

# Session Overview: Climate and Landscape Change Over Time<sup>1</sup>

Constance I. Millar<sup>2</sup>

In this chapter, we strive for something different. Whereas a goal of the other sessions at the Sierra Nevada Science Symposium was to present new research on familiar themes, our goal in the session “Climate and Landscape Change Over Time” was to introduce a topic that itself is likely unfamiliar to many resource scientists and managers. The limited discourse to date between the fields of climatology and resource ecology is surprising for two reasons. First, in the past two decades, there has been a revolution in research on climatology that has led to dramatic new understanding about the functioning and dynamics of the climate system. Second, these new insights are relevant to the resource sciences—so much so that fuller understanding in our research community could restructure thinking about how ecological systems work and revolutionize strategies for resource management and conservation.

The topic of climate change often invokes images of global warming, greenhouse gas impacts, and 21st century politics. There is a larger context that we must begin to understand and assimilate into resource science thinking—that is, the role of the natural climate system as an ecosystem architect. To understand this larger picture requires looking back in time to analyze historic climate variability and also forward in time to model the interaction of natural climate effects and human influences.

## Climate Variability as an Ecosystem Architect: In Perspective

Conceptual views of the natural world influence tactical approaches to conservation, restoration, and management. Advances in ecological sciences during the mid- to late 20th century increased our understanding of succession, disturbance, and spatial variability, causing biologists to view nature as dynamic and process driven rather than static and typological. In turn, conservation and management perspectives matured, shifting emphasis from museum-like nature preservation to the maintenance of variability and natural function. As a result, prescribed fires and managed floods, for instance, became important conservation tools, and emphasis on ecosystem function as well as structure was added to restoration goals.

Important as these changes have been, static concepts still constrain our understanding of natural dynamism and limit our potential for conservation successes. In the same way that resource science embraced fire as a significant natural process, climate variability must be understood as a primary driver of ecological change. Recent advances in climate system sciences characterize recurrent climate change as a central physical force on Earth and a significant agent of physical and ecological change at micro- to macro-scales. Analysis of historic climate change at high resolution with new and precise

---

<sup>1</sup> This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

<sup>2</sup> USDA Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, P.O. Box 245, Berkeley, CA 94701-0245.

indicators reveals a picture of oscillating climate that has varied simultaneously, and often abruptly, at nested timescales.

Historically, plants, animals, and landscapes have responded to these climate cycles with dramatic and sometimes rapid changes, including major shifts in species ranges, composition, and structure; in vegetation and ecosystem composition and distribution; in snowpack accumulation, glacial dynamics, and streamflow timing and volume; and with cascading effects on biodiversity and historic human cultures. The picture that emerges is of nature moving an order of change greater than our current ecological perspective embraces; that is, ecological response to climate change becomes a third order of change, or a “variable chasing a variable not a constant” (Jackson 1997). Climate can thus be considered a macro-disturbance element in that it is the background stage of change on which all successional dynamics (including those following disturbance such as fire and flood) play out. Such dynamism has not yet been consistently incorporated into evolutionary and ecological theory nor translated into conservation and management practice. As a result, many management actions, such as evaluation and diagnosis of ecological change, determination of baselines and evaluation of change based on inventory and monitoring, and development of targets for restoration, are at best limited in applicability and at worst wrong.

## **Sierra Nevada Climate Variability from Past to Future**

In this session, the authors introduce basic concepts that describe the mechanisms that regulate climate variability in the Sierra Nevada, document the nature of physical and ecological responses to climate change, and anticipate effects of future climate variability on Sierra Nevada landscapes and implications for resource management. Malcolm Hughes (in these proceedings) sets the context for climate by providing historical perspective. Arguing that the current era, the “Anthropocene,” is human-dominated means we must look to the past for information about how Earth’s natural climate system functions. From the many natural archives available to reconstruct climate, Hughes shows that the 20th century is anything but representative of the kinds of extreme climate combinations and variability possible. Scott Anderson (in these proceedings) echoes this sentiment by summarizing the nature of vegetation change as it responded to climate variability at long to short timescales. The transition from glacial to interglacial 10,000 years ago in the Sierra Nevada was marked by dramatic replacement of community assemblages and major species range shifts. Nonanalog plant communities, that is, plant species growing together that do not now, were present around the Sierra Nevada. By 7,000 years ago, further warming climates triggered advances of pine-dominated forests to high elevations and far greater dominance of shrub communities on both sides of the crest than at present. During the modern period (past 5,000 years), as climates cooled and alternated between wet and dry, modern communities emerged.

Scott Stine (in these proceedings) uses geomorphic evidence from lake- and river-level changes to document that the Sierra Nevada's modern climate is, by the standards of the past four millennia, abnormally wet and warm. Multidecade-scale swings in moisture availability, unlike any seen in modern time, have characterized the Sierra Nevada over the past millennium. Stine emphasizes that more such swings—induced naturally or artificially, or both—must be expected to recur within a time period relevant to land management. Henry Diaz (in these proceedings) further describes changes in physical systems, especially water regimes, as climates change in the modern period. Glaciers are retreating, snowpacks are melting earlier, and runoff is less, leaving the Mediterranean-based Sierra Nevada summers effectively longer and drier. Diaz argues that only with integrated interdisciplinary assessments and studies will we be able to effectively manage for these changes at the resource level. Dave Schimel (in these proceedings) concludes the section by addressing relationships of Sierra Nevada ecosystems to carbon dynamics. Mountains are important contributors to carbon uptake in the western United States as a result of their unique climate within a semi-arid to arid region and because of historical and present-day

management. Fire management strategies must reflect a balance between hazard management, long-term risk management, and preservation of forest health. Any changes to fire regime or fire management practices are likely to have widespread impacts on forest ecosystem function, affecting carbon storage and tightly linked water resources. Although fire suppression has probably led to a larger carbon sink in the West, much of this sink is present in the fine and coarse fuel categories (dead plant material) or in dense stands of small trees and thus contributes to increased risk in drought years. Improved carbon management must consider both the amount of carbon stored and the stability of that storage as climate and fire regimes evolve.

## Lessons about Climate Variability and Implications for Conservation and Management

Together the narratives in this chapter and others like them (see references cited section that includes some suggested references for further reading) generalize about the relevance of climate variability to ecosystem science and management. First, climate historically has *oscillated* rather than been dominantly directional or stochastic. Thus, at a coarse scale, climate regimes change but recur over time. As a consequence, distant periods in the past may be more similar to the present than is the recent past. Similarly, past variability may give us better insight into the future than do current conditions. Importantly, although average regimes oscillate (for example, cold: warm, wet: dry), exact climates (combinations of variables) are expressed uniquely over time. Second, climate has varied simultaneously at *multiple and nested scales*, operating at interannual, decadal, centennial, millennial, and multi-millennial scales. Daily and annual weather are the cumulative expression of all mechanisms operating together. Third, transitions between major as well as minor climate phases often occur *abruptly* (over a few years to decades), accompanied by significant changes in climate. Climate states are highly sensitive, catalyzed by threshold events, triggered by stochastic effects, and especially vulnerable during times of high variability (such as the present) (NRC 2002). Fourth, *ecological and physical systems respond to climate change* at each scale and often exist in nonequilibrium state with regard to climate. Plants and animals of the Sierra Nevada have responded to historic climate change with dramatic shifts in population size, distribution, composition, abundance, and ecology.

Management and conservation strategies will be successfully conceived and executed when they are designed with a recognition and understanding of the processes detailed in this chapter. Many management situations will be affected by changes in climate, as the following examples suggest (excerpted from Millar [in press]).

### *Sustainability as a Guiding Concept in Conservation and Management*

Ecological sustainability is a dominant current paradigm routinely used as an implicit or explicit goal in conservation, restoration, and management practice, such as may be found in resource plans of Sierra Nevada National Forests and resource districts, county plans, and the Record of Decision for the Sierra Nevada Framework. Various definitions of sustainability imply the endurance and persistence of species, communities, and ecosystems over time (Lele and Norgaard 1996). Operationally, sustainability has been difficult to describe but is generally accepted to pertain when natural species diversity is maintained, species are well-distributed in their native ranges and occur in historic abundances, community associations are maintained, and natural processes occur at "reference" intervals and conditions (Hunter 1996, Lackey 1995).

The contributions of this chapter emphasize that many conditions we often associate with ecological sustainability did not occur naturally in the history of Sierra Nevada ecosystems. For instance, species diversity changed at timescales of years to decades to centuries.

Similarly, individual species ranges and population abundances shifted, often drastically. Vegetation assemblages changed over time or shifted locations, or both, as individual species followed climate gradients. For example, some vegetation communities sometimes appeared to move “as a whole” when individual species responded to shifts in climate conditions. In other cases, communities changed in composition and dominance relations when species moved individually, following trajectories dictated by their own ecologies. Communities representing assemblages of species that are not found today were common, and population sizes, densities, and productivities fluctuated greatly at multiple scales. Reconstructions of historic fire regimes, snow accumulations, streamflows, and lake levels indicate that physical systems also changed continually over time.

In sum, records suggest that our current, widely used concepts of sustainability, which emphasize the persistence of species and communities within current ranges and in current population relationships and abundances, against a relatively static physical backdrop do not accommodate natural dynamics adequately. If there is any conclusion from the paleorecord, it is that at scales from years to millennia, ecological conditions do not remain stable, and details of structure, composition, or distribution fluctuate rather than persist. The flux is not random, chaotic, or unlimited but is influenced by climate (and other agents of change) and mediated by local environmental and ecological conditions. Resilience, at least in terms of species persistence, occurs through the capacity of plants and animals to track favorable environments as they shift over time and through adjustment in range distribution, habitat, and population and genetic characteristics.

### *Concepts of Rarity, Population Decline, and Native Range*

Rarity in plant and animal species has often been linked to species history (for instance, recent speciation or paleorelictualism) or to direct human impacts. The perspective of climate and species variability, however, illustrates that rarity may also be transient and recurring and may alternate with periods of widespread distribution. Species have adjusted to climate change historically by increasing in abundance in some areas and dying off or migrating from other areas. Thus, climate change must be considered among other factors when evaluating causes for species rarity and population decline (or increase).

A challenging corollary question is, “what is the native range of a species?” Native range is the *sine qua non* of conservation. To define the range of a species forms the basis for a number of standard ecological and conservation benchmarks such as monitoring its “health,” attributing causes of change, understanding favorable habitat, determining restoration targets, and indicting species as exotic. Viewed against historic changes in distribution and natural flux, the native range of a species must be considered a transient and dynamic phenomenon, readily capable of moving in space on the landscape over time. Recognizing that nonequilibrium conditions exist and lags occur means acknowledging that, like Lewis Carroll’s Red Queen, plant and animal populations chase a target (climate) that is itself changing and lag behind current conditions to varying degrees. Distribution ranges may appear stable if climate is in a more stable phase or if the environment of a species offers considerable local heterogeneity (for example, elevation, soil, aspect, hydrology gradients), or both. In these cases, species may track shifts in climate with relatively minor geographic changes. By contrast, in regions that are relatively homogeneous—for instance, broad flat landscapes with little diversity—even small shifts in climate may trigger large changes in population conditions.

### *Reference Conditions and Restoration Targets: Discerning Natural from Human-Caused Changes*

Predisturbance conditions are often used to characterize reference variability and describe desired conditions for restoration in the Sierra Nevada and elsewhere. In western North America, predisturbance conditions are defined as those before Eurasian settlement, in other words, about A.D. 1600–1850. From a climatologist's standpoint, this period is an inappropriate reference for modern conditions in the Sierra Nevada because the Little Ice Age occurred during these centuries, with its coldest period in the 19th century. Many current Sierra Nevada forests were established during this time and thus were influenced in their formative stages by climate conditions that no longer pertain. Vegetation changes that have occurred during the past 150 years are not solely the result of human-caused impacts (for example, fire suppression) but include natural adjustments to changing climate conditions. Misunderstanding of this leads to inaccurate diagnosis of ecological conditions and misprescription of treatment.

Rather than returning species to former conditions (“restoration”), a climate-informed approach might attempt to understand the full niche breadth of a species (from the historic perspective), species' shifts related to climate change in the past, and historic distributions under climates similar to that of the present. Integrating this with knowledge of species responses under less-disturbed modern conditions would give options for restoration (“realignment”) (see Millar 1998 as an example).

### *Global Warming and Conservation*

The specter of global warming raises much concern in conservation communities. As we now understand, this is not a future threat, but a current reality. Warming observed in the past 120 years is partly rebound in the natural climate mechanism and partly anthropogenic (IPCC 2001). Abrupt climate change and ecological responses to it have been common in Earth's history. On the one hand, this is comforting, in that species must be at least somewhat adapted to changes such as are occurring now. Accommodating these changes—if we choose to acknowledge and accept them—will require rethinking our concepts about what and where is native habitat, what are “healthy” population sizes, what are causes of changes in population size, and when is change natural and acceptable. On the other hand, natural as they are, consequences such as population and species declines, minor and major extirpations, shifts in native ranges, or changes in community composition may be undesired socially. If we choose not to accept such consequences, we should know that our management and conservation efforts might run counter to natural processes.

Even more important is the fact that species live now, even in our Sierra Nevadan wildlands, in human-dominated landscapes. If a primary natural mechanism by which species accommodate climate change is movement, anthropogenic constraints, including some of our well-intended plans for conservation, now pose challenging obstacles for many species. Human activities—from fragmentation to land conversion, from atmospheric pollution to invasion by introduced species, and even conservation attitudes about where species ought to be (native ranges) and policies that set static land designations—limit the potential of species to move as they naturally would. Adapted as they may be to natural climate change, the current human imprint on the landscape may severely limit natural adaptive responses, unless we reevaluate our actions.

From the societal standpoint, ecosystems services provided by the Sierra Nevada, especially water and hydropower, will also change in the future as a result of climate change. In contrast to most Sierra Nevadan ecosystems, social systems have proven to be rigid and inelastic to abrupt changes in availability of resource goods. The infrastructures and demands of California's urban areas especially create a dependency on Sierra Nevadan resources that will be significantly challenged in the future.

We are just beginning to integrate climate science into resource management and conservation planning for the Sierra Nevada. Our attempts at understanding its implications for specific plans and actions are rudimentary. It will take the concerted efforts of Sierra Nevadan scientists, managers, planners, and conservationists to integrate concepts of temporal dynamism fully into our practice and to develop robust and enlightened approaches to protecting and maintaining natural biodiversity. A potential forum for such analysis would be a collaborative, interdisciplinary assessment of climate change for the Sierra Nevada. Such a project, similar in nature to the Sierra Nevada Ecosystem Project, would provide a crucial opportunity to evaluate the implications of climate variability and future uncertainties for current planning efforts in the Sierra Nevada.

## References

- Bradley, R.S. 1999. **Paleoclimatology: Reconstructing climates of the Quaternary**. 2nd edition. International Geophysics Series, Vol. 64. San Diego, CA: Academic Press; 600 p.
- CRAG (California Regional Assessment Group). 2002. **The potential consequences of climate variability and change for California**. California Energy Commission; U.S. Global Change Research Program, Draft June 2002.
- Cronin, T.M. 1999. **Principles of paleoclimatology**. Perspectives in paleobiology and earth history series. New York: Columbia University Press; 560 p.
- Field, C.B.; Daily, G.C.; Davis, F.W.; Gaines, S.; Matson, P.A.; Melack, J.; Miller, N.L. 1999. **Confronting climate change in California. Ecological impacts on the Golden State**. Report of the Union of Concerned Scientists and the Ecological Society of America; 63 p.
- Grayson, D.K. 1993. **The desert's past. A natural prehistory of the Great Basin**. Washington, DC: Smithsonian Institution Press; 356 p.
- Grove, J.M. 1988. **The little ice age**. London: Methuen Publishing; 498 p.
- Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J.; Dai, X.; Maskell, K.; Johnson, C.A. 2001. **Climate change 2001: The scientific basis**. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. (IPCC). Cambridge, UK and New York: Cambridge University Press; 881 p. For a summary, see [http://www.grida.no/climate/ipcc\\_tar/wg1/pdf/WG1\\_TAR-FRONT.PDF](http://www.grida.no/climate/ipcc_tar/wg1/pdf/WG1_TAR-FRONT.PDF).
- Hunter, M.L. 1996. **Fundamentals of conservation biology**. Cambridge, MA: Blackwell Science; 482 p.
- Jackson, S.T. 1997. **Documenting natural and human-caused plant invasions using paleoecological methods**. In: Luken, J.O.; Thieret, J.W., editors. Assessment and management of plant invasions. Springer-Verlag; 37-55.
- Lackey, R.T. 1995. **Seven pillars of ecosystem management**. Landscape and Urban Planning 40: 21-30.
- Lele, S.; Norgaard, R.B. 1996. **Sustainability and the scientist's burden**. Conservation Biology 10: 354-165.
- Millar, C.I. 1998. **Reconsidering the conservation of Monterey pine**. Fremontia 26: 12-16.
- Millar, C.I. [In press]. **Climate change as an ecosystem architect: Implications to rare plant ecology, conservation, and restoration**. In: Proceedings of the conference on conservation and management of rare plants; February 2002; California Native Plant Society Conference, Arcata, CA.
- Millar, C.I.; Woolfenden, W.B. 1999a. **Sierra Nevada forests: Where did they come from? Where are they going? What does it mean?** In: McCabe, R.E.; Loos, S.E., editors. Natural resource management: Perceptions and realities. Transactions of the 64th North American Wildlife and Natural Resources Conference[s13]; Washington, DC: Wildlife Management Institute; 206-236.
- Millar, C.I.; Woolfenden, W.B. 1999b. **The role of climate change in interpreting historical variability**. Ecological Applications 9: 1207-1216.
- National Assessment Synthesis Team. 2001. **Climate change impacts on the United States: The potential consequences of climate variability and change, 2001**. U.S. Global Change

Research Program, Washington, D.C. Sections include *The West*, including a California subsection, and *Forests*. Forest Sector reports summarized in special issue of *BioScience* 2001 (Sept) 51(9).

NRC (National Resource Council). 2002. **Abrupt climate change: Inevitable surprises**. Committee on Abrupt Climate Change, National Academies Press. Online at: <http://www.nap.edu/books/0309074347/html/>.

Ruddiman, W.F. 2001. **Earth's climate: Past and future**. New York: W.H. Freeman Publishers; 465 p.

Woolfenden, W.B. 1996. **Quaternary vegetation history**. Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II; Davis, CA: University of California, Centers for Water and Wildland Resources; 47-70.