the 1950s that had severe impacts on rural farming and ranching, highlighting international differences in the economic environments in which this severe regional drought developed (Florescano 1980).

The first major drought of the twenty-first century (Seager 2007), which began in 1999 and currently afflicts much of the western United States and northern Mexico, already has had major environmental and human consequences. Severe precipitation shortfalls have caused crop failures and cutbacks in both small- and large-scale dryland farming. Irrigation agriculture, municipal water supplies, and the generation of electricity have been threatened by unprecedented low water levels in Southwestern reservoirs. All this has occurred at a time when skyrocketing human population is vastly increasing demand for water and electricity and driving fierce competition among the affected groups, cities, and states. Massive fires have consumed more than a million acres of desiccated forests, fueled by living trees with moisture levels below that of kiln-dried lumber. These catastrophic fires have been linked with drought and regional climate change (Westerling and Swetnam 2003; Westerling et al. 2006) and have displaced burned-out communities, destroyed watersheds, and ravaged the tourist and lumber industries. Millions of moisture-stressed conifers (especially pinyon) have succumbed to the drought, or insect infestations, or the lethal combination of both, leaving barren landscapes exceptionally vulnerable to fire and erosion. The current forest dieback appears to exceed the mortality associated with the 1950s drought (Breshears et al. 2005), which had major ecological consequences across the Southwest (Swetnam and Betancourt 1998). Tree-ring data suggest that other major forest mortality events may have occurred during the droughts of the late thirteenth and sixteenth centuries (Swetnam and Betancourt 1998, Fig. 15), but the extent to which the current dieback is related simply to drought or may also reflect other human impacts on Western woodlands has not been determined.

Wet climate extremes may also have significant long-term socioeconomic consequences, as was illustrated from 1905 through 1917 during the early twentieth-century pluvial (Fye et al. 2003). The most recent assessment of the available tree-ring data for the western United States indicates that the first two decades of the twentieth century was the wettest multiyear episode in the past 1200 years (Cook et al. 2004). The tree-ring-reconstructed Palmer Drought Severity Indices (PDSIs; defined in Fig. 10.2) during the wettest decade of the twentieth-century pluvial (1907–1916) indicate prolonged wetness from Baja California across the Rockies to the Canadian border (Fig. 10.3). In fact, Stockton (1975) reconstructed Colorado River streamflow at Lees Ferry, Arizona, to arrive at perhaps the most famous number ever calculated with tree-ring data, a long-term mean annual flow of only 13×10^6 acre feet/year compared with 16.4×10^6 acre feet/year estimated by

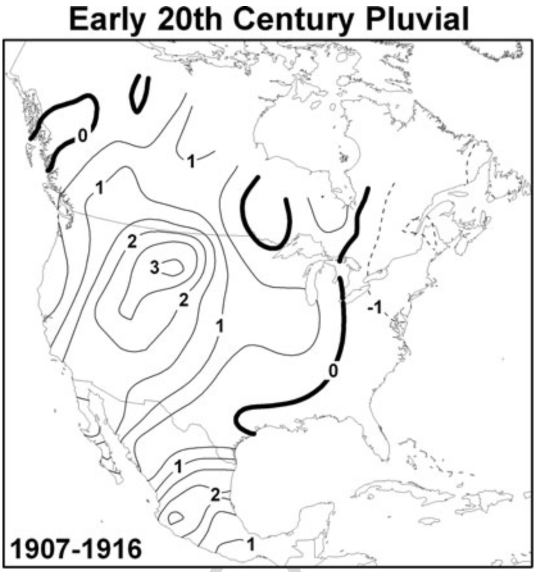


Fig. 10.3 Tree-ring-reconstructed summer PDSI averaged at each of the 286 grid points and mapped for the 10 most extreme consecutive years of the early twentieth-century pluvial (1907–1916; same mapping conventions as in Fig. 10.2). Note the two cells of reconstructed wetness over the central Rocky Mountains and Mexico

the Bureau of Reclamation from discharge data compiled during the twentieth-century pluvial (Hundley 1975; Fye et al. 2003; see Woodhouse et al. 2006 for a recent reanalysis). Streamflow reconstructions for the Salt, Verde, and Gila Rivers (Graybill 1989; Graybill et al. 2006) show a similar positive anomaly for the Colorado River drainage below Lees Ferry. The early twentieth-century period of elevated flow was certainly not sustained, but it coincided with the negotiations that led to the Colorado River Compact, which over-allocated the flow of the Colorado River among the basin states and later included Mexico (Brown 1988). This wet period also coincided with massive ecological changes on the forest and rangelands of the West, and even in the absence of human activities would have favored reduced fire and a pulse of forest regeneration (Swetnam and Betancourt 1998; Westerling and Swetnam 2003). These favorably wet conditions may have contributed to the 'unhealthy' overstocked forests with elevated fire risks in the West that also have been encouraged by overgrazing, deliberate fire exclusion, and anthropogenic warming associated with warmer spring temperatures and earlier snowmelt (Westerling et al. 2006).

This chapter cites a selection of tree-ring studies of climate extremes with demonstrated or *suspected* societal impacts, including both moisture and temperature extremes. We then use the gridded tree-ring reconstructions of the summer PDSI for North America (Cook et al. 1999, 2004; Cook and Krusic 2004) and other regional climate reconstructions to estimate the intensity and spatial extent of selected drought and wetness extremes that are related at least chronologically, if not causally, to major societal changes in parts of North America. This retrospective discussion begins with the data-rich modern era, for which we know much more about the impacts of climatic extremes on society; it then extends back in time to consider examples from the historic, colonial, and prehispanic eras. The climate and social associations witnessed during the modern and historic eras provide a proof of concept for the possible role of climatic extremes in selected social changes in prehistory. Further documentary and archaeological research will be needed to help test these climatic hypotheses of social change during the historic, colonial, and prehispanic eras.

10.2 Tree-Ring Analyses of Climate Extremes and Human Impacts

A.E. Douglass pioneered the use of proxy climate data from tree rings to study cultural change. Douglass documented severe multiyear drought over the Colorado Plateau dating from AD 1276 to 1299 and speculated on the hardships such an extended dry spell must have had on the Anasazi ancestors of the modern Pueblo Indians (Fig. 10.4; Douglass 1929). In fact, the first absolute tree-ring dating chronology for the Southwest was based on living trees and wood and charcoal recovered from historic and prehistoric sites (Douglass 1929). The exact chronological link between the living tree record and the archaeological time series was complicated by the prehistoric migration of people and the abandonment of

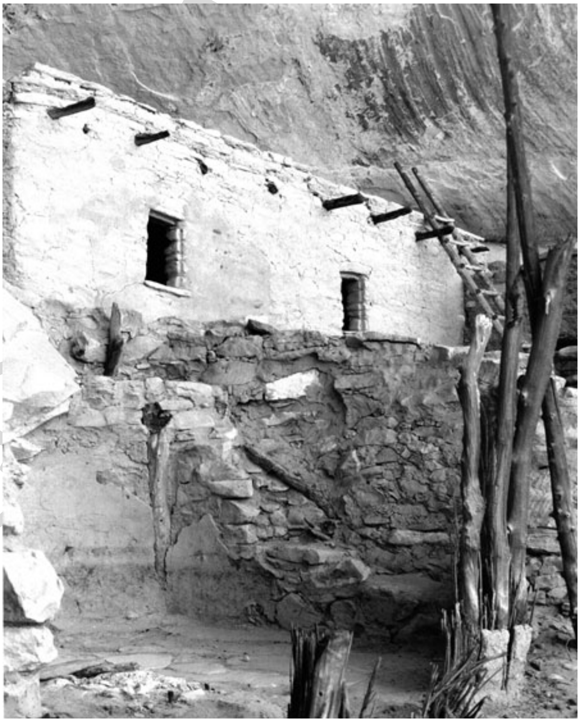


Fig. 10.4 Rooms 44, 45, and 74 (rear *right*, rear *left*, and *foreground*, respectively) at Kiet Siel in northeastern Arizona, one of many Southwestern sites abandoned during Douglass' Great Drought (AD 1276–1299). Room 74 is an annex to the adjacent kiva (a ceremonial structure). Grooved door jambs identify Rooms 44 and 45 as granaries built in 1275 to store food against future shortages (Dean 1969)

village sites during the Great Drought of the late thirteenth century (Douglass 1935). Datable timbers from the late thirteenth and early fourteenth centuries were scarce in the region. Douglass and his collaborators finally found charcoal samples bridging the gap between the modern and archaeological chronologies south of the classic Anasazi heartland near Jeddito Wash and along the Mogollon Rim, in fourteenth- and fifteenth-century archaeological sites believed to have grown in part by immigrants from sites abandoned in the Four Corners area (Haury and Hargrave 1931; Haury 1962; Adams 2002).

The causes of regional abandonment on the Colorado Plateau are still debated, but experiments have shown that the tree-ring record is well correlated with dryland crop yields in the Four Corners region (Burns 1983; Van West 1994), suggesting a drought sensitivity of the Anasazi practicing dryland agriculture. Burns (1983) used tree-ring-reconstructed crop yields to simulate food storage shortfalls and surpluses that identified probable famine among the Mesa Verde Anasazi during droughts, and expanded construction activity during periods of surplus crops, just as Douglass had suggested in 1935.

A number of other provocative studies describing tree-ring evidence for climate impacts on society in Europe and elsewhere have been published. Le Roy Ladurie (1971), for example, linked the period of exceptional growth from 1312 to 1319 in oak chronologies from southern Germany developed by Bruno Huber with flooding, harvest failure, and famine across France and England during one of the most severe periods of famine of the Middle Ages. Lamb (1995) discussed a number of climate inferences based on tree-ring data from Europe and North America, including a shift to colder conditions in the fifth century AD contemporaneous with Roman decline in western Europe.

Perhaps the most unambiguous link between tree-ring data, climate effects, and societal impacts has been demonstrated with frost-damaged rings. LaMarche and Hirschboeck (1984) and Salzer (2000) linked bristlecone pine records of frost rings in the western United States to large-magnitude volcanic eruptions through dust veil effects on the global climate system. The bristlecone pine records include frost rings in 1817 and 1884, following the eruptions of Tambora in 1815 and Krakatau in 1883. These were two of the largest volcanic eruptions in the past 500 years, and both had global-scale climatic and societal impacts. LaMarche and Hirschboeck (1984) tentatively linked the severe frost-ring event dated to 1626 BC in the White Mountain region of California to archaeological and radiocarbon evidence for the destruction of the late Bronze Age site of Akrotiri by the cataclysmic eruption of Thera (Santorini), an assignment that still generates heated debate (Manning 1999).

Baillie (1994, 1999) compiled evidence for profoundly suppressed growth in temperature-sensitive tree-ring chronologies from Europe, North America, and South America during the period AD 536–545. This evidence for anomalous cold was supported by early documentary references to severe cold, crop failure, and dry fogs, suggesting the global climatic effects of a cataclysmic volcanic eruption or the impact of an extraterrestrial object. The societal impacts of the cold climate conditions in the mid-sixth century appear to have been severe and included famine, pandemics (e.g., the Justinian Plague occurred in the 540s), and widespread

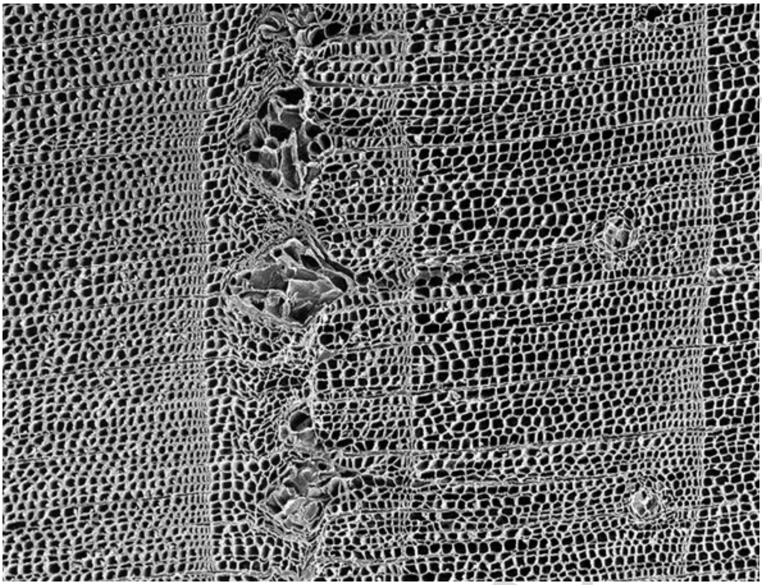


Fig. 10.5 A scanning electron micrograph by Dee Breger (2003), illustrating the annual growth rings from a Siberian pine (*Pinus sibirica* Du Tour) from AD 535 to 539, including the corrupted latewood during the extraordinary growing season freeze event of 536 (i.e., frost ring; D'Arrigo et al. 2001). The 536 event has been linked to an atmospheric dust veil arising from a massive volcanic eruption or extraterrestrial impact event and had global-scale climatic and societal effects (Baillie 1999)

mortality (Baillie 1999; Keys 1999). D'Arrigo et al. (2001) found severe frost damage in the rings of Siberian pine from Mongolia for AD 536 (Fig. 10.5), which was associated with documentary references to the attenuation of starlight, summer frost, crop failure, and famine in northern China from AD 536 to 537. The causes of the extraordinarily cold conditions during the mid-sixth century remain unclear, but they do appear to have occurred at the global scale and had severe societal impacts.

Brunstein (1995, 1996) significantly expanded the bristlecone pine frost-ring record for the Rocky Mountains and described the 'near extinction' of large animals on the High Plains of Colorado and Wyoming during the catastrophic winters of AD 1842–1845, which caused hunger and sickness among the southern Cheyenne. Stahle (1990) described the synoptic climatology and social impacts of the spring freeze events recorded by post oak frost rings from the southern Great Plains, including the epic spring cold wave of 1828: record-setting winter warmth was followed by an arctic outbreak of subfreezing temperatures in April that damaged fruit trees and crops across much of the eastern United States (Ludlum 1968; Mock et al. 2007). St George and Nielsen (2000) used the frequency of 'flood rings' in bur oak to estimate high-magnitude floods on the Red River in Manitoba. The most extreme flood ring in the 500-year record occurred in 1826, when the largest known flood in the history of the region nearly wiped out the Red River Settlement. The recurrence of a flood of this magnitude would exceed the design capacity of the flood protection system for Winnipeg, force extensive evacuations, and cause extensive property damage (St George and Neilsen 2000).

Other interesting tree-ring studies of climatic extremes and social impacts include Jacoby et al. (1999), who used white spruce ring density data to reconstruct extremely cold conditions following the Laki eruption of 1783, when hundreds of Inuit people perished of famine in northwestern Alaska. Gil Montero and Villalba (2005) used moisture-sensitive tree-ring chronologies of *Juglans australis* and *Polylepis tarapacana* as proxies of drought and rural socioeconomic stress in northwestern Argentina. They note a relationship between severe, sustained, and spatially extensive drought beginning in the 1860s and heavy human mortality. The effects of prolonged drought on human mortality appear to have been leveraged by the decreasing availability of water, which concentrated humans and livestock around the few remnant water sources. This concentration favored the spread of epidemic diphtheria, which in the absence of an effective response by governmental authorities, contributed to the mortality and depopulation of the region (Gil Montero and Villalba 2005).

Severe nineteenth-century droughts have been identified in the documentary record for Africa (e.g., Nicholson 1994; Endfield and Nash 2002), including a decadal drought from 1857 to 1865. Food was very scarce and from 'the sea coast to the Zambesi, fountains, streams, and pools have dried up…cattle of all descriptions died everywhere from sheer poverty, and the losses of draught oxen to travelers, hunters and traders have been very severe' (London Missionary Society, quoted by Nash and Endfield 2002). A new tree-ring reconstruction of rainfall based on African bloodwood (*Pterocarpus angolensis*) identifies the period from 1859 to 1868 as the driest decade in the past 200 years in western Zimbabwe (Therrell et al. 2006); the reconstruction also highlights the potential for using tree-ring chronologies from deciduous hardwoods in seasonally dry tropical woodlands to help document the historical impacts of climate extremes.

Extreme climate has been implicated in many other important historical events, and the developing network of climate-sensitive tree-ring chronologies worldwide may allow new insight into these debates. For example, the decline of the Ming Dynasty in China has been linked in part to severe drought extending from AD 1637 to 1644 (Davis 2001). This drought and the associated socioeconomic impacts have been identified with documentary sources, but the new moisture-sensitive chronologies from Asia (e.g., Buckley et al. 1995; Pederson et al. 2001; Liu et al. 2004) will help researchers determine the intensity and spatial impact of this drought and of other climatic extremes over the past several centuries.

Kiracofe and Marr (2002) suggest that the devastating epidemic of ca. 1524 among the Inca of Peru, which killed a reported 200,000 people just prior to the Spanish conquest, was probably caused by bartonellosis (*Bartonella bacilliformis*) transmitted by infected sand flies (*Lutzomyia* sp.). Climate anomalies associated with El Niño events have been linked with a huge increase in the numbers of infected sand flies in the areas of Peru affected by bartonellosis. The co-occurrence of El Niño–related climate extremes during the suspected outbreak of 1524 might be tested with the expanding network of tree-ring chronologies for South America. The discovery of the dendroclimatic value of *Polylepis tarapacana*, a small arid-site tree of the Andes, which grows at the highest elevations of any tree species on earth, is one of the most interesting recent developments in dendrochronology (Argollo et al. 2006). These *Polylepis* chronologies may help test the 1524 climate-bartonellosis hypothesis if time series of sufficient length can be developed.

10.3 Social Impacts of Climate Extremes During the Historic Era

The gridded tree-ring reconstructions of the summer Palmer Drought Severity Index for North America recently produced by E.R. Cook and colleagues provide an exactly dated, spatially detailed record of the hydroclimatic conditions attending many tumultuous events in American history and prehistory (Cook et al. 2007). To highlight the selected climatic extremes, we used the time series of tree-ring-reconstructed summer PDSIs (e.g., Cook et al. 2004) averaged from all 286 individual grid point reconstructions across North America for the past 500 years (Fig. 10.6). This reconstruction highlights the most important continent-wide annual to decadal dry and wet regimes and is highly correlated with the continent-wide average of summer PDSIs based on the instrumental data ($r = 0.84$ for 1900–1978). We then mapped the patterns of reconstructed PDSIs during the specific time periods of interest to estimate the intensity and spatial distribution of these climate extremes. Multiyear droughts with severe social impacts in the new North American PDSI reconstructions include, or are suspected of including, the late nineteenth-century drought over the central and northern Great Plains, the mid-nineteenth-century drought focused over the central Great Plains, the late

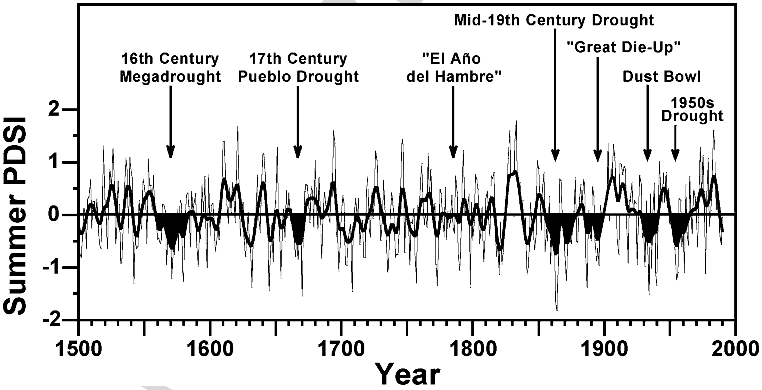


Fig. 10.6 The time series of tree-ring-reconstructed summer PDSI averaged each year for all 286 North American grid points (from Cook et al. 2004), illustrating continent-wide wet and dry spells from AD 1500 through 1990. Selected severe droughts of the past 500 years are highlighted and discussed in the text

eighteenth-century drought over the southern Plains and Mexico (including ‘El Año de Hambre’), the seventeenth-century Pueblo drought over the Southwest, the early seventeenth-century Jamestown drought in Virginia, and the sixteenth-century megadrought across North America. We also discuss the Aztec drought of ‘One Rabbit’ in the mid-fifteenth century, the late thirteenth-century Great Drought first documented and discussed by Douglass, and the prolonged droughts contemporaneous with the Classic Period decline in Mesoamerica late in the first millennium AD. Many of the wettest years now evident in the North American PDSI reconstructions also had significant social consequences, including the early nineteenth-century pluvial, one of the wettest episodes in the tree-ring record for western North America in 500 years (Fig. 10.6).

In the dendroclimatic perspective of the past 500 years, the twentieth century was unusually wet, in spite of the Dust Bowl and 1950s droughts. The nineteenth century was drier, punctuated by several prolonged droughts that we know had significant socioeconomic and environmental impacts, magnified in part by human activities (Fig. 10.6). The so-called ‘Great Die-Up’ during the blizzards of 1886–1887 occurred during widespread drought in the central and northern Great Plains from 1886 through 1890 (Fig. 10.7). The drought appears to have been most severe over the Dakotas and Canadian prairies; it is reported to have degraded the forage value of the grasslands and contributed to the poor condition and subsequent mortality of cattle and to the ultimate collapse of the speculative, overstocked High Plains cattle empire in the late nineteenth century (Stegner 1954). The heavy mortality of cattle during the drought and blizzards of 1886–1887, which extended into the southern Great Plains (e.g., Wheeler 1991), was made famous by Charley Russell’s

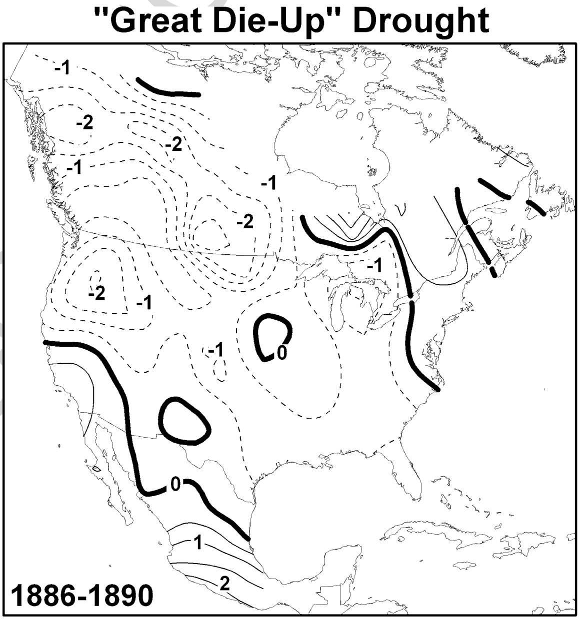


Fig. 10.7 Tree-ring-reconstructed summer PDSI averaged and mapped for the 5-year period from 1886 to 1890, and indicating prolonged drought over the northern Plains and Pacific Northwest (see Fig. 10.2 for mapping details). The impacts of this dry period were magnified by the extreme blizzards of 1886, which resulted in the ‘Great Die-Up’ of range cattle across the Great Plains

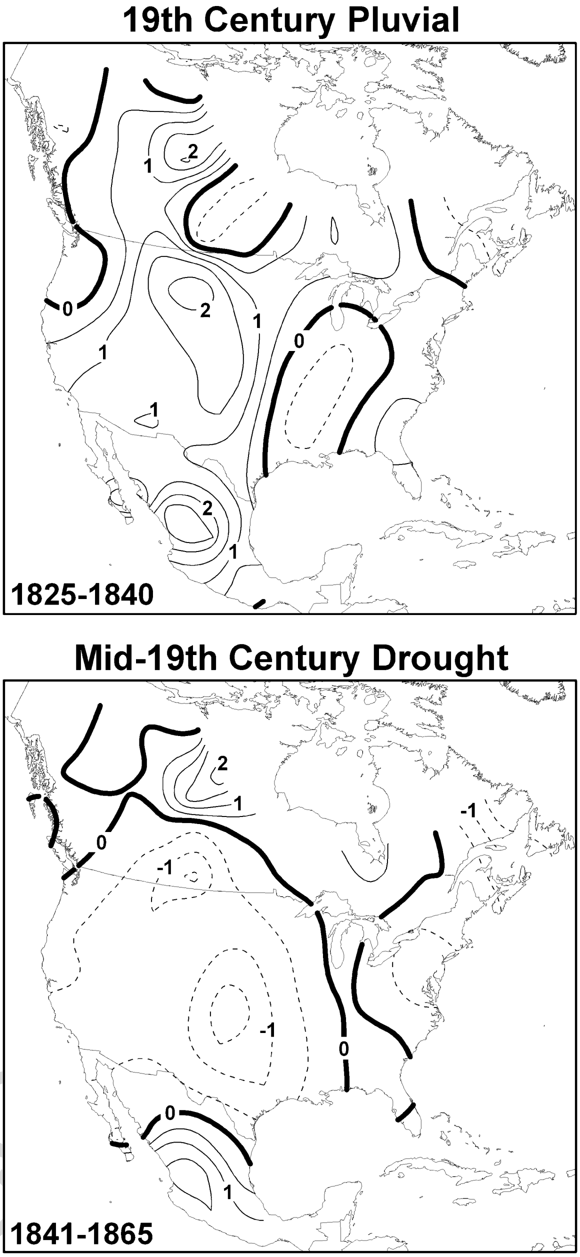
painting ‘Waiting for a Chinook,’ a grim portrait of a starving steer confronting a pack of wolves in a bleak winter landscape.

The Great Plains homesteaders also suffered in the blizzard and drought, as described by Wallace Stegner (1954): ‘In some of the shacks, after five days, a week, two weeks, a month of inhuman weather, homesteaders would be burning their benches and tables and weighing the chances of a desperate dash to town—lonely, half-crazed Swedes, Norwegians, Russians, Americans, pioneers of the sod house frontier. Sometimes they owned a team, a cow, a few chickens; just as often they had nothing but a pair of hands, a willingness to borrow and lend, a tentative equity in 160 acres of Uncle Sam’s free soil, a shelf full or partly full or almost empty of dried apples, prunes, sardines, crackers, coffee, flour, potatoes, with occasionally a hoarded can of Copenhagen *snus* or a bag of sunflower seeds. More than one of them slept with his spuds to keep them from freezing. More than one, come spring, was found under his dirty blankets with his bearded grin pointed at the ceiling, or halfway between house and cowshed where the blizzard had caught him’ (Stegner 1954, p. 294). The drought, which began in 1886, ‘was a slow starvation for water, and it lasted through 1887, 1888, 1889, into the eighteen-nineties. Homesteader hopes survived the first year; in fact, the speculative prices of land in eastern Dakota continued to spiral upward, and the rush to Indian Territory took place in the very heart of the dry years. By the second year the marginal settlers had begun to suffer and fall away; by the third year the casualties were considerable. By the fourth it was clear to everybody that this was a disaster, a continuing disaster. What began in 1886 was a full decade of drouth, the cyclic drying-out that [John Wesley] Powell had warned of in 1878’ (Stegner 1954, p. 296).

The drought of the 1880s and 1890s was part of a recurring pattern of surplus and deficit moisture on the Great Plains that contributed to the waxing and waning of nonirrigated farms in the uplands. To describe the social impacts of these recurrent Great Plains droughts, Walter Prescott Webb (1931, p. 343) quoted A.M. Simons: ‘following the times of occasional rainy season, this line of social advance rose and fell with rain and drought, like a mighty tide beating against the tremendous wall of the Rockies. And every such wave left behind it a mass of human wreckage in the shape of broken fortunes, deserted farms, and ruined homes.’ The population losses in the dry-farming margins of the Great Plains were extreme in the 1890s (integrating the impacts of both the late 1880s through early 1890s and subsequent dry years in the 1890s), when some regions lost 50–75% of their citizens (Bowden et al. 1981). As Stegner noted, Cyrus Thomas coined the phrase ‘rain follows the plow’ in 1868, but ‘by 1888 he knew better’ (Stegner 1954, p. 298).

The most severe and long-lasting tree-ring-reconstructed drought of the nineteenth century occurred with little relief from 1841 through 1865, closely following the early nineteenth-century pluvial, one of the wettest periods in the past 500 years (Figs. 10.6 and 10.8). The center and intensity of the mid-nineteenth-century drought shifted over time and was interrupted by a few wet years (e.g., Woodhouse et al. 2002), but the western United States, Canada, and the borderlands of northern Mexico are estimated to have averaged incipient drought or worse for the entire 25-year period. This multidecadal drought appears to have been most extreme

Fig. 10.8 Tree-ring-reconstructed summer PDSI averaged and mapped for the 'environmental crisis' of the mid-nineteenth century, when a pluvial (**a**, 1825–1840) was followed by a 25-year-long dry period (**b**, 1841–1865), which West (1995) argues interacted with overgrazing of vital riparian corridors by Native American ponies and Euroamerican stock animals to contribute to the extirpation of bison from the central High Plains



over the central Great Plains (Fig. 10.8), where an 'environmental crisis' described by West (1995) afflicted the Arapaho and Cheyenne Indians and interacted with their newly adopted horse culture and with the stock animals of Euroamerican overlanders to degrade critical riparian habitat and lead to the extirpation of the bison from the central High Plains.

The Arapaho and Cheyenne adopted the horse culture and bison hunting in the eighteenth century and migrated from the Great Lakes region into the central High Plains by 1800. They participated in trade with Spanish outposts at Santa Fe and Taos during a time of generally favorable climate, including the early nineteenth-century pluvial. Vivid descriptions by Henry Dodge and other explorers describe scenes of incredible abundance on the central High Plains, including vast herds of bison (West 1995). However, West argues that the Arapaho and Cheyenne became victims of their own technological innovation and ultimately came into competition with the very animal upon which they depended, the bison. The riparian corridors of the Platte, Republican, Smoky Hill, Arkansas, and Cimarron Rivers were key to the High Plains adaptation of the bison, providing water, nutritious winter forage, and shelter from winter storms. But the Native Americans and their ponies required these same resources, as did the stock animals of the Euroamerican overlanders. West (1995) chronicles the increasing use of the riparian resources during the 1840s and 1850s, the same period when the prolonged wet conditions of the early nineteenth-century pluvial were shifting into the persistent drought regime of the mid-nineteenth century. He argues that it was the convergence of Native American bison hunting, human utilization and degradation of the riparian 'habitat islands' of the High Plains, and the onset of multidecadal drought that led to the extirpation of the bison from the central High Plains by 1860, long before the rapacious market hunting of bison following the Civil War. The catastrophic winters of 1842–1845 must have contributed to the bison decline as well (Brunstein 1996).

El Año del Hambre, the year of hunger, described by Gibson (1964) as the 'most disastrous single event in colonial maize agriculture' in Mexico, occurred in 1786 after the August frost of 1785 in highland Mexico and during the severe 3-year drought of 1785–1787 (Therrell 2005). The gridded PDSI reconstructions indicate moderate drought (or worse) for this 3-year average extending from central Mexico into Texas (Fig. 10.9). Some 300,000 people are reported to have perished in the famine and epidemic disease that followed the frost, drought, and crop failures (Florescano 1980; Garcia Acosta 1995). The value of tithes paid to the Church inflated during the drought and frost of 1785–1787 due to the crop failures and increased cost of grain (Therrell 2005). Before El Año del Hambre, substantial droughts in Sonora were accompanied by crop failures, famine, disease outbreaks, and insurrections among the Yaqui, Pimas Bajos, and Seri Indians in 1740, 1737, and 1729, respectively (Brenneman 2004).

A severe 6-year drought occurred across the Southwest and into the central Plains from 1666 through 1671 (Fig. 10.10). A series of disasters among the Pueblo societies of New Mexico in the seventeenth century—including Apache raids, drought, famine, and disease—led to great population loss and submission to Spanish missionary control (Sauer 1980; Barrett 2002). As the drought progressed to 1670, the Pueblos and Spaniards were both reduced to eating 'hides and straps boiled with herbs and roots,' and 950 inhabitants of the Jumanos Pueblos died of starvation (Sauer 1980, p. 66). A great pestilence broke out in 1671 among the Pueblos and their cattle, and more than 400 people perished in one village. Documentary information on crop production during the Spanish occupation of the region is correlated with regional tree-ring estimates of precipitation (Barrett 2002; Parks et al.

Fig. 10.9 Tree-ring-reconstructed summer PDSI mapped for the 3-year period (1785–1787) coinciding with El Año del Hambre (1786–1787) in Mexico, one of the most famous famines in Mexican history, resulting from a drought- and frost-induced crop failure

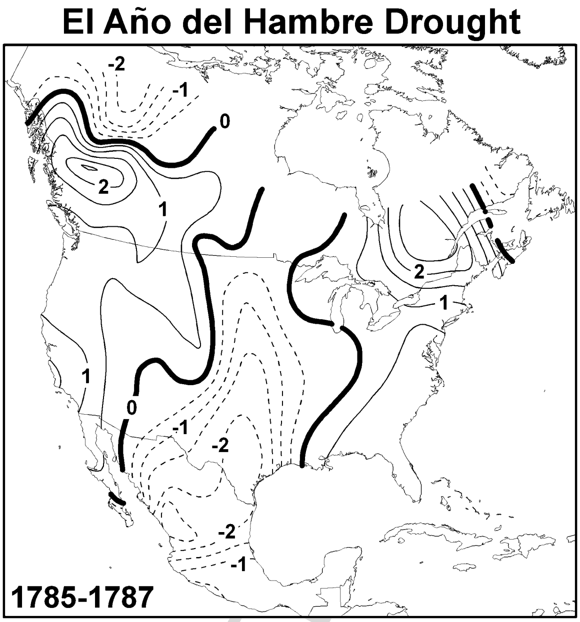
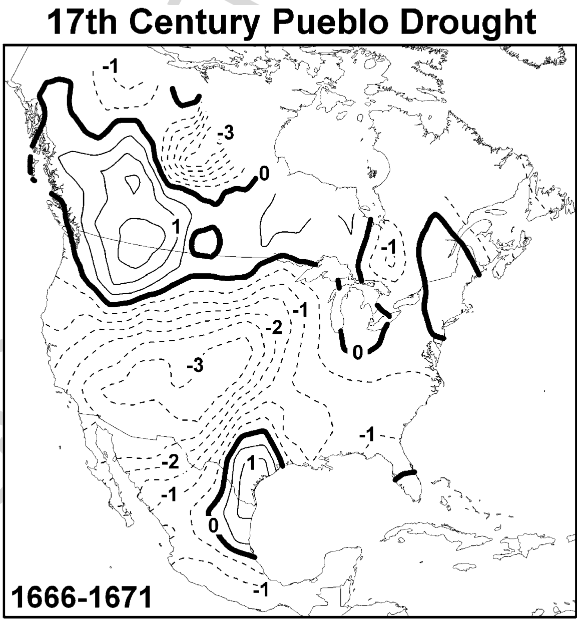


Fig. 10.10 Tree-ring-reconstructed summer PDSI mapped for the severe seventeenth-century drought, which lasted 6 years (1666–1671) and contributed to famine, disease, death, and village abandonment among the Pueblo societies of New Mexico



2006) illustrating the apparent sensitivity of the seventeenth-century economy in New Mexico to severe drought. Indeed, the hardship associated with this dry spell may have helped trigger the Pueblo Revolt of 1680, which drove the Spaniards out of New Mexico for more than a decade. This seventeenth-century ‘Pueblo’ drought, named for the region where the socioeconomic impacts have been documented in greatest detail, may serve as a useful model for the environmental and agricultural impacts of protracted drought among prehispanic Puebloan societies. These impacts may include the controversial effects of the Great Drought on the Anasazi societies of the Colorado Plateau, although the Anasazi did not suffer Apache raids or Spanish colonization in the late thirteenth century. The seventeenth-century Pueblo drought also offers a vivid spatial contrast to the geographical distribution of the early twentieth-century pluvial (Fig. 10.3), but it reproduces reasonably well the intensity, duration, and spatial impact of the recent drought over the Southwest that began in 1999 (Drought Monitor 2004).

Bald cypress tree-ring data from the Tidewater region of Virginia provide an interesting perspective on the human impact of drought extremes during the early English settlement of North America. Jamestown was founded in April 1607, the second year of a 7-year regional drought more severe and long-lasting than any other such event in more than 700 years (Stahle et al. 1998). The tree-ring data were calibrated with the Palmer Hydrological Drought Index (PHDI; Stahle et al. 1998) and, along with archival information on mortality among the colonists, provide statistical evidence for the sensitivity of this early English colony to drought. Mortality and the reconstructed PHDI for the Tidewater region of Virginia and North Carolina are significantly correlated for the first 18 years of English occupation, with most deaths arising from starvation and disease in drought years (Fig. 10.11; $r = 0.71$; $P < 0.001$, for 1608–1624 at Jamestown and including 1586, the one year with mortality data from the Roanoke Colony [Stahle et al. 1998]). In fact, just 38 of the initial 104 colonists survived the first year at Jamestown, and only 1200 out of the 6000 settlers sent to Jamestown in the first 18 years of settlement were still living by 1624.

The drought sensitivity of the early English settlers at Jamestown seems to have been heightened by their dependence on the trade and tribute of food supplies from the native Algonquin. The Spanish sphere of influence in North America during the sixteenth century extended from Mexico and Florida northward up the Atlantic coastline into the Chesapeake Bay, and it included missionary settlements in modern South Carolina (Paar 1999) and Virginia (Lewis and Loomis 1953). Father Juan Bautista de Segura at the Chesapeake Bay and authorities at the Santa Elena colony in South Carolina both referred to extended drought, parched soil, food shortages, famine, and death in the 1560s (Lewis and Loomis 1953; Anderson et al. 1995). These accounts refer to the hardships and food shortages suffered by the native people during drought well before the settlement of Jamestown, but this drought sensitivity would presumably have been shared by Spanish or English colonists who depended on the natives for their food supply.

The drought sensitivity of the early English settlers at Jamestown also arose from the specific location of the colony on the lower James River estuary near the

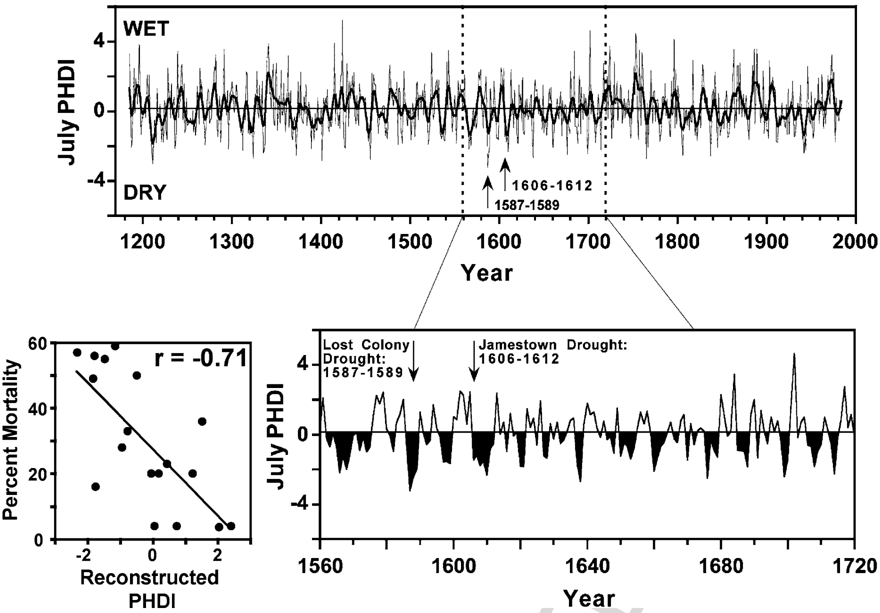


Fig. 10.11 This tree-ring reconstruction of the Palmer Hydrological Drought Index for the Tidewater region of Virginia and North Carolina extends from AD 1200 to 1985 and illustrates record drought during the initial English attempts to colonize America (Stahle et al. 1998). The Lost Colony of Roanoke Island disappeared during the most extreme reconstructed drought in 800 years (1587–1589), and the first successful settlement at Jamestown suffered prolonged drought from 1606 to 1612. Thousands of settlers died during the first two decades of English colonization, and the percent mortality was correlated with growing season moisture conditions (June PHDI, inset *left*)

brackish water/freshwater front. The location of this salinity gradient in the James River is sensitive to precipitation and streamflow (Prugh et al. 1992). In dry years, brackish water extends well upstream from Jamestown, and we know from firsthand accounts that the settlers suffered poor water quality and ill health during these dry years (Stahle et al. 1998). The Jamestown colony ultimately survived the drought and suffering during the first two decades of settlement to become the first successful English settlement in America. The drought sensitivity of the colony appears to have been lessened by increased support from England, expanded agricultural production, an improved water supply, and the development of the tobacco trade.

The drought of the 1560s in the Carolinas and Virginia was part of a severe, long-lasting drought that impacted much of the North American continent during the sixteenth century. This multidecadal sixteenth-century megadrought was focused over Mexico and the Southwest and persisted with little relief in some areas for nearly 30 years (Fig. 10.12). The drought appears to have developed over the far West in the 1540s, moved into the Great Plains during the 1550s, was most intense over Mexico and the eastern United States in the 1560s, expanded into the southwestern United States during the 1570s, and culminated in the 1580s over the Rocky

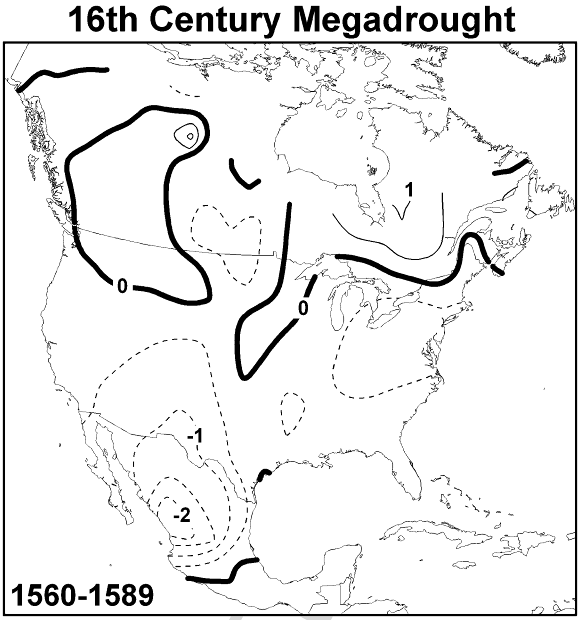


Fig. 10.12 Tree-ring-reconstructed summer PDSI during the sixteenth-century megadrought (see Fig. 10.2 for map details), the most severe sustained North American drought evident in the tree-ring record for the past 500 years (Stahle et al. 2000, 2007). Dry conditions prevailed for 30 years (1560–1589), but the epicenter of decadal drought shifted across the continent during the late sixteenth century (not shown)

Mountains (Stahle et al. 2007). During its most intense phase, the sixteenth-century megadrought appears to have exceeded the severity and geographical coverage of the Dust Bowl drought and may have been the worst drought over North America in the past 500 years (Stahle et al. 2000).

Significant environmental and socioeconomic impacts of the sixteenth-century megadrought have been reported for Mexico, the southwestern United States, and the Spanish and English colonies in the southeastern United States. Sir Walter Raleigh's colony on Roanoke Island (North Carolina) disappeared in 1587, which tree-ring data suggest was the driest single year in 800 years for the Tidewater region of Virginia and North Carolina (Stahle et al. 1998). The Spanish colony at Santa Elena, South Carolina, occupied during 1565–1587, endured many hardships associated with drought during the 1560s. The Juan Pardo expedition into the interior of the Carolinas and Tennessee during 1567–1568 was organized in part to seek food supplies for the colony (Anderson et al. 1995). In northern New Mexico, some pueblos were abandoned during the sixteenth-century drought (Schroeder 1968, 1992). Many of these settlements relied on rainfall agriculture and evidently could not be sustained during the extended drought.

The most severe impacts of the sixteenth-century drought appear to have occurred in Mexico, where extreme drought interacted with conquest, colonization, harsh treatment of the native people under the encomienda system of New Spain, poor crop yields, and epidemic disease to result in one of the worst demographic catastrophes in world history. The size of the native population of Mexico at the time of European contact is controversial, with the low count of 'minimalists' such as Angel Rosenblatt estimating some 8 million inhabitants, and the high count of

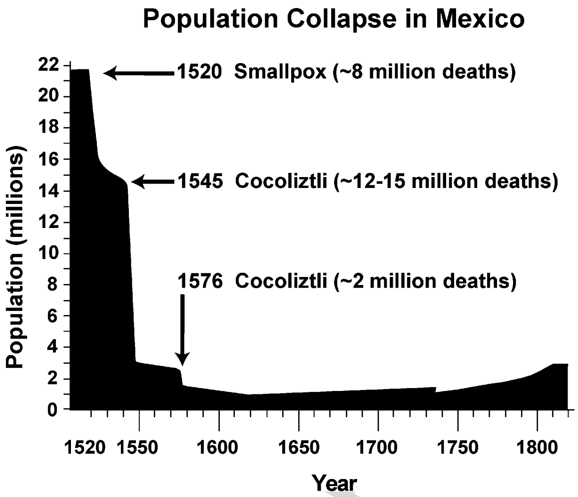


Fig. 10.13 The demographic collapse in Mexico following conquest in the sixteenth century is illustrated with population estimates from Cook and Simpson (1948) and Gerhard (1993). The heavy mortality in the 1540s and 1570s has been linked to indigenous hemorrhagic fevers (i.e., 'cocoliztli') and climate extremes by Acuna-Soto et al. (2002). The population of Mexico did not return to pre-conquest levels until the twentieth century

'maximalists' such as Sherburne Cook and Woodrow Borah estimating 15–20 million (Cook and Simpson 1948). The weight of opinion seems to favor the high count, and the population estimates for Mexico shown in Fig. 10.13 are based on the work of Cook and Borah (Gerhard 1993).

The epidemic of 1519–1520 was certainly caused by smallpox and killed an estimated 8 million native Mexicans during the war of conquest with Cortez (Acuna-Soto et al. 2002; Fig. 10.13). The conventional wisdom has been that the catastrophic epidemics of 1545–1548 and 1576–1580, which killed an estimated 12–15 million and 2–2.5 million people, respectively, were also the result of introduced European or African diseases such as measles, smallpox, and typhus (Acuna-Soto et al. 2000; Marr and Kiracofe 2000). The epidemic of 1545–1548 killed an estimated 80% of the native population of Mexico, which in absolute and percentage terms approaches the severity of the Black Death of bubonic plague from 1347 to 1351, when, conservatively, 25 million people perished in western Europe, or about 50% of the population. But the devastating Mexican epidemics of 1545 and 1576 are now believed by some epidemiologists to have been indigenous hemorrhagic fevers called 'cocoliztli' and later 'matlazahuatl' (Nahuatl terms for 'pest'). These epidemics may have been misdiagnosed as smallpox and typhus due in part to mistranslations of contemporary descriptions and the repetition of historical error. Two recent articles in the epidemiological literature cite new translations from the original Latin texts to make the convincing argument that the catastrophes of 1545 and 1576 were hemorrhagic fevers—probably caused by an indigenous agent, possibly with a rodent vector—that was leveraged by a sequence of climatic extremes and aggravated by the appalling living conditions of the native people under the encomienda system of New Spain.

Acuna-Soto et al. (2000) and Marr and Kiracofe (2000) cite descriptions of cocoliztli by Dr. Francisco Hernandez, the proto-medico of New Spain and former personal physician of King Phillip II. Dr. Hernandez, who was in Mexico during the epidemic of 1576, described the symptoms of cocoliztli with clinical accuracy and detail. The symptoms included acute fever; intense headache; vertigo; and great effusions of blood from all body openings, especially the nose, ears, eyes, etc. Also reported were black tongue, green urine and skin, a net-like rash, abscesses behind the ears that invaded the neck and face, acute neurological disorder, insanity, and frequently death in 3 or 4 days (Acuna-Soto et al. 2000). Upon autopsy, the heart was found to be black and drained yellow and black blood, the liver was enlarged, and the lungs and spleen were semi-putrefied (Acuna-Soto et al. 2000). These symptoms do not describe smallpox, typhus, or any other European disease known to Dr. Hernandez, but more resemble a hemorrhagic fever such as Ebola or hemorrhagic forms of hantavirus. The mortality during these cocoliztli epidemics reflected the social order of sixteenth-century Mexico; deaths were highest among the native people, then the Indian-African mestizos, the Indian-European mestizos, the Africans, and finally even some Europeans died of this disease (Acuna-Soto et al. 2000). The severity of the epidemic may have been magnified among the native people by their poor living conditions, poor diet, and their overwork incumbent on providing tribute under the encomienda system. The geography of the 1545 and 1576 epidemics is also interesting, indicating a preference for the highland areas of Mexico and an absence from the warm low-lying coastal plains (Acuna-Soto et al. 2000, 2004).

Tree-ring data for Mexico during and after the sixteenth century support the hypothesis that unusual climatic conditions may have aggravated the four worst epidemics of cocoliztli, which began in the years 1545, 1576, 1736, and 1813. The epidemics in 1545 and 1576 occurred during the sixteenth-century megadrought, but all four of these most extreme cocoliztli epidemics actually occurred in wet years following intense droughts (Figs. 10.13 and 10.14; Acuna-Soto, personal communication). This sequence of climatic extremes, particularly the drought years followed

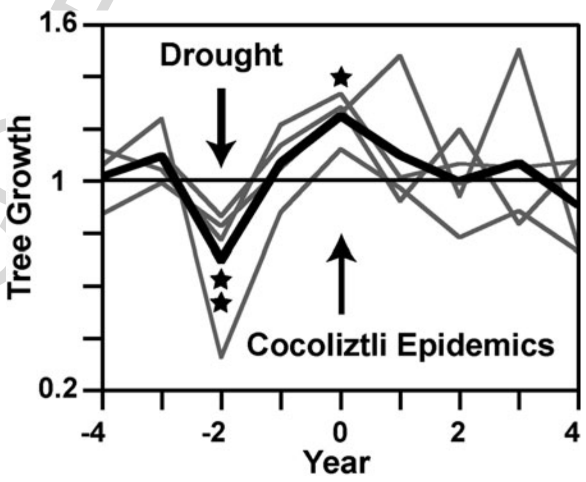


Fig. 10.14 The four most severe epidemics of cocoliztli (hemorrhagic fever) in Mexican history occurred in 1545, 1576, 1736, and 1813. In each case, these epidemics occurred in tree-ring-estimated wet years following severe drought. This superposed epoch analysis indicates that tree growth (mean = 1.0) in Mexico was significantly depressed 2 years prior to the outbreak and elevated during the year of outbreak during these four epidemics ($* = P < 0.05$; $** = P < 0.01$)

by unusual wetness, has been witnessed during other infectious disease events (Epstein 2002), including the hantavirus outbreaks on the Colorado Plateau in 1993 and 1998 (Hjelle and Glass 2000). In the case of hantavirus, the incidence of infection in the rodent host is believed to have been magnified by a population bottleneck during drought. During the subsequent wet conditions, rodent populations expanded and infection was spread to human populations through rodent excreta. The agent responsible for the cocoliztli epidemics of sixteenth-century Mexico has not been identified. However, the tree-ring data suggest that extreme climate conditions may have magnified the impact of these disease catastrophes.

10.4 Suspected Social Impacts of Drought Extremes During the Precolonial Era

The native populations of Mesoamerica developed calendrical and hieroglyphic writing systems centuries before the arrival of Cortez. The Aztec calendar was based on the combination of a 260-day religious calendar and a 360-day solar calendar. The Aztec year was divided into 18 ‘months,’ each 20 days long, leaving 5 days each year that were not included in the formal calendar and were considered bad luck by the superstitious Aztecs (Caso 1971; Keber 1995). The religious and solar calendars rotated through all 18,980 unique daily combinations, resulting in one complete cycle of the two counting systems every 52 years. Each year of the 52-year cycle was identified by one of four possible iconic symbols, which were rabbit, reed, flint knife, and house (Keber 1995). The individual years were then numbered consecutively as follows: the year One Rabbit, Two Reed, Three Flint Knife, Four House, Five Rabbit, Six Reed, Seven Flint Knife, Eight House, Nine Rabbit, etc., until the 52-year cycle was completed with the year Thirteen House. The sequential order of each unique 52-year cycle is not obvious from the Aztec calendar alone, but the sequence of cycles was specified by the Aztec scribes according to royal succession and major political events. Each cycle was then related to the Julian calendar by Jesuits and surviving Aztec scribes during the mid-sixteenth century, so that every year of Aztec traditional history can be tentatively linked to a specific year in the Western calendar, especially during the 14th, 15th, and 16th centuries preceding Conquest.

The Aztecs recorded notable political, celestial, and environmental events with pictorial images linked to specific calendar year signs in ancient diaries known as codices. Codices were prepared by scribes for each city-state of the Aztec empire, but they were considered blasphemous by the Spaniards, and most were destroyed soon after the conquest (Keber 1995). Nevertheless, a few important codices survive and with them fragments of recorded Aztec history. Therrell et al. (2004) noted 13 events specifically identified in the codices as dry years and used independent tree-ring data from Mexico to substantiate most of these Aztec droughts.

Perhaps the most extreme drought of the prehispanic Aztec era occurred in the year of One Rabbit in 1454, for which the codices indicate parched fields, wilted crops, and human corpses littering the ground (Therrell et al. 2004). The tree-ring data from Durango, Mexico, indicate intense drought spanning the period 1453–1455, being most intense in 1454. The ‘Drought of One Rabbit’ in 1454 seems to have contributed to the Aztec superstition regarding all One Rabbit years, which were feared for their association with famine and calamity. The available tree-ring data from Mexico supply some substance to this superstition, indicating that drought occurred in most of the Thirteen House years immediately prior to the One Rabbit years of the Aztec traditional history (10 of 13 cases from AD 882 to 1558), which would have reduced crop yields and could have contributed to hunger and hardship during the subsequent One Rabbit years (Therrell et al. 2004).

The network of 850 climate-sensitive tree-ring chronologies developed across North America by the dendrochronological community, and used by Cook et al. (2004) to reconstruct the summer PDSI, fulfills the potential demonstrated by Douglass (1929, 1935) when he compiled the first master tree-ring chronology based on living trees and archaeological timbers. The new network and the derived reconstructions confirm the Great Drought in the late thirteenth century, which was most intense over the Anasazi cultural area on the Colorado Plateau and persisted for at least 21 years (Fig. 10.15). However, the precise role of climate in the development and decline of the Anasazi on the Colorado Plateau remains controversial. Paleoenvironmental information, including tree-rings, indicates that environmental conditions of the period 950–1130 were relatively favorable (Dean 1988, 1996; Dean and Funkhouser 1995). During this interval, Anasazi populations expanded to their maximum geographical extent and achieved their greatest sociocultural complexity in the regional interaction system focused on Chaco Canyon, New Mexico

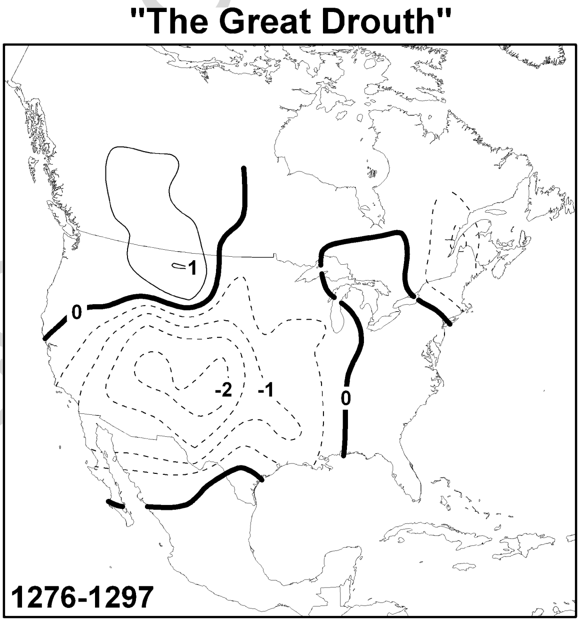


Fig. 10.15 Tree-ring-reconstructed summer PDSI is mapped from 1276 to 1297 (see Fig. 10.2) and illustrates moderate drought or worse for the entire 21-year episode centered over the Anasazi cultural area, as first documented by A.E. Douglass (1929, 1935). This drought has been implicated in environmental degradation and Anasazi abandonment across much of the Four Corners region

(Vivian 1990; Noble 2004). At the same time, Hohokam populations developed immense irrigation systems and a complex social organization in the Sonoran Desert (Reid and Whittlesey 1997, pp. 69–110).

A prolonged bimodal drought from about 1130 to 1180 was associated chronologically with a series of human behavioral and organizational changes throughout the Southwest: Anasazi groups withdrew from the peripheries of their maximum range and from upland areas as previously scattered groups aggregated into larger settlements in better watered lowland localities, the Chacoan regional system ended with the depopulation of its Chaco Canyon core to be succeeded by more localized polities, the Hohokam Sedentary Period pattern gave way to that of the Classic Period, and many others. The late thirteenth century saw widespread environmental degradation, including massive arroyo cutting, falling alluvial groundwater levels, decreased effective moisture, and Douglass' Great Drought (Fig. 10.15). Anasazi emigration from the Four Corners area began before the environmental crisis of the late 1200s, and by the close of the thirteenth century much of the Anasazi cultural area on the Colorado Plateau was abandoned. Although highly unfavorable environmental conditions can certainly be documented for that time, agent-based modeling of environmental and social interactions among Anasazi households in Long House Valley, Arizona (Dean et al. 2000; Gumerman et al. 2003), indicates that the carrying capacity of the environment was not entirely depleted by the end of the thirteenth century. This outcome suggests that the Anasazi abandonment of the Four Corners area must have involved social or cultural considerations in addition to the environmental crisis of the time.

One of the most challenging problems in American archaeology concerns the decline of Classic Period city-states in Mesoamerica during the late first millennium AD, including the abandonment of Teotihuacan in central Mexico (ca. AD 750) and the large urban centers in the Mayan lowlands (ca. AD 770–950). The Terminal Classic Period (AD 750–950) has been recognized in the archaeological record by a decline in the production of fine manufactured goods, the end of large construction projects, the collapse of large-scale trade networks, the abandonment of large urban centers, and the general depopulation of the region. The cause of Classic Period decline is unclear, but drought, human degradation of the environment, disease, warfare, and collapse of the social order needed to sustain the complex exchange networks and urban infrastructure have been implicated (e.g., Millon 1970; Sharer 1994; Gill 2000).

The North American tree-ring network for the first millennium is extremely sparse and limited largely to the American West. No tree-ring chronologies more than 1000 years long have yet been developed for Mesoamerica near the center of the cultural changes during the Terminal Classic Period. Many of the longest Western chronologies have been developed for high-elevation conifers such as bristlecone pine and limber pine, some of which exhibit ambiguous growth responses to climate. However, Grissino-Mayer (1996) developed a long, precipitation-sensitive tree-ring chronology at El Malpais, New Mexico, arguably one of the most important tree-ring chronologies ever produced. The El Malpais chronology is based on long-lived Douglas fir and ponderosa pine trees and subfossil logs of both species, which allowed Grissino-Mayer to develop an exactly dated chronology extending continuously from 136 BC to AD 1992, for a total length of 2129 years.

El Malpais is an extreme moisture-limited site, and the derived chronology has been used to estimate annual rainfall totals over west-central New Mexico for the past two millennia (Grissino-Mayer 1996). The El Malpais reconstruction suggests that the multidecadal droughts in the eighth and sixteenth centuries may have been the most severe and sustained droughts to impact the Southwest in the past 1500 years. The eighth-century megadrought extended from AD 735 to 765 at El Malpais, coincidental with the approximate timing of the abandonment of Teotihuacan, 600 km to the southeast on the Mesa Central of Mexico. We do not know that the eighth-century drought extended into central Mexico (Fig. 10.16), but the 1950s drought in the instrumental record (Fig. 10.2) and a few other tree-ring-reconstructed droughts (e.g. Figs. 10.9, 10.10, and 10.12) indicate that annual and decadal droughts can simultaneously impact the entire region from New Mexico and Texas down into central Mexico (Acuna-Soto et al. 2005).

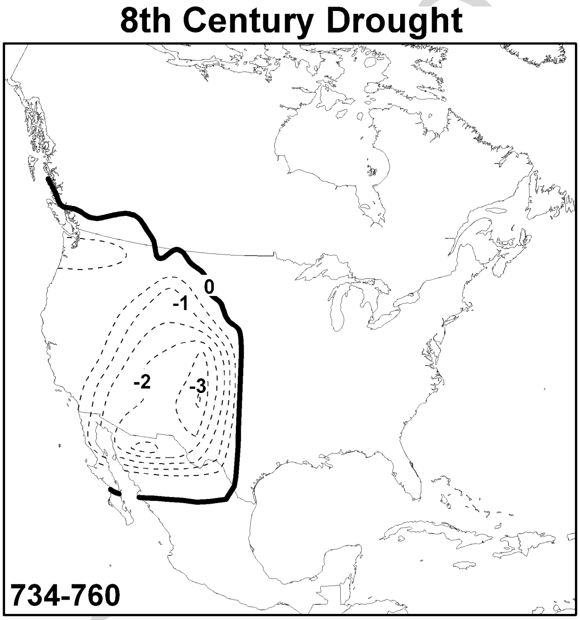


Fig. 10.16 Tree-ring-reconstructed summer PDSI is mapped across the available grid points for the severe sustained drought during the mid-eighth century (AD 734–760; see Fig. 10.2 for mapping details). The predictor tree-ring chronologies are restricted to the western United States, North Carolina, and West Virginia during this time period, and the eastern and southern margins of this drought are not well defined by the available data. The sharp decline in reconstructed summer PDSI in northern Mexico is entirely an artifact of the mapping software and the absence of tree-ring chronologies. Other proxies indicate drought conditions over Mesoamerica from AD 750 to 950 and have implicated climate in the decline of Classic Period cultures (e.g., Hodell et al. 1995, 2005; Gill 2000; Haug et al. 2003)

Evidence for the geographical impact of the eighth-century drought is limited, but tree-ring and lake sediment data indicate that multidecadal drought centered near AD 750 extended from the northern Great Plains, across the southwestern United States, and into central Mexico (e.g., Fig. 10.16). Haug et al. (2003) and Peterson and Haug (2005) documented multidecadal pulses of drought over northern Venezuela and the Caribbean Sea in the sediment record of the Cariaco Basin, beginning in the eighth century and extending into the mid-tenth century. They argued that the anomalies in the Intertropical Convergence Zone (ITCZ) implied by this record would have impacted rainfall over the Mayan lowlands. Intense drought during the Terminal Classic Period has been reconstructed by Hodell et al. (1995, 2005) in lake sediment records from the Yucatan, and it has been implicated in the Mayan collapse (Hodell et al. 1995; Gill 2000). Hunt and Elliott (2005) have simulated severe multidecadal drought over the Mesoamerican sector in a 10,000-year run of the CSIRO Mark 2 global coupled climatic model based only on naturally occurring global climatic variability, demonstrating the plausibility of the prolonged drought identified in the proxy records from the Yucatan Peninsula and elsewhere.

These are interesting *potential* associations between the Classic Period decline and drought. The only certainty is that the eighth-century megadrought—and subsequent droughts in the ninth and tenth centuries evident in the North American, Yucatan, and Cariaco records—*may* have interacted with anthropogenic environmental degradation, epidemic disease, and social upheaval to contribute to the collapse of the Classic Period in Mesoamerica. More paleoclimatic and archaeological information will be required to constrain these hypotheses, including the development of long, climate-sensitive tree-ring chronologies for Mesoamerica and realistic agent-based modeling of Classic Period societies.

10.5 Summary

Tree-ring-reconstructed climatic extremes contemporaneous with severe socioeconomic impacts can be identified for the modern, colonial, and precolonial eras. These events include the drought of the 1950s, the 1930s Dust Bowl, mid- and late nineteenth-century Great Plains droughts, El Año del Hambre, and the seventeenth- and sixteenth-century droughts in the English and Spanish colonies. The new tree-ring reconstructions confirm the severe, sustained Great Drought over the Colorado Plateau in the late thirteenth century identified by Douglass (1935), and they document its spatial impact. The available tree-ring data indicate a succession of severe droughts over the western United States during the Mesoamerican Terminal Classic Period, but these are located far from the cultural heartland of Mesoamerica. Recently, Montezuma bald cypress (*Taxodium mucronatum*) more than 1000 years old have been discovered in central Mexico (Villanueva et al. 2004), and if they can be exactly dated may provide tree-ring reconstructions of precipitation useful for testing the role of drought in cultural decline during the Classic Period.

The only clear connections between climate extremes and impacts on humans are found during the period of written history—including the prehispanic Aztec era codices, which describe the drought of One Rabbit in Mexico and other precolonial droughts. The links between reconstructed climate and societies in the prehistoric era may never be made irrefutably, but testing these hypotheses with improved climate reconstructions, better archaeological data, and modeling experiments to explore the range of potential social responses have to be central goals of archaeology and high-resolution paleoclimatology.

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