The Little Ice Age in the Sierra Nevada

The term "Little Ice Age," now applied in many mountain regions of the world (Grove 1988), was conceived in the Sierra Nevada. As originally used by Matthes (1939), it referred to the past 4,000 years, during which, he believed, Sierra Nevadan glaciers advanced because of a general cooling trend that followed a putative mid-Holocene thermal maximum. The more recent convention (Porter and Denton, 1967) is to lump the world's mountain glaciations of the past 4,000 (or 5,000, 6,000, or 7,000) years into a "Neoglacial Period," with "the Little Ice Age" being restricted to the few centuries preceding the mid- to late 1800s. The phrase Little Ice Age is used here in this more limited sense.

That small glaciers exist high in cirques of the Sierra Nevada was recognized early on by Muir (1875) and Russell (1885, 1889). Matthes (1939) established that the moraines of these glaciers overlie deposits of talus (as opposed to bedrock), thus demonstrating that the birth of the small ice bodies had been preceded by a thorough deglaciation. In recognition of that and other contributions, Birman (1964) named the ice advance the "Matthes glaciation"—a colloquialism for Little Ice Age glacier activity in the Sierra Nevada.

Dating this activity has been at best imprecise. Wood (1977) observed that, unlike the surrounding lands, the Matthes-age moraines lack a cover of volcanic ash from the Mono-Inyo Craters and Domes—the volcanic chain that rises just east of the central Sierra Nevada. He reasoned that the Matthes glaciation must therefore be younger than the most recent west-blowing eruption of that chain—an event that he (1977; corrected by Wood and Brooks [1979]), and Sieh and Bursick (1986) dated to about 1,300 years ago. On the basis of a number of nonglacial proxy indicators of past climate, Konrad and Clark (1998) argued convincingly that the Matthes advance commenced sometime within the past 700 years. Lichenometric dates on stabilized (thus, post-advance) Matthes-age moraines indicate that the glaciers likely withdrew from their maximum positions sometime within the past 200 years (Konrad and Clark 1998). Photos taken in the early 1880s by Russell (1885) show that the glacier fronts had receded only a few hundred feet or less, at that time. Since then (thus, throughout "modern time" as defined here) wastage of the ice has been proceeding at an accelerating pace (for some of the documentation of this recession, see Matthes 1939, 1942a, 1942b; Stine 1996; and photo comparison by Stine [Bradley 2000]).

Given that modern climate is not conducive to the maintenance of glaciers in the Sierra Nevada, the conditions that caused them to form and advance during Matthes' time must have been, by comparison, wetter (that is, snowier) or less ablative (the latter likely due to relatively low melt-season temperatures), or both. Some investigators have stressed wetness as the overriding driver of glaciation, but this overlooks important lessons from other proxy records. Thus, the hydrographically closed lakes of the eastern Sierra Nevada, which fluctuated substantially during Matthes' time (Stine 1990a, 1990b, 1994a, 1994b), spent centuries of that interval dropping to levels that, by modern-natural standards, must be considered low (though not as low as during the Medieval time). Indeed, during the first half of the 19th century, when the Sierra Nevadan glaciers were near their maximum Neoglacial extent, Mono, Owens, and Pyramid lakes were lower than their lowest natural level of modern time, and much lower than they would be today but for diversions of their influent streams (Stine 1996). This coincidence of large glacier size and low lake levels is best explained by a combination of (by modern standards) relatively cold, relatively dry conditions. However, climate was not consistently dry throughout Matthes' time—indeed, on two occasions during that interval, the surface of Mono Lake reached elevations higher (in one case, more than 25 feet higher) than any level attained in the modern period. Rather, precipitation in the Sierra Nevada was well below the modern average for several extended intervals of the past 500 years.

The tree-ring record confirms the lake-level evidence. Graumlich (1993), for example, found that temperatures remained below the modern mean (defined as A.1928–1988) for nearly the entire period from A.D. 1450 to 1850. Although some intervals of this period were wet (for

example, the late 15th and early 16th centuries and the early to mid-18th century), others were remarkably dry (including A.D. 1834–1883, which was the fifth-driest 50-year period of the past millennium). Other evidence for a cold, episodically dry Little Ice Age in the Sierra Nevada is summarized by Stine (1996).

Implications for Management of Wildlands

The proxy records discussed above highlight the peculiarity of the warm, wet climate that has characterized the Sierra Nevada during the past 120 years. Equally importantly, they demonstrate that substantial fluctuations in relative wetness, on scales from multiple decades to centuries, have occurred on numerous occasions over the past millennium. For several reasons, these findings point to the need for resource managers to take a multi-decade- to centuries-scale view of wildlands—one that bases long-term planning on an understanding of the long-term past and treats the landscape as a perpetually changing entity, rather than as one that might change someday.

First, shifts in Sierra Nevadan climate will occur in the future, just as they have in the past under natural conditions; however, unlike the shifts of our natural past, those of the future will be (and likely have already been) also influenced by anthropogenic forcing.

Second, given the recency of the latest shift in climate (it commenced around A.D. 1880), it is likely that much of the Sierra Nevada's vegetation has not yet come into distributional equilibrium with the new warmth and wetness. In fact, if the frequency and magnitude of the past millennium's climatic swings are any indication, it seems probable that distributional equilibrium in the Sierra Nevada is never reached or even closely approached. Thus, in a long-term view of the Sierra Nevada that acknowledges climate change, it is not static distributions of plants and animals that must be managed but rather distributions that are constantly in flux and transition, moving up, down, or laterally along complex and variable temperature and moisture gradients.

Third, because of the above-noted flux and transition, long-term management schemes must not constrain wildlands within "hard boundaries" (those along which wildlands are bounded by thoroughly altered landscapes), because such boundaries restrict the ability of species to shift their distributions in response to climate change. Thus, "soft boundaries" and corridors must be part of any realistic long-term management plan for wildlands.

Fourth, while it seems likely that climate will continue to warm in the coming decades, it is impossible to predict whether the next shift in wetness will be toward drier, or even wetter, conditions. But this uncertainty does not preclude the formation of sound management plans. The goal of such a plan cannot be to accommodate just one type of climate change; rather, the goal must be to accommodate change in general, no matter what its direction or severity.

Finally, the paleodroughts of the past millennium undoubtedly inflicted much stress on the high-moisture-dependent biota of the Sierra Nevada and surrounding regions. Aquatic, amphibious, and riparian species probably suffered the most, as lakes and streams shrank, marshes and wet meadows desiccated, and spring sites diminished in size and number. Clearly, the indigenous species that we see today in the Sierra Nevada survived these past droughts and ultimately may have been genetically invigorated by them. But could these same plants and animals, now so stressed and so constricted and fragmented in distribution, survive epic drought again? Only if land managers take the long view, conserving during what may currently be the best of times but preparing for the worst of times ahead.

References

Birman, J.H. 1964. **Glacial geology across the crest of the Sierra Nevada, California.** Geological Society of America Special Paper vol. 75; 80 pp.

Bradley, R. 2000. **1000 years of climate change.** Science 288: 1353-1355.

Graumlich, L.J. 1993. **A 1000-year record of temperature and precipitation in the Sierra Nevada.** Quaternary Research 39: 249-255.

Grove, J.M., 1988. **The Little Ice Age.** London: Methuen; 498 pp.

Konrad, S.K.; Clark, D.H. 1998. **Evidence of an early Neoglacial glacier advance from rock glaciers and lake sediments in the Sierra Nevada, California.** Arctic and Alpine Research 30: 272-284.

LaMarche, V.C., 1974. **Paleoclimatic inferences from long tree-ring records.** Science 183: 1043-1048.

Matthes, F.E. 1939. **Report of the Committee on Glaciers.** Transactions of the American Geophysical Union; 518-523.

Mattes, F.E. 1942a. **Report of the Committee on Glaciers.** Transactions of the American Geophysical Union; 374-392.

Matthes, F.E. 1942b. **Glaciers.** In: Meinzer, O.E., editor. Hydrology. New York: McGraw Hill; 149-219.

Muir, John. 1875. **Living glaciers of California.** Harper's Monthly, November 1875.

Porter, S.C.; Denton, G.H. 1967. **Chronology of neoglaciation in the North American cordillera.** American Journal of Science 265: 177-210.

Russell, Israel C. 1885. **Existing glaciers of the United States.** Fifth annual report for 1883-1884. U.S. Geological Survey; 303-355.

Russell, Israel C. 1889. **Quaternary history of Mono Valley, California.** Eight annual report for 1886-1887. U.S. Geological Survey; 261-394.

Sieh, K.E.; Bursick, M.I. 1986. **Most recent eruption of the Mono craters, eastern central California.** Journal of Geophysical Research 9: 12539-12571.

Stine, S. 1990a. **Late Holocene fluctuations of Mono Lake, California.** Palaeogeography, Palaeoclimatology, Palaeoecology 78: 333-381.

Stine, S. 1990b. **Past climate at Mono Lake.** Nature 345: 391.

Stine, S. 1994a. **Extreme and persistent drought in California and Patagonia during Medieval time.** Nature 369: 546-549.

Stine, S. 1994b. **Late Holocene fluctuations of Owens Lake, Inyo County, California.** Technical Report to Far Western Anthropological Research Group, Inc., Davis, California; 16 p.

Stine, S. 1996. **Climate, 1650–1850.** In: Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II. Davis: University of California, Centers for Water and Wildland Resources; 25-30.

Wood, S.H. 1977. **Distribution, correlation, and radiocarbon dating of late Holocene tephra, Mono and Inyo craters, eastern California.** Geological Society of America Bulletin 88: 89-95.

Wood, S.H.; Brooks, R. 1979. **Panum Crater dated at 640 ±40 radio carbon Y.B.P., Mono Craters, California.** Geological Society of America, Abstracts with Programs 11: 543.