

THE ROLE OF CLIMATE CHANGE IN INTERPRETING HISTORICAL VARIABILITY

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Abstract. Significant climate anomalies have characterized the last 1000 yr in the Sierra Nevada, California, USA. Two warm, dry periods of 150- and 200-yr duration occurred during AD 900–1350, which were followed by anomalously cold climates, known as the Little Ice Age, that lasted from AD 1400 to 1900. Climate in the last century has been significantly warmer. Regional biotic and physical response to these climatic periods occurred. Climate variability presents challenges when interpreting historical variability, including the need to accommodate climate effects when comparing current ecosystems to historical conditions, especially if comparisons are done to evaluate causes (e.g., human impacts) of differences, or to develop models for restoration of current ecosystems. Many historical studies focus on “presettlement” periods, which usually fall within the Little Ice Age. Thus, it should be assumed that ecosystems inferred for these historical periods responded to different climates than those at present, and management implications should be adjusted accordingly. The warmer centuries before the Little Ice Age may be a more appropriate analogue to the present, although no historic period is likely to be better as a model than an understanding of what conditions would be at present without intervention. Understanding the climate context of historical reconstruction studies, and adjusting implications to the present, should strengthen the value of historical variability research to management.

Key words: *climate change; forest management; historical variation, use in ecosystem management; natural variability; paleoecology.*

INTRODUCTION

Historical reconstructions are often done to guide restoration of modern ecosystems. Restoration assumes that degradation from a more natural or desired condition has occurred; usually the degradation of concern is human caused. A goal of restoration is to return the ecosystem to a more natural state of both function and biodiversity through active management (Bradshaw 1983, 1984, Hunter 1996). This usually involves removing or mitigating the offending activities (Cairns 1988). In the Pacific Southwest and Northwest, for example, considerable attention has been focused on understanding the impacts to ecological productivity and biodiversity caused by past and present activities, such as timber harvest, road building, grazing, and fire suppression (Forest Ecosystem Management 1993, Quigley et al. 1996, Sierra Nevada Ecosystem Project 1996). From this understanding, management goals and practices are developed, for instance, to restore natural fire regimes, improve viability of species, and rebuild forest structure (e.g., old growth) in patterns reminiscent of the original ecosystem.

Restoration and management in these situations require reference conditions as guides. Reference is needed to understand (1) what the original or preferred condition was, compared to the current condition; (2) what the degrading factors were and how large they were; (3) what the causes of change were; and (4) what needs to be done to restore the ecosystem. Questions such as these underlie general approaches to ecosystem management (Kaufmann et al. 1994, Swanson et al. 1994, Washington Forest Practices Board 1994, Regional Interagency Executive Committee 1995, U.S. Forest Service 1995a, Sierra Nevada Ecosystem Project 1996). An ideal situation to address these questions would be the “control” of modern landscapes where the assumed impacts have not occurred, such as ecologically comparable areas to restoration sites where, for instance, no harvest or grazing has occurred, or where fires have not been suppressed. This situation is rare to nonexistent for most western forested ecosystems. Instead, surrogates are used for reference, such as nearly comparable contemporary landscapes (different forest types and geographic regions; e.g., Minnich et al., *in press*), or historical reconstructions of pre-impact conditions of the ecosystem under concern. Historical reconstructions of pre-European settlement (several centuries prior to the mid-1800s; e.g., U.S. Forest Service

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1993) fire and forest conditions are increasingly being undertaken (Taylor 1993, 1995, Stephenson 1994, Skinner and Chang 1996, Swetnam et al. 1999). These are often used as reference conditions to guide restoration and to assist in setting goals for ecosystem management.

Climate is a potentially confounding factor in analyzing historical reconstructions, both because it strongly influences biodiversity, vegetation structure, and ecosystem functioning, and because climate changes over times relevant to management. Historical climate, however, is often not considered in analysis for restoration and ecosystem management. If climate effects are not considered, management interpretations of cause and effect, and of appropriate benchmark conditions, may be flawed (Millar 1996, 1997, Woolfenden 1996). The purpose of this paper is to introduce some of the confounding influences that climate change could have in interpreting historical data for management, to briefly illustrate these points with two ecosystem management examples, and to encourage further research and consideration of this issue within application of historical data to management. We illustrate these issues with examples from the Pacific Southwest region of North America, and specifically the eastern Sierra Nevada.

CLIMATE CHANGE AND HISTORICAL ANALYSIS

Whether climate has a significant confounding effect on historical analysis for management depends, among other things, on the following: (1) the longevity of individual species and the depth of the historic record commonly used (e.g., dendrochronology, fire history, and pollen analysis), relative to the time period of regional historical climate phases; and (2) the magnitude and significance of the climate differences to vegetation and other ecosystem elements. For instance, conifers in most Sierran forests commonly live 200–500 yr, and many live for centuries more. Historical reconstructions using fire scars, dendrochronology, pollen, and packrat midden analysis extend back in time several centuries to many millennia. Significant global and regional climate anomalies are recognized on these same scales. Within the last 1000 yr, several prominent climate phases have been recorded that appear to have had significantly large effects on vegetation and ecosystems to warrant evaluation in restoration and ecosystem management analyses.

Insights from Quaternary science, where time periods of decades to millennia are studied, reveal complexities of climate change over time (e.g., Delcourt and Delcourt 1991, Williams et al. 1993). Critical research is focused on the forces that affect climate at hierarchic time scales, from short- to long-period fluctuations, and on the origin and mechanisms of these forces (Imbrie et al. 1984, 1992, 1993, Kutzbach and Guetter 1986, Broecker 1991). Increasingly, physical connections are being found that relate changes at an-

nual to decadal levels (such as El-Niño–Southern Oscillation events; Cane 1998), century to millennial level (such as so-called Heinrich and Dansgaard–Oeschger events; Bond et al. 1992, Rind and Overpeck 1993), and large-scale patterns (10 000–100 000 yr) of glacial–interglacial fluxes to comprehensive climate models (Imbrie et al. 1984, 1992, 1993, Cooperative Holocene Mapping Project 1988; and see summaries in Bradley 1985, Williams et al. 1993, Broecker 1995) and to global connections (e.g., Broecker 1991).

Global and regional patterns of temperature have been described at high temporal resolution, through the analysis of oxygen isotopes and other stored gases extracted from deep cores taken in ocean sediments and polar ice caps (e.g., Dansgaard et al. 1985, Lorius et al. 1985, Martinson et al. 1987). These and other high-resolution proxies for historic climate reveal much about periods relevant to management. Specifically, within the last 1000 yr, three distinct climate periods have affected climates enough to cause observable changes in vegetation (Grove 1988, Hughes and Diaz 1994, Mann et al. 1998). These periods relate to global effects, although patterns and significance vary regionally. Evidence of physical mechanisms causing the climate effects comes from variations in solar radiation, CO₂ changes, and effects of volcanism (Damon and Sonnett 1991, Rind and Overpeck 1993). Biological proxies (tree-ring indices, patterns of pollen and microfauna in sediment cores, and packrat middens) and physical proxies, such as glacial behavior and hydrology of closed basin lakes, corroborate climate effects. This time period is within the range of one to two generations of our current forests, and contains the pre-settlement period often used as reference in historical analysis for restoration. These periods had important effects on vegetation structure and composition, as we illustrate with examples from the southwestern United States.

Medieval Warm Period

Relative to the current interglacial period (i.e., the last 11 000 yr, or Holocene), global temperatures have been gradually declining from a maximum (2°C warmer on average than present) reached in the early Holocene ~9000 yr ago (Huntley and Prentice 1993, Feng and Epstein 1994). Within this general cooling trend have been short periods of anomalous warm temperatures (Lamb 1976, Graumlich and Lloyd 1996). Beginning about AD 900 and lasting to about AD 1350, temperatures have been recorded in many parts of the world as much warmer and regionally drier relative to phases before and after (Williams and Wigley 1983, Briffa et al. 1992, Hughes and Diaz 1994). Environmental as well as cultural responses have been traced to this period, known as the Medieval Warm Period (or Medieval Climate Anomaly), although its expression and intensity vary greatly from place to place (Hughes and Diaz 1994).

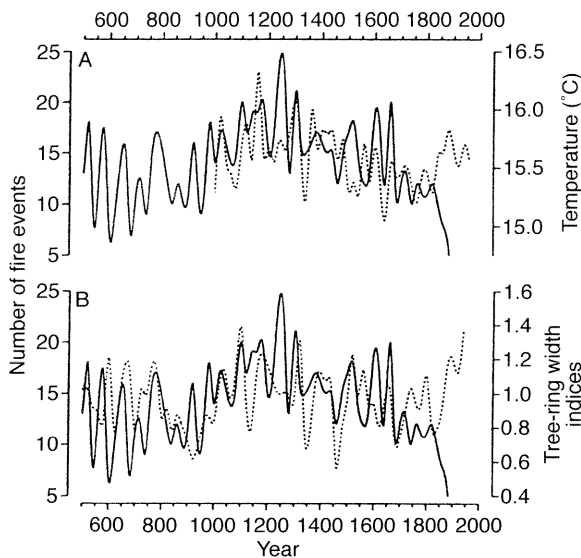


FIG. 1. Long-term variation in tree-ring-reconstructed summer temperatures (.....) and number of fire events (—; smoothed). (A) Data recorded from dendrochronological analyses in five giant sequoia stands (with temperature reconstructions from Graumlich [1993]), and (B) similar reconstruction using tree-ring width indices in bristlecone pine (*Pinus longeva*). Note that 1 ft = 0.3048 m. This figure originally appeared in Swetnam (1993) and is reprinted here with permission from the American Association for the Advancement of Science.

In the Sierra Nevada and western Great Basin, California, USA, several types of regional evidence document warming and drying, with two long drought periods, occurring at AD 900–1112 and AD 1200–1350 (Stine 1994, 1996). Forests responded in several ways. Ring width indices from dendrochronological analyses at tree line in subalpine species show decreases in tree line elevation and increased growth during this period (Graumlich 1993, Scuderi 1993, Graumlich and Lloyd 1996). Conifer stumps, exposed unnaturally due to recent water diversions, are rooted 11–15.5 m below pre-diversion levels of the closed-basin Mono Lake, California, indicating earlier natural low lake levels corresponding to dry periods (Stine 1994). Similar examples occur in other closed-basin and alpine lakes and bogs (e.g., Walker Lake, Tenaya Lake, Donner Lake, and Osgood Swamp, California) and major river channels (e.g., West Walker River, California) where submerged logs date to the two drought intervals of the Medieval Warm Period (Stine 1990, 1994, 1996; S. Stine 1997, *personal communication*). Fire history studies document that the number of fire events recorded from long records in giant sequoia (*Sequoiadendron giganteum*) ecosystems increased significantly during this interval, while temperature indices derived from bristlecone pine increased (Fig. 1; Swetnam 1993). Abundance of firs (*Abies*) in high-elevation communities increased (Anderson 1990). Changes in

subsistence behavior and settlement patterns of aboriginal peoples, such as population declines at lower elevations, movements upslope, abandonment of villages, and increased violence, also reflect warming and drying during Medieval Warm Period centuries in California (Moratto et al. 1978, Raab and Larson 1997).

Little Ice Age

Following the Medieval Warm Period, and after a century of more average conditions (relative to the late Holocene trend), Northern Hemisphere climates cooled. Evidence exists in many parts of the Northern Hemisphere, for the period ~AD 1400–1900, that average temperatures declined nearly 2°C below present averages, glaciers advanced, productivity in montane forests declined, and ecosystems reacted to a cold world (Matthes 1939, 1941, Grove 1988, Mann et al. 1998). Although this period was not stable, and warm intervals occurred within it, the dominant character was cold.

Much evidence in written history records the impact of the Little Ice Age in Europe, where grain and wine harvests show major reductions during this time, agricultural losses were great, and sea ice made navigation difficult or impossible (Williams et al. 1993). In the Pacific Northwest, temperatures declined on average up to 1.2°C (Graumlich and Brubaker 1986), and, in the Sierra Nevada, California, glaciers advanced to their maximum extent since deglaciation at the end of the Pleistocene 13 000 yr ago (Matthes 1941, Birman 1964, Clark and Gillespie 1997). Tree-line elevation declined in the White Mountains and the Sierra Nevada (LaMarche 1973, Lloyd and Graumlich 1997), and tree-ring indices showed temperature decreases of ~1°C and growth decreases at high elevations that correspond to this period (Graumlich 1993, Scuderi 1993, Graumlich and Lloyd 1996). In high-elevation sites, subalpine communities (more typical of late-glacial conditions) replaced upper montane, mixed-conifer forests that had been present during previous millennia (Anderson 1990). Giant-sequoia fire events and bristlecone pine tree ring indices decreased significantly (Fig. 1; Swetnam 1993), and closed-basin lakes declined in lake levels, suggesting less effective precipitation (Stine 1990, 1996). Changes in transmontane trade routes and other changes in subsistence patterns suggest aboriginal peoples also were responding to colder climates (Moratto et al. 1978).

Current period

Coinciding with the onset of settlement by Euro-Americans in much of the forested regions of western North America, the Little Ice Age came to an end by AD 1880–1900 (Matthes 1941, Grove 1988, Graumlich and Lloyd 1996, Mann et al. 1998). Subsequently, temperatures increased globally, and in the Pacific Southwest, the beginning of the 20th century is recorded as having been warm and wet (the wettest 50 yr in the

last millenium; Graumlich 1993, Stine 1996). Glaciers receded (Matthes 1941, Birman 1964), tree line has risen to near-highest levels of the Holocene in the White Mountains (LaMarche 1973, 1982) and in some locations in the Sierra Nevada (Lloyd and Graumlich 1997), tree-ring widths show increased growth (Graumlich 1993, Scuderi 1993, Swetnam 1993; doubled in *Pinus albicaulis*, J. King and L. Graumlich, *unpublished data*). Tree-line ecosystems expanded upslope in Lassen National Park (Taylor 1995), and changes in meadow hydrology occurred that have been attributed to warming climates (Wood 1975). Lake and river levels increased, flooding stumps in the Sierra Nevada and western Great Basin (Stine 1990, 1996).

Because of the general coincidence in time of Euro-American settlement in parts of western North America and the end of the Little Ice Age, it is more difficult to separate nonhuman from human effects in this period than for earlier times. The pattern of climate change in the last century may be consistent with increases in tree regeneration at middle and upper elevations, causing increased density of conifer forests, changes in species' dominances, changes in pattern and abundances of forest mortality, and changes in montane meadow hydrology and associated vegetative changes, although these are conjectural and need testing. Often these effects are assumed to result primarily or solely from historic logging, fire suppression, and grazing (e.g., Sierra Nevada Ecosystem Project 1996). The relative significance of human vs. nonhuman influences on these changes no doubt varies by site, with some situations dominantly influenced by human activities, others by nonhuman forces, while most are probably some combination of both.

This potential of climate to confound analysis exists independently of whether living individuals (e.g., long-lived trees) remain in current ecosystems. Fire history analyses or forest and climate reconstructions are often done entirely on dead wood, and pollen and packrat midden analyses reveal biodiversity conditions of individuals long gone. A potential for misinterpretation arises whenever the assumption exists that the ecosystem of a past period (as recorded in dead wood, packrat middens, etc.) responded ecologically in the same way as the modern ecosystem does.

In cases where long-lived trees do persist into current ecosystems, evaluations based on present conditions should consider potentially lingering climate effects. Recruitment seems to be especially sensitive to climate (Graumlich and Lloyd 1996). For instance, many living old-growth trees in current forests germinated under Little Ice Age conditions, and may inaccurately reflect how old-growth would develop under present and future climates. Similarly, reproduction in forests today may exhibit different species mixes and abundances than occurred when today's old trees were young. Thus, patterns of reproduction in present forests might naturally differ from patterns and species mixes of older

trees in the same forest, for climate reasons as well as succession and disturbance. In long-lived species, such as high-elevation pines, giant sequoia, cedar, redwood, and junipers, individuals older than 1000 yr are common; these may span several climate periods. Assessing forests by cohorts and relevant climate periods, especially those during recruitment, could help in factoring climate effects.

APPLICATIONS FROM ECOSYSTEM MANAGEMENT

To illustrate how historical climate effects have been treated in management, and to indicate how misinterpretations can arise, we summarize two examples from the Sierra Nevada of California. These also illustrate how incorporation of historical climate effects into analysis can usefully inform management and provide appropriate contexts for planning.

The Mono Basin ecosystem

Mono Lake and its associated ecosystem is well known for integrated ecosystem science, critical conservation case law, collaborative conservation policy, and ecological restoration (Winkler 1977, Patten et al. 1987, Botkin et al. 1988, Jones and Stokes 1993, Wiens et al. 1993, California State Water Resources Control Board 1994, Los Angeles Department of Water and Power 1996, Hart 1997). Mono Lake is a hydrologically closed, hypersaline alkaline lake, 20 000 ha in surface area, situated at the foot of the eastern Sierran escarpment on the western edge of the Great Basin. It is an ancient lake, >700 000-yr-old (Lajoie 1968), with well-characterized biodiversity and relatively simple trophic relationships (Wiens et al. 1993, Winkler 1977). Extremely high productivity contributes to Mono Lake's importance to migratory waterfowl: Mono Lake is the breeding territory for 15–25% of the California Gull population (Patten et al. 1987), stopover for 30% of Eared Grebes, and one of the largest concentration points for Wilson's Phalaropes (Jehl 1981, 1988). The suite of life supported by Mono Lake depends, among other things, on lake water level and lake salinity, itself related to lake level.

Beginning in 1940, four major Sierran streams that feed Mono Lake were diverted to supply municipal water to the city of Los Angeles, eventually supplying up to 15% of the city's water supply (Jones and Stokes 1993, Wiens et al. 1993). Except for during extreme weather events, diversions caused the streams to dry up and Mono Lake level to decline. By 1982, the lake surface had dropped 13.7 vertical meters to its historic low stand of 1942.2 m (Stine 1991). With lower lake elevation, salinity increased, and other complications of low lake level developed, which cumulatively resulted in collapses in biodiversity and productivity of the Mono Lake ecosystem. With Mono Lake well on its way to desiccation, which was the fate of similar nearby Owens Lake, conservationists stepped in and advocated for a win-win solution that would stably

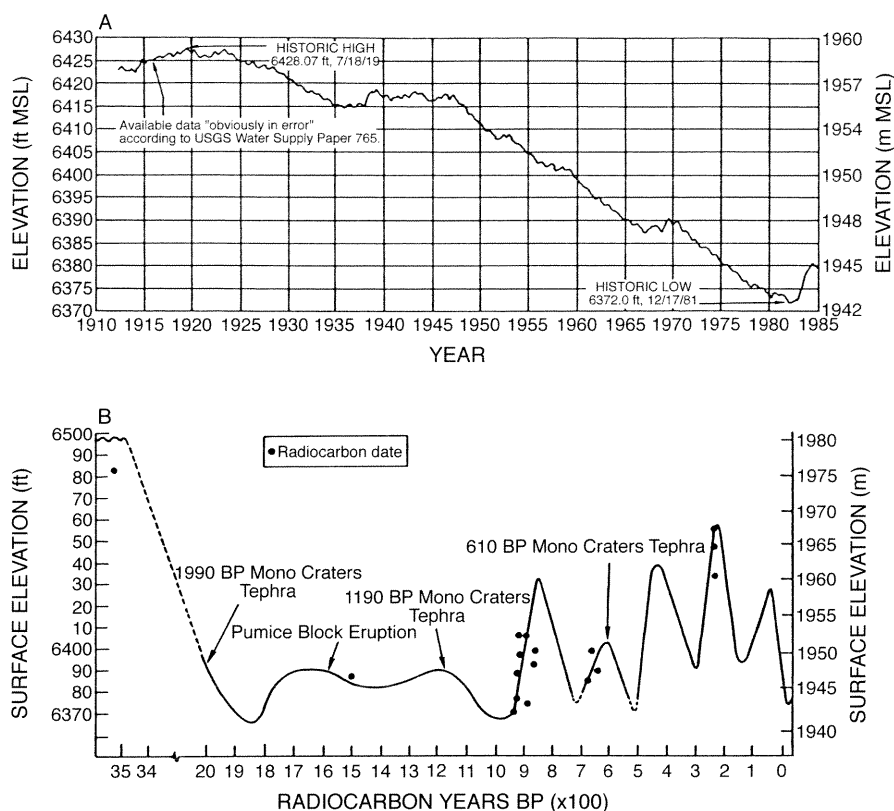


FIG. 2. Historical surface fluctuations of Mono Lake. (A) Surface elevations during 1912–1984 based on recorded measurements (Los Angeles Department of Water and Power, from Patten et al. [1987]). (B) Surface elevations from 3500 yr BP to present. Note that 1 ft = 0.3048 m. This figure originally appeared in Stine (1990) and is reprinted here with permission.

support Mono's unique ecosystem while still supplying water to Los Angeles.

The scientific, legal, and conservation history leading to the Mono Basin court decision of 1994 that would maintain water to Los Angeles, yet restore the lake level at 1948.3 m (well within the range that was estimated would support Mono Lake's biodiversity), are well-documented (Jones and Stokes 1993, Wiens et al. 1993, California State Water Resources Control Board 1994, Hart 1997). Relevant to the current paper is the application of historical data on lake level and regional climate in arriving at conservation solutions. Stine (1987, 1991) studied the past 4000 yr of Mono Lake's geomorphology and hydrology, and developed both a chronology of historically documented elevations since diversion and estimated lake levels over three millennia (Fig. 2).

Several observations are notable about these graphs, points that have been argued by Stine and others through the Mono Lake case. First is that if only the graph of lake elevations from recent history, spanning 75 yr of data (Fig. 2A), were available, the declines in lake elevation due to diversions would seem extreme and unprecedented. Extending back in time, however, reveals a story of repeat and significant changes in lake

level, some attaining similar low levels to those in 1982 (Fig. 2B). Geomorphic studies revealed that a critical point exists at 1941 m, where slope gradients change abruptly from shallow to steep (Scholl et al. 1967, Stine 1987, 1990). Within recent millennia, the lake appears to have dropped near to, but not below, this elevation several times, causing a significant minimal shoreline plateau, or "nickpoint," to develop. If lake levels were to be dropped artificially below this historic threshold elevation, however, erosion and stream incision would be far more rapid and greater in magnitude than estimated from bathymetry alone (Stine 1991).

With evidence from other climate proxies, Stine correlated several of the low and high lake levels with regional climate anomalies. Notably, low levels correspond to the two extensive drought periods of the Medieval Warm Period (Stine 1994), with higher lake levels being attained during the Little Ice Age. A water balance model was developed for Mono Lake that factored regional weather and climate (Vorster 1985). It indicated that if water had not been diverted, the lake surface in 1982 would have stood at an elevation of 1957.1 m. This is 15 m higher than the 1982 low stand, 2.1 m lower than the high stand prior to diversion, and 1.5 m higher than the condition at the time of diversion.

Arguments about the role of historical climate periods and lake levels contributed to the final decision of the California State Water Resources Board (1994; Stine 1991, 1993). The proximal cause of recent declines since 1940 was clearly due to water diversions. This was shown by the water balance model, despite a natural declining trend in the lake elevation in the decades prior to 1940, due to "Dust Bowl" conditions of the 1920s and 1930s. The water balance model helped to estimate what the lake level would have been in the late 1980s without diversions, an improvement over the need to use pre-impact conditions as comparison. That is, recent interpretations of climate, included in a water balance model, allowed goals to be set toward *realignment* of lake levels to what they might have been today rather than simply *restoration* to pre-impact levels, thus acknowledging that conditions are inherently different between the present and 1940.

Historical climate interpretations also contributed to the decision to accept a high level as a compromise resolution of this politically contentious issue (Stine 1990, 1991, 1993). Low lake elevations may have been attained by the lake naturally in the past, but they occurred during historic extreme droughts, unlike the present, and placed the lake near vulnerable threshold levels. The water balance models and historical reconstruction argued for much higher levels, acknowledging current climates. Stine argued, however, that extreme drought periods such as the Medieval Warm Period, were not improbable for California's near-term future (Stine 1990, 1994, 1996). Pointing to potential effects on water availability if this should happen, he argued that significant buffers were needed to maintain the lake at the court-decided lake level. Further, he cautioned water delivery systems in California to consider the climate lessons learned at Mono Lake regarding the drought periods of the last 1000 yr as serious warning for potential water conditions of the future. Considering long-term trends and the fact that wet decades of the 20th century are anomalous for the last millennium (Graumlich 1993), in the near future California could experience widespread and severe dry periods, such as have been uncommon during the settlement period of the state.

The Glass Creek watershed

Another example draws from our historical-reconstruction research and comparisons to a national forest landscape analysis. Glass Creek is a 2500 ha forested watershed of the eastern Sierra Nevada, California, southwest of Mono Lake. The watershed spans elevations from 2300–3050 m and contains a large spring-fed meadow with a rich flora. The slopes around the meadow support lodgepole pine (*Pinus contorta*)–red fir (*Abies magnifica*) forests, at low elevations, and western white pine (*P. monticola*), whitebark pine (*P. albicaulis*) and aspen (*Populus tremuloides*), at higher elevations. The area is within an active volcanic zone,

with nearby vents that have erupted as recently as 550–650 yr ago (Miller 1985). We are conducting a series of historical studies in the meadow, the forests, and the subalpine zone of this watershed.

Glass Creek is managed by the Inyo National Forest (INF) as a roadless area; its primary uses are nonmotorized recreation and sheep grazing, although timber harvest has occurred in adjacent forests. The area is a focus of intense and conflicting public interest, with advocates for both wilderness status and development as an alpine ski area. The INF recently completed a landscape analysis of the bioregion containing Glass Creek watershed (U.S. Forest Service 1995b, 1997), following the Forest Service regional guide for landscape analysis (U.S. Forest Service 1995a). In general, this approach is based on a comparison of existing conditions to reference conditions (usually inferred from historical variability) and developing desired future conditions (or management goals) based on the comparison. Management actions are then determined to promote the desired conditions. We focus on the INF interpretations for forest, fire, and meadow conditions in the Glass Creek portion of the bioregion.

The historical period for analysis in the INF report was considered to be presettlement, unexplicitly from about AD 1700 to late 1800. Some new fieldwork was done, including a small fire history study, and former work summarized, but inferences about historical conditions were drawn primarily from other parts of California. From these, the INF concluded that the most common historical condition for red fir–mixed conifer forests of the area was a distribution of small patches, each primarily a single age class. Patches historically would have been mostly dominated by red fir, and, over the extent of the forest, most age classes would be represented. Pine would dominate some patches with fir in the understory. Fire history analysis from an area adjacent to Glass Creek was interpreted by the INF team to indicate that from ~AD 1700 to the late 1800s, fires burned with a mean interval of 8–9 yr. The INF further interpreted that, although overall fire areas historically may have been large, most fires burned at low intensity, with small patches of high intensity fires intermixed. These localized patches would create small openings for red fir regeneration, thus the overall forest would become a mosaic of age classes. Occasional large fire-created openings would be regenerated by lodgepole pine. As the pine aged, red fir would succeed into the understory, returning the patch to red fir.

Although this was considered a basic pattern in fir–pine forests of the area, the INF team concluded that several parts of the bioregion, including Glass Creek, were not currently in this historical condition and exhibited atypical structure, where old red fir dominated the overstory, lodgepole pine occupied the midcanopy, and red fir was the regeneration layer. This was interpreted as an unusual but natural event where a catastrophic fire 100–200 yr ago killed all but a few old

red firs. Lodgepole pine seeded the area after the fire and in time provided shelter for regeneration of red fir, which would eventually replace the pine. Fire suppression was concluded to be inhibiting the development of patchiness and return of natural landscape pattern.

Our preliminary research offers an alternative explanation, where climate change and stochastic events may have been equally or more important in the development of the red fir and pine structure than succession alone. From regional information on climate change in the last 1000 yr (Graumlich 1993, Scuderi 1993, Stine 1994, Graumlich and Lloyd 1996, Clark and Gillespie 1997, Lloyd 1997, Lloyd and Graumlich 1997), and our own dendrochronological analyses at tree line in the area, we conclude that between ~AD 900–1300 climate was warmer, causing increases in conifer ring growth, and changes in species composition and growth habit (e.g., from krummholz to upright tree form). This was followed by several centuries of declining regional temperature until the mid-1800s, when the regional climate warmed again.

From plots established over the fir–pine forests and fire history studies, we dated the three-tiered distribution (fir:pine:fir) of the INF study to be three discrete age classes, with old-growth firs 300–550-yr-old, lodgepole pines 100–250-yr-old, and young red firs <100-yr-old. Many old and rotting stumps similar in size to the old-growth category attest to a larger number of red fir now dead. Our evidence suggests that fire has had different effects over time in the 1000 ha Glass Creek sample area. For the last 125 yr, fire seems to have been absent in the watershed, and only one fire suppression effort (a single burning snag) has been recorded in this area. Prior to that, and to the beginning of our record in AD 1706, fire scars suggest that low-moderate intensity fires burned at ~30-yr intervals. There is also evidence from many burned and highly pitched stumps of a widespread, high-intensity fire with radiocarbon analyses suggesting a date >400 yr ago.

From preliminary evidence, we offer an alternative hypothesis for the history of these forests. Glass Creek Vent, part of the Inyo Craters chain that has deposited ash and tephra repeatedly over the watershed (Miller 1985), erupted ~550–650 yr ago and appears to have been directly or indirectly responsible for the large stand-terminating fire. The pattern of species and age classes in this area may reflect the tolerances of red fir vs. lodgepole pine during regeneration in the eastern Sierra Nevada: in areas where the species overlap, red fir recruits best under mesic conditions, whereas lodgepole pine tolerates extreme moisture stresses (U.S. Forest Service 1995b). Regional climate (warm and effectively wet at this elevation) following the fire may have favored red fir regeneration on these slopes; trees from this establishment period would have become the remaining old-growth firs (and recent stumps) now in the area. In the centuries following, however, temper-

atures were colder (Little Ice Age), which may have preferentially favored regeneration of lodgepole pine under the fir, a condition likely maintained by fires at 30-yr intervals. Approximately 100 yr ago, warming climates would increase effective moisture, favoring red fir regeneration again. Lack of fire in the past century would have allowed fir to persist, forming the <100-yr fir age class.

The INF also evaluated historical conditions in Glass Creek meadow relative to existing conditions (U.S. Forest Service 1995b, 1997). Based on comparisons to other Sierran montane meadows, the INF team concluded that the present meadow has fewer grasses and sedges, lower willow abundance, more bare ground, more forb diversity and abundance, and more lodgepole pine invasion than expected from the historical undisturbed condition. The team concluded that the meadow had been heavily impacted by historical (late 1800s) and possibly recent grazing, and was not functioning at its historical potential.

We extracted a sediment core from Glass Creek meadow that extended 4000 yr BP, and has been dated by radiocarbon analysis, as well as from known ash and herbivore dung spore (*Sporomiella* sp.) markers. Pollen analyzed from the top of the core, including the grazing era (0–150 yr ago) and the period preceding it (200–500 yr ago), show no significant changes in meadow species composition or diversity over time. Furthermore, the abundance of taxa considered indicative of grazing impacts (willows, grasses, and sedges, in particular) did not show changes in direction predicted by the INF if the meadow were overgrazed.

The sediment core records a charcoal abundance that generally corroborates the pattern of fires seen from fire scars in the basin over the last centuries; trace amounts of charcoal at the top of the core suggest limited localized events or background drift. Large concentrations of macrocharcoal occur just above three ash layers in the core, including the one dated tentatively at AD 1325–1350, supporting the interpretation of a large fire in the watershed, which may have resulted from the stochastic event of the eruption rather than part of the regular fire regime. We also dated the lodgepole pine invasion of the meadow, and found that ages clustered 30–45-yr-old, potentially related to climate, but not related to known changes in grazing. Thus, we offer as an alternative explanation for the current conditions of the meadow that natural succession occurred following a volcanic eruption with vegetation responding to regional and local climate. Grazing effects were undetectable.

CONCLUSIONS

Applications of historical data are crucial for translating ecosystem management into practice (Swetnam et al. 1999). Interpretation of the influence of climate on vegetation, as revealed in the historical record, can improve our application of historical variability to cur-

rent contexts. Elements to consider include the following:

1) Assumptions that climate is stable (or that climate differences are unimportant) between the reference (historical) and current periods may lead to inaccurate or incomplete interpretations for management. Evidence globally and regionally indicates that climates have changed within time scales and magnitudes significant enough to cause considerable changes in forests over the last ≥ 1000 yr, although effects vary locally. Interpretations of past and present forest structures would benefit by considerations of the combined effects of climate with other environmental and succession changes. Furthermore, the longevity of most tree species means that there are lags in response; current old-growth forests in much of western North America, for instance, were established during the Little Ice Age and may reflect recruitment responses to those now-gone climate conditions.

2) Because of the nature of climate change and vegetation response, the past is not necessarily or even likely an accurate analog for the present or future. In particular, presettlement forests, when referred to as the several centuries before Euro-American settlement and commonly used as a benchmark for ecological restoration and ecosystem management, may not be accurate models for the present. Restoration of Little Ice Age conditions (i.e., presettlement forests) makes little sense for the current climate period. A more appropriate analogue for the present in some parts of western North America may be the Medieval Warm Period (AD 900–1350), although the present appears to be generally wetter than that period was, at least in the Pacific Southwest. In sum, restoration using any single historical period as model is probably inappropriate. Rather, understanding what kinds of changes have occurred in a region, and how particular ecosystems respond, gives clues on how to manage for adaptability and resilience (e.g., Millar and Woolfenden 1999).

3) The onset of the major Euro-American settlement period (mid- to late 1800s) generally coincided with a significant known climate transition out of the Little Ice Age, which was the only significant glacial period in 13 000 yr. Thus, changes in the last 100–120 yr may often be due to combined human effects and natural climate-induced changes. These may be difficult to separate, especially because many of the effects seem to elicit similar responses in vegetation.

4) The concept of “managing for historical range of variation” may lead to problems, if the context of climate change and vegetation response to change is not understood. For instance, setting a management goal (desired condition) to include the range of variation that was found to occur over the last millenium would include species and structures adapted to at least three distinct climate periods, and would mean including variation that may be detrimental to forest adaptability

under present and future climates. Thus, in addition to using the “wrong time model” as we have suggested, a related problem in analysis would be to use an excessively long period for analyzing historical range of variation, if this variation is meant to be incorporated in current forests without an understanding of climate similarities or differences.

5) Misunderstandings or misapplications of historical information, such as summarized in points (1)–(4), in no way argue against the value and need for historical reconstructions. To the contrary, as the examples here suggest, we cannot understand present forests and why they respond as they do without studying their histories. We study the past to understand the present, to understand what forces locally or globally affect vegetation response, to gain insight into possible natural trajectories of future forests, and to use this information to guide management decisions. Because forests are in constant movement through time, we cannot hope to manage sustainably without understanding and working with these environmental trends.

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