

Historic Variability: Informing Restoration Strategies, Not Prescribing Targets

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The concept of historic range of variability (HRV) is briefly evaluated within the context of its application in ecosystem management over the past two decades. Despite caveats to the contrary, an implicit assumption continues to emerge of climatic stationarity, and, by corollary, that presettlement centuries provide an appropriate reference period. This is examined from the perspective of historic climate change and ecosystem response. As a means of developing reference prescriptions and management targets, HRV is generally inappropriate, although if historic periods are used for reconstruction that have coarse resemblance to present or projected future climates, such as the Medieval Climate Anomaly or middle Holocene rather than the presettlement centuries, these might be defensible. In cases of reclamation of severely degraded ecosystems, HRV prescriptions developed from analogous climate periods could provide coarse guides. In most situations, however, historic reconstructions are best used to improve understanding of ecological response to a wide range of forcing factors, and thereby to inform (rather than prescribe) management strategies. Such historically informed approaches are likely more effective than an HRV approach under future changing climate regimes for managing and restoring ecosystem function and for assisting transitions to new ecosystem states.

KEYWORDS *climate change, ecological restoration, ecosystem management, forest management, historical ecology, historic range of variability*

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INTRODUCTION

Development of new resource-management strategies benefits by ongoing evaluation of concepts and methods that are currently in practice. “Historic Range of Variability” (HRV) has been a foundational concept in public land management for more than two decades. Here I briefly reevaluate some elements of this approach in the context of functional restoration strategies, including review of the questions, “What historic periods are appropriate, and how is it best to use historic reconstructions?”

BACKGROUND ON THE CONCEPT

For more than four decades in the mid-20th century, public lands forestry in North America was dominantly influenced by utilitarian goals that focused on providing enduring streams of goods and services to the American public. In the USDA Forest Service (USFS) this was codified by the conceptual framework of multiple-use-sustained yield (MUSY), with emphasis on providing products, such as timber, minerals, and livestock, and services, such as recreation (Robertson, 2004). Targets for annual yields and outputs that could be ensured over time were developed from sound scientific principles of the time; for example, timber targets (e.g., annual allowable sale quantity) were set within the European normal-forest model where trees were harvested at culmination of mean annual increment, and patch sizes were determined by total amounts of land divided by the rotation length.

By the early 1980s, and for a number of reasons, partly including overestimation of inventory and capacity and underestimation of ecological and physical cumulative impacts, “Multiple use management,” in the words of former USFS Chief Robertson (2004), “hit a wall. For the first time in history, the USFS began to fall short . . . of meeting its financed goals and targets” (p. 3). Concurrently over these decades environmental concerns were escalating in the Western social consciousness. This movement culminated with many critical environmental protection laws enacted by Congress, among them the National Environmental Policy Act, Wilderness Act, Endangered Species Act, Clean Air Act, and Clean Water Act.

These revolutionary new regulatory instruments, and equally revolutionary societal demands for a new approach to forestry, radically affected the trajectory of USFS land and water management. New initiatives followed rapidly, proceeding from “New Perspectives” through “Biodiversity Conservation,” and finally maturing into a comprehensive framework known as “Ecosystem Management” (EM; Grumbine, 1994; Lackey, 1995; Christensen et al., 1996). Rather than utilitarian bases, the goals for EM derived primarily from environmental ethics. Rather than even flows of board feet and animal units, the overarching vision became to protect environments, sustain

healthy ecosystems, and conserve biodiversity (Hunter, 1996). While these goals were prominently stated, unclear was an understanding of what they would look like on the ground and what science-based knowledge would guide development of management methods to these ends.

The concept that historic conditions could provide targets for healthy and sustainable future forests emerged logically. From an environmental ethics point of view, undisturbed natural systems, with their range of ecological dynamics, were obvious reference conditions for what sustainability would look like on the ground. Predisturbance reconstructions became widely sought to inform EM projects. The limitations of a *snapshot* approach—a single historic point in time (predisturbance) or one unit in space (a single reference location)—rapidly became apparent. With increasing understanding of ecological dynamics, the important roles of disturbance—especially fire, insects, and floods—made clear that a *range* of conditions documented from predisturbance times was more important than any single historic time or place.

The role of HRV rapidly gained center stage in EM, and was thoughtfully outlined and elaborated in important theoretical discussions over the next decade (e.g., Morgan et al., 1994; Landres, Morgan, & Swanson, 1999; Swetnam, Allen, & Betancourt, 1999; Keane, Hessburg, Landres, & Swanson, 2009), evaluated for regional forest types (e.g., Agee, 2003; Veblen & Donnegan, 2005), translated into management direction (e.g., Kaufmann et al., 1994; Manley et al., 1995), and applied in many land-management planning and project efforts. From the theoretical discussions, the following premises relevant to the current evaluation emerged: Natural variability in space and time (ecological dynamics) is central to sustainable ecosystem functioning (Swetnam et al., 1999). HRV should be assessed over relatively consistent historic climatic conditions (Morgan et al., 1994). Approximating historical conditions provides a coarse-filter management strategy to sustain species viability and “offers one of the best means for reducing impacts to present-day ecosystems” (Landres et al., 1999, p. 1180). This was elaborated by the assumption that “if it is possible to produce or mimic the historical ranges in stand structures by forest type on current and future landscapes, then much of the habitat for native flora and fauna should be recreated and maintained”, and, thus, that “most species and ecosystem elements should remain viable” (Agee, 2003, p. 725). Agee (2003) continues, in corollaries to HRV concepts, that its application “implies that the forest landscape possesses at least quasi-equilibrium properties,” and that “future management oriented toward biodiversity should focus on moving [these] ecosystems back towards the historical range of variability” (p. 728).

From the standpoint of this review, I focus on an underlying assumption of stationarity that continues to emerge in the HRV literature even where discussions address historic variability. Further, two elements in the discussion of HRV remain unfronted and problematic: First, what historic time

period is most relevant to current and future conditions (and, in contrast, what periods are inappropriate); and second, whether “approximating historic conditions” of any historic time period is a wise approach to managing for functional ecosystems of the future. Much discussion has put toward elaborating issues of time depth in developing HRV for management reference. Appropriate historic conditions have been defined both generally, as “unaffected by people, within a period of time . . . appropriate to an expressed goal” (Landres et al., 1999, p. 1180); and specifically, for instance, the pre-Euro-American settlement period (Morgan et al., 1994), which has been widely adopted in practice. On the one hand, there was recognition that historic climates and forests differed from those at present: “relevance is lost if too long a time period [for developing HRV] is used, because conditions such as climate and species composition may have changed drastically” (Landres et al., 1999, p. 1181). On the other hand, there is little explicit recognition that the historic periods most often used for developing HRV (e.g., presettlement) were in fact very different from (i.e., inconsistent with) the present. Neither has there been explicit discussion about which historic time periods might be most appropriate to the present or anticipating the future—more accurately, there is confusion about these recommendations. For instance, Hessburg, Smith, and Salter (1999), as recommended by Keane et al. (2009), make the assumption that “recent historical variation [implying the presettlement interval] represents the broad envelope of conditions that support landscape resilience and its self-organizing capacity” (p. 1026). As described in the next section, there is little discussion of the fact that the recent historic variation indicated (the centuries before ~1900 CE) comprised the Little Ice Age, with very different conditions from the 20th century. By contrast, Landres et al. (1999) endorse the use of the last 2,000 yr as a reference for developing HRV, which was the reference period used in the Interior Columbia Basin Ecosystem Management Project. The last 2,000 yr do not, as reviewed in the next section, constitute an interval of consistent climate. By contrast, this time period contains both the cold Little Ice Age and the anomalous dry and warm Medieval period, with significant implications for how forest vegetation might have differed from present.

As such, while historic climate variability is acknowledged in the discussions of HRV, and descriptions of Holocene-long climate are occasionally outlined, there remains a disconnect in some of the literature framing HRV. Although discussing the importance of historic climate intervals, specific reconstructions of HRV that follow (as in calculations of historic fire return intervals—e.g., Agee, 2003; Veblen & Donnegan, 2005) do not explicitly describe the time period used, although once the methods are investigated, these are almost exclusively the presettlement Little Ice centuries. Finally, the recommendation that managing within the constraints of history is more effective than managing for goals outside these bounds (Landres et al., 1999) makes the implicit assumption of background climatic stationarity. That is,

that (undefined) historic conditions in fact have similar bounds to current and future ecosystems and thus are relevant as direct references and management targets for projects aimed at sustaining ecosystems.

From these theoretical bases, general guidance for natural resource planners and resource managers was widely developed for regional forest ecosystems around the country. For example, four planning steps from a USFS Pacific Southwest Region EM guidebook (Manley et al., 1995; Figure 1) were developed and implemented on USFS national forests in California:

- Step 1: Assess historic (“Reference”) range of variability;
- Step 2: Develop desired conditions for the future from HRV (“management variability”);
- Step 3: Describe existing condition;
- Step 4: Outline methods to move from existing to desired conditions.

In this framework, managing within HRV was explicitly an approach to manage for sustainability; HRV was assumed to be a surrogate for sustainability and provided a scientifically based reference for defining conditions on the ground that matched the desired condition (Hunter, 1996). Thus emerged such USFS slogans as: “Forests with a Future: The forests of the future must become more like the forests of the past.”

A translation of the theoretical discussions, and perhaps emerging from the lack of clarity about historic climate variability, an assumption developed

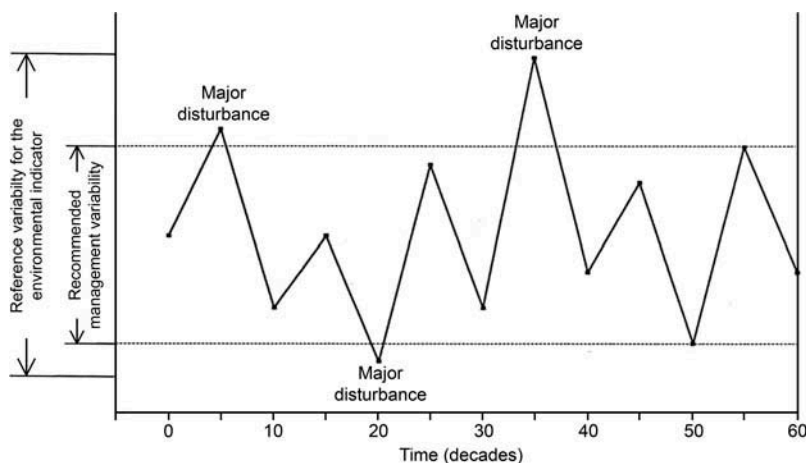


FIGURE 1 Schematic diagram demonstrating the historic (“reference”) range of variability for a generalized environmental indicator under resource planning as used in the late 20th century in USFS ecosystem management practices. The bounding lines indicate the recommended range of conditions for developing targets for desired future conditions, which was a subset of the total observed range of historic variation (modified from Manley et al., 1995).

in management contexts that historic conditions in general (without regard to which historic periods) were similar enough to be relevant to contemporary contexts. Dynamics such as succession, disturbance, growth, and mortality had their role in EM, but, “as a basis for long-term plans and projections, relatively constant environmental conditions can be assumed” (Manley et al., 1995, p. 21). The flat bounding lines for the recommended management variability in Figure 1 derive from this assumption. In the section following I review the importance of historic climates and ecological response in light of the (mis)-interpretations that have been made in implementations of HRV.

HISTORY AND CLIMATE: THE BIGGER PICTURE

Prior to the period of significant human impact (~early to mid-1800s for much of North America) climate was the primary driver of ecological variability and change. To evaluate EM assumptions and applications of HRV, several facts about historic climate conditions and processes are critical (Figure 2, Millar & Brubaker, 2006):

- Climates have been changing constantly through the history of life on Earth; this includes dramatic changes throughout the periods of evolutionary history of species we manage today.
- Climates are expressed at hierarchic (scalar) levels, with interannual regimes nested in decadal modes, nested within multicentury modes, and these nested within even longer term multimillennial cycles.
- Different physical mechanisms drive modes at the different scales. While these are quasi-independent, drivers interact.
- Climate at any one moment in history is expressed as the cumulative effect of all modes acting together. This results in changes that are gradual and directional; episodic or reversible; characterized by abrupt changes and extreme events; and/or chaotic.
- Ecosystems respond at all scales of climate variability and change.

Because it is important to understand the scales of historic change and their influences on biodiversity, I briefly summarize these below. For further development, see Millar and Woolfenden (1999a, 1999b) and Millar and Brubaker (2006).

Glacial-Interglacial Cycles

For the past 2 million yr (the Quaternary), more than 40 cycles of long (20,000- to 90,000-yr duration) cold intervals known as glacial periods have fluctuated with warm intervals known as interglacial cycles

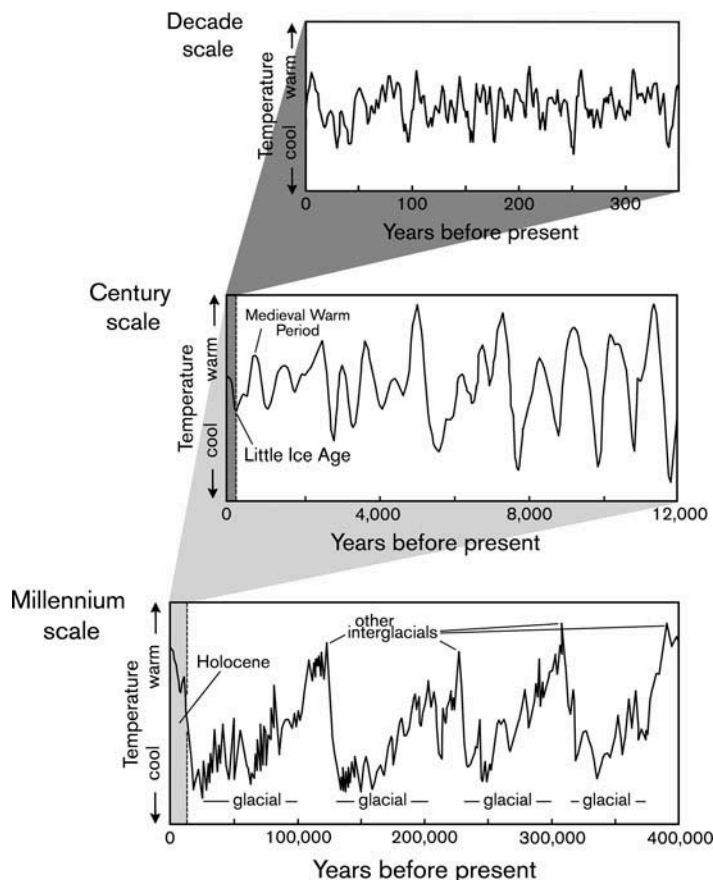


FIGURE 2 Global temperature cycles showing the nested nature of climate modes at different temporal scales. Top: Decadal cycles driven by ocean circulation and sea temperatures. Middle: Century cycles driven by solar variability. Bottom: Millennial cycles driven by changes in Earth's orbit relative to the sun. These and other cycles interact continually and, in combination, result in ongoing changes in earth's natural climate system.

(average 15,000-yr duration in the last 800,000 yr; Tzedakis et al. 2012; Cronin, 1999; Ruddiman, 2001). Global mean temperatures from glacial to interglacial cycles differed by 4–6°C; methane and carbon dioxide also cycled (Petit et al., 1997). These alternating macroclimate regimes are driven by the ongoing orbital cycles of the earth's position relative to the Sun, mediated by complex interactions of greenhouse gases (Imbrie, Berger, & Boyle, 1993; Imbrie et al., 1992). While this scale might seem to be irrelevantly long for forest management and restoration, when addressing “What history?” these time periods are well within the longevity of species we manage, most of which evolved in the middle Tertiary more than 15–50 million yr ago (Millar, 1993). Further, the magnitude of differences in temperature at the glacial-interglacial scale is similar to projected changes for the coming century under

anthropogenic warming. Thus, examining the nature of ecosystem response at this magnitude of change is useful. The annual resolution now possible to analyze from polar ice cores further shows that during periods of rapid transition, climate reorganization was common, with abrupt changes in temperature of 4°C in only 1–3 yr (Steffensen et al., 2008) and cumulative changes of 15°C in 40 yr (Taylor et al., 1993). High variability, climate “flip-flops” were far more common during long glacial periods than in warm interglacials (Heinrich, 1988; Dansgaard et al., 1993), and exerted significant evolutionary pressure for species adaptation to such challenges (Grimm, Jacobson, Watts, Hansen, & Maasch, 1993).

Species and ecosystems at these scales responded by moving geographically, adapting genetically, reassembling into transient communities that emerged as climates changed, and suffering population extirpation as well as species extinction. Novel climates emerged as a result of complex interactions of climate mechanisms and spurious factors, and vegetation and animal communities that were nonanalogous to modern or to known prior assemblages appeared and disappeared following climate. In regions of low relief, species often shifted hundreds of kilometers, usually northward as ice caps melted, then after the height of warmth in the mid-Holocene (6,000–8,000 yr ago), started to shift southward again (Webb, 1988). In mountainous regions, species shifted by as much as 1,000 m up or downward following changing climates and depending on their life history traits and habitat dependencies (Thompson, 1990).

Century-Scale Cycles

Punctuating the historic glacial-interglacial cycles have been pulses of warm to cold phases that expressed at centennial periodicities (Bond et al., 1997). These were triggered by changes in solar activity interacting with ocean circulation processes, and drove temperature changes on the order of magnitude of 2–3°C (Bond et al., 2001). Variably expressed in different regions on earth, these multicentury intervals were at some times intensified by such stochastic phenomena as volcanic aerosols. The last warm phase prior to the 20th century was the Medieval Climate Anomaly (ca. 900–1300 CE), a 400-yr interval expressed in many regions worldwide as prolonged warmth and persistent, severe drought (Hughes & Diaz, 1994). Following this was a worldwide 420-yr-long Little Ice Age (1400–1920 CE; Grove, 1988), which in western North America resulted in the largest glacial advance in more than 11,000 yr (Clark & Gillespie, 1997). The Little Ice Age, which reached its coldest phase only about 100–150 yr ago, is significant in that many of our current forests established during this period, and trees that survived during this interval had to be adapted to significantly colder and wetter climates than experienced before or in the decades since. Similar ecological responses have been documented for climate changes at this scale as to the glacial-interglacial but at correspondingly lesser magnitude.

High Frequency Cycles

Highest resolution climate cycles express within centennial and millennial regimes, and include the familiar interannual El Niño-La Niña regime (Diaz & Markgraf, 2000), and mechanistically related multidecadal modes—such as the Pacific Decadal Oscillation, North Atlantic Oscillation, and Arctic Multidecadal Oscillation (Cronin, 1999). Driven by changes in ocean circulation in the Pacific, Atlantic, and Arctic Oceans, these phenomena affect regions of the world differently, and many are characterized by opposite phases in different parts of each region affected. For instance, during a strong El Niño, winters in the Pacific Northwest of North America are unusually dry while the Southwest is wet. Ecosystems respond to these climate cycles less with range shifts or population migrations but through changes in demography, forest stand structure and composition, individual form or behavior, species dominances, and by episodes of high mortality (e.g., insect epidemics) and type conversions (e.g., meadow to forest; Swetnam & Betancourt, 1998; Biondi, Gershunov, & Cayan, 2001; Millar, Westfall, Delany, King, & Graumlich, 2004).

HISTORIC CHANGE AND IMPLICATIONS OF ENVIRONMENTAL STABILITY

In sum, persistent climate changes have characterized the history of Earth, influencing the way species evolve and persist (or not) at long to short scales. Species present today are the biogeographic-genetic survivors (winners) of the challenges presented by ever-changing historic climatic and environmental conditions. In the course of confronting change, they evolved traits and behaviors that enable capacity to respond and persist. Thus, the reality of historic climate change challenges a working assumption that continues to underlie the application of HRV, that is, that background environmental conditions have been stable (or similar enough) over the time period of reference. The conclusion from paleorecords is that, at scales from years to millennia, ecological conditions are not in equilibrium, do not remain stable, nor are they sustained; but, by contrast, are in ongoing flux (Jackson & Overpeck, 2000). Biotic response to change over time is a “variable chasing a variable, not a constant” (Jackson, 1997, p. 42).

This condition of background dynamism challenges notions of historic variability as a proxy for ecologic sustainability (What is being sustained?), confronts the meaning of native species and their distributions (Which native? Which range limits?), begs the question of function (What ecosystem hasn't had functions?), and demonstrates the shifting nature of community diversity and the frequency of novel historic climates and nonanalog communities (Webb, 1988; Davis, Woods, Webb, & Futyma, 1986; Jackson & Overpeck, 2000). These concepts are time dependent, and statements about them, as

well as the appropriate timescale for developing HRV, must be made in regard to the temporal scale for which they apply. Importantly, the period most often used for developing HRV in practice, although rarely specified, is the presettlement interval corresponding to the Little Ice Age, during which time climates and ecological processes were much different than at present or anticipated in the future.

LESSONS FROM HISTORY FOR RESOURCE MANAGEMENT: “WHAT HISTORY?”

From the above discussion, we may conclude that there is no historic period or range of historic conditions that is appropriate to use as once intended in EM, i.e., as a reference for developing desired future condition targets. Rather than look to history for a picture of the ideal or reference for sustainable future ecosystems, however, we benefit greatly by historically informed management and restoration strategies (Safford, North, & Meyer, 2012). For instance, our strategies will be most efficient when we work with rather than against the flow of change, when we exploit the natural capacities (biogeographic and genetic) of species to adapt to change, where we maintain conditions of highest health that enable these capacities to express, and when we resist concepts based on stationarity to guide strategies detrimental to species adaptation (Milly et al., 2008).

The reality of historic change, its complexity, nonlinearity, and multi-scalar manner, might suggest a conclusion that “anything goes” in managing or restoring current and future ecosystems. This is farthest from a conclusion that derives from understanding of history. To the contrary, historically informed management strategies attempt to incorporate natural patterns and processes to the benefit of societal goals.

Restoring Severely Degraded Systems

In cases where ecosystems have been severely altered, usually through human actions such as mining, land-development, overgrazing, or heavy pollutant application, restoration becomes a strategy of reconstruction. These are likely the only situations where a range of historic conditions could serve as a rough guide for putting parts back in place. An example is the Mono Lake ecosystem at the western edge of the Great Basin in California (National Research Council, 1987; Millar & Woolfenden, 1999a). A highly productive saline lake, Mono Lake historically supported high biodiversity and served important ecological functions such as critical stopover locations for regional to interhemispheric migratory birds. Diversions of water from tributary streams to supply water to Los Angeles, more than 600 km distant, began in the early 1940s. Water diversion soon threatened Mono

Lake ecosystems, first with excessive salinity, and increasingly with the likely fate of lake and tributary desiccation and complex ecosystem collapse.

The long road toward functional restoration of the Mono Lake ecosystem began with setting goals that were informed by recent historic conditions, that is, the known predisturbance ecosystem diversity and function. These were further informed by projections about future climates—especially temperature, precipitation, snowpack, and evapotranspiration. Development of a water-balance model assisted in understanding relations of lake level variability and response to climates of the future. Knowledge of local ecological conditions during historic droughts of the Medieval Climate Anomaly also provided insight into what lake levels might resiliently host diverse future aquatic and lacustrine communities. From these integrated insights, target goals for functional restoration were developed.

Managing Ecosystems for a Changing Future

For the many ecosystems not severely degraded, historically informed strategies focus on (a) removing barriers that impede inherent ecological capacities to respond to change, and (b) assisting species and communities to transform in ways most compatible with their inherent capacities and with social goals. In regard to the first, we learn from historic retrospect that the truly novel conditions at present and increasing in the future are not so much about the magnitude or even pace of climate change, rather the overwhelming transformation modern humans have imposed on Earth. The Anthropocene era (Ruddiman, 2003) is characterized by nonanalog conditions for species survival, and the accelerated pace of extinction shows that many species have not been able to use their inherent capacities to respond to change in the face of such barriers. Functional restoration thus can emphasize, to the extent possible, removal or mitigation of impacting barriers derived from land development; fragmentation; air, land, and water pollution and contamination—carbon dioxide being among the worst offenders; land-use changes, invasive species, and many others (Millar, Stephenson, & Stephens, 2007).

Assisting ecosystems to transform in ways most compatible with their inherent capacities involves exploiting species tendencies to move geographically and to adapt genetically in the face of change. In regard to the former, if barriers to dispersal cannot effectively be removed, assisted translocation, either of species beyond their current range limits or of genotypes beyond their current provenances, might be effective. Understanding changes that are already underway will enable restorationists to ease transitions to future states, often with less extreme variability or outcomes than socially tolerable. Assisting genetic adaptation can occur in many ways informed by natural selection—such as experimenting with seed diversity in restoration mixes, taking advantage of the significant opportunities that insect-mediated

mortality events can have to ratchet population adaptedness forward, and setting goals at bioregional not local scales.

Goal Setting

While much can be learned from reconstructions of historic responses to climate change, and especially from historic periods similar to what might be expected in the future (e.g., the Medieval interval or the middle Holocene), historic conditions generally, and especially those from nonanalogous historic periods (such as the Little Ice Age) make inappropriate reference conditions for the future. In such a case, target and goal setting for functional restoration must pioneer additional approaches. The return to more utilitarian goals and targets recognizes both the reality of the Anthropocene and that resource-management has, in fact, always been a human-directed and conceived endeavor. Emphasis on ecosystem services—including essential utilitarian functions such as clean air and water, landscapes for recreation, production of fiber and meat, and sustenance of biodiversity desired by humans and provided by healthy ecosystems—will guide the next generation of management strategies. Achieving these goals will be greatly benefited by historically, as well as ecologically informed management.

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