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Climate, 1650–1850

ABSTRACT

Climate exerts a profound influence on landscape by determining the flux of both energy (solar radiation) and mass (rain, snow, and water vapor). If climate changes significantly, the landscape can be expected to respond geomorphologically, hydrologically, and biologically. These individual responses, in turn, can feed on one another, creating a cascade of landscape perturbations.

Around 1850, just as large numbers of Europeans descended on the Sierra Nevada for the first time, the region experienced a marked shift in climate, from the abnormally cool and moderately dry conditions of the previous two centuries (the "Little Ice Age"), to the relatively warm and wet conditions that have characterized the past 145 years. This climatic shift should concern land managers for two interrelated reasons: First, the landscape changes that have occurred since 1850 may not be entirely anthropogenic but rather attributable in part to the shift in climate. Second, the landscape of the immediate pre–gold rush period should not be considered an exact model for what the Sierra would be today had Europeans never colonized the region. Thus, attempts to restore "natural conditions" as part of an overall Sierra Nevada management plan should focus not on the pre-European landscape but rather on the landscape that would have evolved during the past century and a half in the absence of Europeans.

Using proxy climatic records, this chapter explores the Sierra Nevada climate of the period 1650–1850 and compares it to that of the modern (post-1850) period. The focus is on climate at the decade to century scale, rather than on individual years or meteorological events. Emphasis is placed on records from lakes, glaciers, tree lines, and tree rings that can be resolved to time scales of multiple decades or less. Other types of proxy indicators, such as pollen and pack-rat records, while indispensable for illuminating multiple-century to millennial changes in climate, are not included in this analysis.

CLIMATE GENERALIZATIONS

Climate is not a landscape component as much as a landscape determinant. It exerts an overriding influence on such landscape components as vegetation (including its type, biomass, and distribution), hydrology (including the size, distribution, fluctuations, and water quality of lakes and rivers), soils (including their thickness, stability, and nutrient capacity), and landforms (including their rates of formation and loss). It also strongly influences other landscape determinants, the most important of which may be fire (including its location, frequency, and intensity).

Climate is inherently changeable, whether by the decade, century, or millennium. It is inherently variable, with some periods characterized by frequent and/or wide departures from the average and others by infrequent and/or narrow departures. And it is inherently site-specific, differing even over small areas depending on such variables as topography, slope orientation, vegetation cover, and elevation. In a range as high, extensive in area, and complex in topography as the Sierra Nevada, the variety of local climates is too extensive to enumerate here. The following generalizations can be drawn, however:

- Temperatures generally decline with increasing elevation in the range, though drainage of cold air into valley bottoms can provide exceptions to this rule.
- Precipitation generally increases with increasing elevation in the range, though wind can keep high-elevation areas swept of snow.
- Winds generally strengthen with increasing elevation in the range.
- Snowfall composes a greater percentage of total precipitation at higher elevations in the range.

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- At a given elevation, the western slope of the range receives greater amounts of precipitation than the eastern slope.
- At a given elevation below 3,000 m (10,000 ft), precipitation generally decreases in the southerly direction through the range.
- At a given elevation below 3,000 m (10,000 ft), temperature generally increases in the southerly direction through the range.
- At a given elevation above 1,000 m (4,000 ft), temperatures on the eastern side of the range are generally higher in the summer and lower in the winter than on the western side of the range.

CLIMATE IN THE SIERRA, 1650–1850

Climate varies not only spatially but also temporally, with some periods being relatively wet and others relatively dry, some relatively cool and others warm. Putting aside for now the year-to-year and decade-to-decade variations in climate, it is possible to characterize the period from the mid-1600s to the mid-1800s as having been, by modern standards, abnormally cool and moderately dry. This interval was preceded by several centuries of cool and wet conditions and was followed by the relatively warm and wet conditions of the past 145 years. Evidence for these generalizations comes from several sources.

Evidence from Hydrographically Closed Lakes

Under natural conditions, runoff from the eastern Sierra Nevada terminates in lakes that lack outlets. These hydrographically closed lakes (including Pyramid, Mono, and Owens) lose water only to evaporation. They thus fluctuate widely through time, rising when inflow exceeds evaporative loss and falling when the relationship is reversed. By reconstructing the past fluctuations of such lakes, it is possible to determine if a particular period was relatively wet and/or cool (i.e., "effectively wet," represented by rising lake levels and a high stand) or relatively dry and/or warm (i.e., "effectively dry," represented by declining levels and a low stand). The closed lakes of the eastern Sierra all show evidence of having been relatively high around the years 1550–1650, reflecting effectively wet conditions; of having fallen to relatively low levels between 1650 and 1850, reflecting effectively dry conditions; and of having risen to relatively high levels during "modern" (post-1850) times, reflecting a return to effectively wet conditions.

Pyramid Lake and Winnemucca Slough

Pyramid Lake, the northernmost of the hydrographically closed lakes that are fed by Sierra Nevada runoff, receives the bulk of its inflow from the Truckee River watershed. When the surface of Pyramid Lake exceeds an elevation of 1,177.4 m (3,863 ft), it overflows into Winnemucca Slough, greatly expanding the lake surface area.

Since around 1860, water has been diverted from the Truckee River for irrigation, depriving the Pyramid-Winnemucca system of a large portion of its natural inflow. As a result of these diversions, Pyramid Lake presently stands more than 20 vertical meters (65 ft) below its point of overflow. In the absence of diversions, Pyramid Lake would have spent all but a few exceptionally dry years (likely 1924–34, 1948–51, 1976–77, and 1987–92) of the modern period at the elevation of the spillway (L. Benson, telephone conversation with the author, May 1995). Winnemuca Slough would have been maintained as a lake throughout this period.

During the decades preceding 1850, prior to any significant alteration of the hydrography by humans, Pyramid Lake dropped to a level below its spillway, resulting in the desiccation of Winnemucca Slough. Hardman and Venstrom (1941) and Harding (1965) interpret Frémont's account from 1844 as indicating that in the mid-1840s the Pyramid Lake surface stood several feet below the spillway. Relict tree stumps with as many as 20 growth rings are rooted on the Truckee River delta at a yet lower elevation (about 3.35 m [11 ft] below the sill, according to Harding). For these trees to have grown, Pyramid Lake must have spent at least two decades below the elevation of 1.174 m (3,852 ft). Radiocarbon assays of these stumps (Stine, unpublished data) indicate that they date to sometime after 1750. Because the stumps are known to have existed prior to 1862 (Russell 1885b; Harding 1965), they must have become established during the late eighteenth or early nineteenth century. These lines of evidence indicate that, during the decades prior to the 1850s, Pyramid Lake stood more than 3.35 vertical meters (11 ft) below the level that it would have occupied during the past 145 years in the absence of diversions.

With Pyramid Lake more than 3.35 m below its sill, and Winnemucca Slough desiccated, the surface area of the Pyramid-Winnemucca system, and thus evaporative loss from the system, is reduced by roughly a third. The low stand that characterized Pyramid Lake prior to 1850 thus reflects a substantial diminution of effective inflow—to perhaps 66% or less of the modern natural value.

Mono Lake

Mono Lake, on the lee side of the central Sierra Nevada, receives its inflow from the Rush, Lee Vining, and Mill Creek drainages. Since 1941, much of this inflow has been diverted by the Los Angeles Department of Water and Power for domestic supply, forcing the lake to low levels. But for these diversions, the lake surface during the past century would have fluctuated within a narrow elevation interval (± 2 m [6 ft]) centered on about 1,958 m (6,423 ft) (P. Vorster, telephone conversation with the author, May 1995). This elevation is hereafter referred to as the "natural level" of the modern period.

Around 1650, Mono Lake attained a high stand at 1,967.8 m (6,456 ft), 10 m (30 ft) higher than the calculated natural level of the modern period (Stine 1987, 1990). Radiometrically dated evidence for this high stand (and thus evidence for effectively wet conditions) is seen today in the form of rooted stumps, sedimentary sequences, and geomorphic stand lines. These same lines of evidence demonstrate that between 1650 and about 1840 effectively drier conditions drove Mono Lake to 1,948.9 m (6,394 ft)—9 vertical meters (29 ft) below the calculated "natural level" of the modern period. This low level, corresponding to a surface area approximately 79% that of the modern natural value, indicates that the effective inflow to Mono Lake prior to 1850 was, on average, less than 79% of the effective inflow of the period 1937–79 (Stine 1987, 1990).

Owens Lake

Owens Lake is the natural sink for all eastern Sierra Nevada runoff south of the Mono Basin. Diversion of the Owens River (Owens Lake's main feeder stream), first by irrigation interests in the Owens Valley and subsequently by the Los Angeles Department of Water and Power, has desiccated the lake, exposing the entire playa floor. Were it not for these diversions, Owens Lake since the early 1860s would have stood within a narrow elevation interval (±1 m [3 ft]) centered on about 1,095.5 m (3,594 ft). Such a lake would cover the now-dry lake floor with up to 15.8 m (52 ft) of water (Stine 1994).

Sequences of lake-transgressive and lake-regressive deltaic sediments exposed in the walls of the stream cuts adjacent to Owens Lake provide evidence that around the half-century 1600–1650 effectively wet conditions drove the shoreline to an elevation of 1,098.8 m (3,605 ft), creating a lake with a surface area approximately 110% that of the modern natural value. Effectively dry conditions prevailed during much of the ensuing two centuries, forcing the lake to elevations below 1,088 m (3,570 ft)—more than 7 m (24 ft) lower than the natural level of the modern period. This low stand represents a surface area approximately 77% that of the natural modern value, suggesting that effective inflow to the lake was more than 23% below the natural modern value (Stine 1994; Stine, unpublished data).

In summary, the closed lakes of the eastern Sierra Nevada are consistent in being dominated by declining levels and low stands during the period from the mid-1600s to the mid-1800s. In those two centuries the lakes attained elevations lower than those of the prior century (1550–1650) and lower than the "natural levels" of the twentieth century.

Evidence from Sierra Nevada Glaciers

Following thousands of years of little or no glaciation, high-elevation cirques of the Sierra Nevada experienced ice accumulation for several centuries prior to 1850 (Clark and Gillespie 1995; Curry 1969). This period of minor glacier advance (typically less than 2 km), first described in the Sierra by Matthes (1939), corresponds to the "Little Ice Age"—a period of cooling over much of the globe that began in the fourteenth or fifteenth century and continued through the middle of the nineteenth century (Grove 1988).

Based on the well-documented behavior of glaciers in the European Alps, Matthes (1939), speculated that these small ice bodies of the Sierra Nevada reached their maximum extent during the period 1850–55. Maps and photos produced by Russell (1885a, 1889) show that by the early 1880s the Lyell, McClure, and Dana Glaciers had begun to retreat from their maximum positions of the Little Ice Age, with the ice front lying several hundred feet (in the case of the Lyell Glacier) up the canyons from the terminal moraines. With the exception of a few years of net positive glacier balance (Curry 1969), this shrinkage, and the loss of many small ice patches, continued into the early decades of the twentieth century. Matthes (1939, 1942a, 1942b) noted that between 1933 and 1938 the Palisades Glacier thinned by 8.2 m (27 ft); that between 1931 and 1939 the East Lyell Glacier retreated 26.5 m (87 ft); and that between 1933 and 1941 the West Lyell Glacier thinned by 3.7 m (14 ft) and the East Lyell Glacier by 6.7 to 10.4 m (22 to 34 ft). Further shrinkage of the glaciers is evident from a comparison of the U.S. Geological Survey quadrangles from the late 1940s and early 1950s with those from the 1980s.

Evidence thus indicates that the centuries prior to 1850 were abnormal in the context of Holocene climate, in that they favored ice accumulation in cirques of the high Sierra. Shortly after 1850 the glaciers began to retreat. With the exception of a few aberrant years, Sierran glaciers have experienced a net negative balance since that time.

Theoretically, this minor glaciation of the mid-sixteenth through mid-nineteenth centuries is attributable to some combination of increased precipitation (leading to greater accumulation) and decreased temperature (leading to less melting and sublimation). Since the lake level records presented earlier in this chapter are consistent in suggesting that climate was relatively dry during this period, it might be concluded, as a working hypothesis, that relatively low temperatures caused the advance of the ice. Various types of dendroclimatological evidence, presented later in this chapter, comport with this hypothesis. The dendroclimatic record, in fact, verifies that climate was both relatively cool and relatively dry during the centuries preceeding the California gold rush.

Evidence from the Hydrogen Isotope Record

According to Feng and Epstein (1994), the deuterium-to-hydrogen ratio of nonexchangeable hydrogen in the cellulose of a tree ring is systematically related to the deuterium-to-hydrogen ratio in the water used by the tree to produce that ring. At least in meteoric (i.e., atmospheric) waters, the deuterium-to-hydrogen ratio is a function mainly of air temperature at the time of condensation, with higher temperatures giving rise to greater amounts of deuterium. To the extent that the trees in question are being nurtured by meteoric waters, rather than by long-stored ground waters, the deuterium-to-hydrogen ratios in the rings can be used as a proxy for past temperatures.

Feng and Epstein applied these principles to an analysis of bristlecone pine (Pinus longaeva) tree rings from the White Mountains, immediately east of the Sierra Nevada. Based on that analysis, they infer that a rapid cooling started around 1600, and culminated between approximately 1750 and 1850 with the coolest temperatures of the past 8,000 years. The record indicates that, since then, temperatures have been on the rise.

Evidence from Tree Lines

The cooling of the seventeenth, eighteenth, and early nineteenth centuries inferred from the hydrogen isotope composition of bristlecone pines seems also to be reflected in the position of the upper bristlecone tree line in the White Mountains. LaMarche (1973) noted that during the past several thousand years the bristlecone tree line on both Campito and Sheep Mountains has declined from the high levels of mid-Holocene time. This recession progressed in fits and starts, with the most recent plunge, resulting in the lowest tree line of the past 7,000 and more years, occurring around 1600–1700. Bristlecone reproduction at the upper limits of this depressed tree line ceased between approximately 1700 and 1860. Since then, the pines have been reestablishing themselves at elevations nearly as high as the loftiest tree line of the Holocene epoch (LaMarche 1973, 1982).

LaMarche (1973) argued that upper tree-line elevation on Sheep Mountain is a function of temperature during the growing season, with increased temperatures leading to a higher tree line. The upper tree-line position on Campito Mountain, in contrast, reflects both temperature and precipitation, with increases in both leading to a higher tree line. Since tree lines on both mountains fell around 1600, and remained low until around 1860, LaMarche concluded that climate during this interval was both cool and dry. The warmer and wetter conditions since 1860 account for the ongoing rise in the tree lines, according to him (LaMarche 1982).

Lloyd and Graumlich (1993; Graumlich, telephone conversation with the author, June 1995) report that the foxtail pine (Pinus balfouriana) tree line in the southern Sierra Nevada fell between 1500 and 1600, in concert with the most recent tree-line depression in the White Mountains. Curiously, the foxtail pine tree line on Cirque Peak near the southern end of the Sierra Nevada seems to have reached low levels not around 500 years ago, as reported in the studies of LaMarche and of Lloyd and Graumlich, but around 1,400 years ago (Scuderi 1987); indeed, no further tree-line depression on Cirque Peak appears to have occurred during the Little Ice Age. The Cirque Peak record, however, does show an upward movement of the tree line during the past century, in common with the White Mountain sites and the Sierra sites of Lloyd and Graumlich.

Evidence from Tree Rings

Graumlich's tree-ring record from subalpine conifers (Pinus balfouriana and Juniperus occidentalis) in the southern Sierra, spanning more than 1,000 years, constitutes the most recent, and arguably the most rigorous, dendroclimatic analysis from the range (Graumlich 1993). Her work permits a climatic reconstruction far more detailed temporally (to the multiple-year scale) than that derived from lakes or glaciers. It also allows the temperature factor to be isolated from the precipitation factor, an advantage that neither the lake record nor the glacial record can provide.

Employing response surfaces that relate historical summer temperature and winter precipitation to ring width, Graumlich demonstrates that

- Growing-season temperatures reached their lowest level of the past millennium around 1600 and then remained low, by modern (1928–88) standards, until around 1850.
- While the period 1713–32 was, by modern standards, characterized by relatively wet conditions, it was preceded by a century dominated by low precipitation and was followed by 130 years (particularly the intervals 1764–94 and 1806–61) of anomalous drought.
- The period 1937–86 has been the third-wettest half-century interval of the past 1,000 and more years.

Graumlich stresses that her inferred droughts and temperature variations are reflected in other tree-ring studies undertaken in and adjacent to the Sierra Nevada (Briffa et al. 1992; Michaelson et al. 1987; LaMarche 1973; Graumlich and Brubaker 1986; Fritts 1991; Hughes and Brown 1992). Such coherence indicates that her findings have applicability throughout and beyond the range, rather than just locally.

SUMMARY AND DISCUSSION

A combination of records from lakes, glaciers, tree rings, and tree lines in and adjacent to the Sierra Nevada indicates that, in general, the period from around 1650 to 1850 was characterized by anomalously cool, moderately dry conditions. After being driven to their highest levels in several millennia by effectively high Sierran runoff, Mono, Pyramid, and Owens Lakes began to fall around 1650. Physical, biotic, and historical evidence indicates that during the 1840s and 1850s these lakes stood well below their modern natural levels, leading to the inference that effective inflow was perhaps 23%–34% less than the modern value. By the early 1860s the lakes were rising toward their modern natural levels in response to increased effective runoff from the Sierra.

As the closed lakes of the eastern Sierra were falling to low levels between 1650 and 1850, glaciers were forming and advancing in the high Sierra, arguably for the first time during the Holocene (the postglacial period). (Note that the accumulation of ice in the cirques of the eastern Sierra Nevada played only an insignificant role in decreasing runoff from the Sierra during this period. The building of glaciers during the Little Ice Age is thus not, in and of itself, an explanation for the recession of the closed lakes.) Glacier increase, together with the hydrogen-isotope record from the White Mountain bristlecone pines and the tree-line depression in both the White Mountains and the Sierra, strongly suggests that the centuries prior to the California gold rush were the coolest of the past 8,000 and more years. The modern wasting of the glaciers, the upward expansion of alpine tree lines, and the hydrogen-isotope record all indicate that since 1850 the Sierra has experienced a marked warming.

Graumlich's tree-ring record from the southern Sierra provides the most detailed view of variations in the latest Holocene climate. That record confirms that the period from 1650 to 1850 was generally dry, although it points up an important exception not evident in the lake or glacial records: the interval 1713–32 was anomalously wet. Graumlich's work also provides corroboration that the period from 1650 to 1850 was, by both Holocene and modern standards, abnormally cool.

IMPLICATIONS FOR THE FIRE REGIME IN THE SIERRA NEVADA

Based on an examination of burn scars in the tree rings of giant sequoias (Sequoiadendron giganteum) at five groves on the west slope of the Sierra, Swetnam (1993) reconstructed a 2,000-year-long fire history. Relating fire size and fire frequency to climate series derived from tree rings of giant sequoias and bristlecone pines, he documented a close decade- to century-scale positive relationship between summer temperature and fire activity (frequency and synchrony) and a close multiple-year-scale negative relationship between precipitation and fire activity. He tentatively attributes these relationships to high-frequency (years-scale) precipitation-dependent changes in the moisture content of fuels and low-frequency (decade- to century-scale) temperature-dependent changes in fuel production.

Swetnam's record indicates that throughout the period 1650–1850 fire frequency in the groves sustained its lowest level in 900 years, a result that would be expected, given the low temperatures of the Little Ice Age.

Equally expected would be an increase in fire frequency corresponding to the increase in temperature after 1850. This modern increase in fire frequency did not occur, however, probably for three reasons: decreased fuel loads due to sheep grazing, a decrease in ignition due to the demise of Native Californian culture, and fire suppression policies. Indeed, rather than increasing, fire frequency since 1850 has decreased to its lowest value of the past 2,000 years.

These findings underline the peculiarity of the modern fire regime in the Sierra Nevada: while the disparity between fire frequency of the modern period and that of the period 1650–1850 is clearly large, the disparity between modern fire frequency and the frequency that would occur today absent European settlement is even larger.

IMPLICATIONS FOR MANAGEMENT OF THE SIERRA NEVADA

The period 1650–1850 is of great interest to Sierra Nevada land managers because it is the last interval in which Europeans exerted little if any influence on the Sierran landscape. It may be tempting to use the condition of the landscape as it existed during this two-century period as a model for what the Sierra would be today in the absence of Europeans. In a related way, it may be tempting to attribute all landscape changes that have occurred since 1850 to the agency of Europeans.

There can be no question that many of the changes that have occurred since 1850 are attributable to the activities of Europeans. But it must be borne in mind that the European incursion closely coincided with a marked shift in climate and that some of the landscape change since 1850 may be, at least in part, attributable to that climate shift. The magnitude of the shift underscores its potential importance in instigating landscape change. In temperature, the shift was from the coldest century-scale interval of the Holocene, as indicated by the tree-line and glacier records, to one of the warmest periods of the past 4,000 years, as suggested by the recent upward movement of the tree line. In moisture availability, the shift was from moderate effective drought, as evidenced by the records of tree rings and lake levels, to the relative wetness of the present century—a century that appears, from the records of lake levels, to be the fourth-wettest of the past 4,000 years (Stine 1990) and that includes the third-wettest fifty-year interval (1937–86) of the past millennium (Graumlich 1993).

Thus it seems that, even if the European incursion had never occurred, the Sierra Nevada landscape of today would differ in significant ways from that of the immediate pre–gold rush period. With this in mind, attempts to restore "natural conditions" as part of an overall management plan should focus not on the pre-European landscape but rather on the landscape that would have evolved during the past century and a half in the absence of Europeans.

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