COMMENTS ON HISTORICAL VARIATION & DESIRED CONDITION AS TOOLS FOR TERRESTRIAL LANDSCAPE ANALYSIS[1]

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Abstract. *Historic (natural or reference) variability and desired condition are key ecosystem-management concepts advocated in many approaches to terrestrial landscape analysis. Historical variation is considered to be a conservative indicator of sustainability. If current conditions are outside the range of historic values, management actions are described to realign the system within historic ranges. Based on historic variability and social preferences, a management goal called the desired condition is developed. This paper examines some of the arguments for and against the use of historic analysis as a direct guide to setting management goals. Among the concerns are inadequate time depths used, persistence in inferring historic conditions even where data are unavailable or unknowable, emphasis on using historic values of individual elements rather than composite ranges for multiple indicators, lack of understanding of the hierarchic nature of ecosystem change and higher order environmental influences on ecosystems and their implications for management. Despite criticisms of direct prescriptive applications, however, historic data provide some of the best sources of information about ecosystem behavior, and should remain central to both ecosystem management research and application. With suggested modifications in approach, historic data should be included wherever possible in landscape analysis.*

Key words: landscape analysis, bioregion-Sierra, ecosystem management, desired condition, historic variability, dynamic equilibrium, fire history

BACKGROUND

Historic variation and desired condition have emerged as key concepts among recent efforts to derive operational tools for terrestrial ecosystem management. Current approaches to landscape analysis, especially in Forest Service circles, typically involve some combination of the following steps (e.g., U.S. Forest Service 1992a, 1992b, Kaufmann et al. 1994, Manley et al. 1995):

1. Determine natural boundaries of the landscape.

2. Determine historic (also called natural or reference) ranges of variabilities for key environmental indicators (biological, physical, and social; e.g., Table 1). Historic range of variation (HRV) is the natural distribution of spatial and temporal data for ecosystem structures and processes that would occur over similar sized areas as the landscape under consideration (Swanson et al. 1993).

3. Inventory existing conditions of environmental indicators.

4. Develop a desired condition for the landscape. The desired condition (DC) is a statement of management goals, presented as a detailed description of the landscape as it would be at some future time (e.g., Table 2). Desired conditions usually are intended to integrate physical and ecological aspects (either as they are presently tending or in restored condition) with social values.

5. Prescribe management actions that will move the landscape from the present to the future desired state.

The logic and application of these concepts have been championed and challenged by scientists and natural resource managers alike. The underlying assumption of such approaches is that "restoring and maintaining landscape conditions within distributions that organisms have adapted to over evolutionary time is the management approach most likely to produce sustainable ecosystems" (Manley et al. 1995). In the face of gross uncertainty about most attributes of an ecosystem, managing within ecological and physical ranges that have prevailed historically is widely considered the safest or most conservative path to sustainability. Among the challenges to the concepts have been imperatives to abandon the approach as untenable and undoable, as well as more moderate suggestions for ways to increase effective use of historic analysis in the planning process.

In this paper, I collect several lessons from two case studies in landscape analysis which are briefly summarized here, the Mammoth-June Ecosystem Management Project (Box 1) and the Mono Basin Ecosystem (Box 2). I do not attempt to be exhaustive, but emphasize primarily ecological and physical implications from these analyses, while leaving to others the complex discussions of how best to incorporate social values. I also do not address the role of native people

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Table 1.
Ecological indicators included in analyses of existing and desired conditions in the Mammoth-June Ecosystem Management Project. Ql refers to qualitative information compiled; Qn refers to quantitative information.

Key Resource Area	Ecological Indicator	Existing Conditions	Historic Conditions
Air quality	visibility	Ql	Ql
	PM-10	Qn	Ql
	ozone	Qn	Ql
Watershed	streamflow duration	Qn	Ql[1]
	streamflow timing	Qn	Ql
	streamflow magnitude	Qn	Ql
	springs	Qn	Ql
	channel stability	Qn	Ql
	stream crossings	Qn	—
	soil erosion	Qn	—
	soil productivity	Qn	—
	snowpack water content	Qn	—
Water Quality	temperature	Qn	Ql
	turbidity		
	conductivity	Qn	—
	pH	Qn	Ql
	total suspended solids	—	—
	total dissolved solids	—	—
Biodiversity			
Vertebrate	key species habitat—available		
	spotted owl	Qn	Ql
	goshawk	Qn	Ql
	willow flycatcher	Qn	Ql
	breeding birds	Ql	—
	marten	Qn	Ql
	mule deer	Qn	Ql
Vertebrate			
	key species habitat—distribution for species above	Qn	Ql
	key species population sizes	Qn	—
	key species distribution	Qn	—
Amphibians	habitat availability	Qn	Ql
	habitat distribution	Qn	Ql
	metapopulation structure	Qn	Ql
Plant	vegetation composition (species mix, veg types)	Qn	Ql/Qn
	forest structure	Qn	Ql
	seral stage, density	Qn	Ql
	range of age/size classes	Qn	Ql
	susceptibility to disturbance	Qn	
	downed woody debris	Qn	Ql
	cover of: total vegetation, duff, litter, bare ground	Qn	Ql

[1] Historic conditions being inferred only for Glass Creek watershed.

Table 1. (continued)

Key Resource Area		Ecological Indicator	Existing Conditions	Historic Conditions
Biodiversity				
	Fisheries	pool habitat	Qn	Ql
		biomass	Qn	Ql
		woody debris	Qn	Ql
		species distribution (trout)	Qn	Ql
		trophic status	—	—
		macroinvertebrates	Ql	—
		pool sedimentation	Qn	—
		cobble condition	Qn	—
	Fire	size	Qn	Ql
		intensity	Qn	Qn
		frequency	Qn	Qn
		distribution	Qn	Qn
		fuel loading	Qn	Ql
		fuel model	Qn	Ql
		fuel structure	Qn	Ql
		cause of fire	Qn	Ql
		vegetation type	Qn	Ql
		fire risk	Qn	
	Insects/Pathogens	severity of epidemics	Qn	—
		size	Qn	—
		distribution	Qn	—
		species affected	Qn	—
	Human Use	prehistoric culture	Qn	
	Recreation	recreation facilities	Qn	Qn
		recreation use levels	Qn	Ql
		visual quality	Qn	Ql
		sensitivity levels	Qn	—
		variety class	Qn	—
		visual absorption capability	Qn	—

Table 2.

Examples of draft **Desired Condition** statements for resources and areas within the Mammoth-June area. (From: U.S. Forest Service, 1995a.)

Fire and Fuels: Fire operates as a process throughout the landscape to provide nutrient cycling, fuel reduction, and vegetation succession. The degree to which fire occurs will vary by vegetation type, as detailed in the Desired Condition for vegetation.

The Town of Mammoth Lakes, Mammoth and June Mountain ski areas, the community of June Lake, and the Glass Creek recreation area are protected from high intensity fires that might occur within the area, and the landscape is protected form fires that might originate in these areas of concentrated use. The risk of fire spread is reduced by decreasing ladder fuels around these areas, by reducing fuel loads to less than 20 tons per acre, and by evenly spacing tree crowns in adjacent area so that contact between crowns does not occur.

The risk of large, high intensity fires within the landscape is low. Lightning caused fires may be managed using Prescribed Natural Fire plans, or one of the three fire suppression strategies (confine, contain, control). Human caused wildfires will be suppressed in the most cost effective manner, with cost being defined as suppression cost plus net value change.

Vegetation: The vegetation across the landscape represents a complex mosaic of vegetation series. The relative occurrence or distribution of vegetation series changes little over time, and any large scale changes are in response to climatic changes and not human activities. The structure, species distribution, and size of individual plants will change over time as plant communities respond to processes operating within the landscape.

The Desired Condition for vegetation includes descriptions for species composition, vegetative cover, size class, snags (standing dead trees >12" diameter and >20' tall), logs (downed trees >12 diameter and >20' long), fire frequency, fire intensity, fuel loading, and surface cover. These descriptions apply to the overall condition within the vegetation series. Vegetation conditions for a specific area may vary from the range of conditions described for the series as a whole so that other desired conditions can be achieved. One example out of several vegetation series is illustrated here.

<u>Red Fir Series</u>: The Red Fir Ecosystem comprises much of the western 1/3 to 1/2 of the study area. While red fir is the dominant tree species throughout this area, it is commonly associated with lodgepole pine, Jeffrey pine, western white pine, whitebark pine, white fir and mountain hemlock.

The desired vegetation community types can be grouped into two Red Fir Subseries: Red Fir with a Lodgepole component and Red Fir with a Jeffrey Pine Component. The red fir/lodgepole component is the dominant community type and is found throughout the Red Fir ecosystem. The red fir/Jeffrey pine community is typically found on southern exposures and lower elevations within the Red Fir Ecosystem. One red fir subseries DC is included here.

<u>Red Fir/Lodgepole Subseries</u>: The area will display a mix of pure red fir community types with tree canopy closures of 60% or greater and red fir/lodgepole community types with tree canopy closures of 30-60%. While red fir is expected to be the dominate tree species, disturbance processes will create small to large openings (greater than 10 acres) in which lodgepole pine will dominate for periods of time. When lodgepole is dominate average tree canopy closure is expected to be lower and the larger size classes will account for a smaller percentage of the total cover. Without major disturbances, lodgepole pine might drop out entirely leaving communities comprised of red fir and mountain hemlock. High density, multi-layer stands will be the norm in those areas.

Common associates are western white pine and white fir on southern exposures and lower elevations and mountain hemlock and white bark pine at higher elevations and/or northern exposures.

The shrub and herbaceous understory will typically be less than 1%.

Table 2. (continued)

The tree canopy cover for these red fir community types is expected to be 60% or greater, unless lodgepole pine dominates in which case the canopy cover may be 30% or less. The mix of size classes over red fir community types will be:

Size Class DBH	Percent of Total Tree Cover
1-6"	3-7%
6-11"	3-7%
11-18"	5-9%
18-25"	5-9%
25-30"	5-9%
30-40"	15-35%
40"+	20-40%

The snag component is typically 3 to 8 snags per acre, 10 to 15 logs per acre contribute to the down woody debris, and the duff thickness is approximately 3" covering greater than 85% of the ground. Bare ground is less than 5%.

Fire operates as a process throughout this vegetation series. The range of fire indicators are:

Size	Intensity	Frequency	Fuel Load
acres	Low	25-50 years	30-60 tons/acre
acres	Mod-High	75-100 years	30-60 tons/acre

and their effects on the landscape prior to major EuroAmerican settlement (thus avoiding the discussion of what is natural). I take the assumption that, with local exceptions, the last 200 years is the most significant period of anthropogenic effect in western North America.

1. WHAT IS THE RELATIONSHIP OF HISTORIC VARIATION TO CURRENT AND FUTURE ECOSYSTEM STATES?

The central recognition of time—past, current, and future—in modern landscape evaluation is an important confession of the undeniable fact that ecosystems change. Changes since pre-EuroAmerican settlement are widely visible and frequently described, both dramatic (clear-cutting old-growth forests, damming rivers and draining lakes, extensive surface mining, urbanizing critical habitat) and more subtle cumulative effects (on water quality, species diversities and abundances, and from fire suppression).

The recognition that anthropogenic impacts have led to unraveling of some ecosystems (significant loss of species, decline in species abundances, loss of productivity and critical functions) has catalyzed the search to understand ecological conditions prior to major settlement. The comparisons that result, of presettlement to current conditions, can lead intentionally or unintentionally to a 'back to the golden-era' mindset. Historic snapshots (literal and figurative) become idealized pictures for the future. The golden-era view assumes that if we restore the future back to a presettlement condition, we can undo deleterious effects on species and ecological function, resetting the ecological clock to a sustainable meter.

That such a static view—mimicking a single time or narrow period of the past—is largely misleading is now generally appreciated (e.g., Botkin 1990, Williams & Marcot 1991), as the emphasis on HRV in recent landscape analysis procedures illustrates. Clearly management that seeks to undo mischief created by human actions and reintroduce natural processes must have more than temporal or spatial snapshots as guides. It must understand and accommodate the range of variation resulting from natural processes, appreciate the nature of ecosystem change, and recognize the consequences of often-significant deviations from natural process that have occurred due to anthropogenic effects (Kay 1991, Kaufmann et al. 1994).

Many current interpretations, however, only partially acknowledge the broader implications of temporal change to management in that they focus primarily on ecological succession. Taken in isolation, views of succession and ecological disturbance are essentially recycling views of change; i.e., aside from stochastic effects, they assume that a forest changes from one year (or decade) to the next (e.g., from post-fire opening to seedling to mature forest to old-growth), but that over time the cycle repeats, such that individual stages are much the same from cycle to cycle (Mueller-Dombois & Ellenberg 1974). A recycling view assumes that the past can be recaptured in the future if the dynamics of the cycle are included in the future landscape scenarios.

Insights from Quaternary science, where longer time periods are studied, reveal greater complexities of temporal change. Most important is the occurrence of hierarchic, overlapping scales of change (Bartlein 1988, Delcourt & Delcourt 1991) that result from ecological forces as well as external factors (called 'forcing factors', primarily determinants of climate) (Fig. 1). Short term events, such as El Nino-Southern Oscillations (ENSO), occur within periods of decades to centuries; increasingly longer-term fluctuations, such as changes in solar insolation, orbital oscillations, and other global events (forcing factors believed to influence glacial/interglacial fluctuations), are documented at periods of 20,000 to 100,000 years or more (Fig. 2); plate tectonic events occur at intervals most meaningful at million year scales (see Imbrie et al. 1984, Ghil 1991, Bradley 1985).

There are several management implications of these higher order fluctuations (e.g., see Webb 1986, Hunter et al. 1988, Foster et al. 1990, Schoonmaker & Foster 1991, Campbell & McAndrews 1993, McNeeley 1994, Woolfenden 1994, 1996). One is that changes at different scales continuously and complexly interact to create current conditions. In other words, conditions on the earth at any one time are a composite of all external influences (e.g., Fig.2; COHMAP 1988, Bartlein 1988, Imbrie et al. 1992). Thus even though management scales are on the order of 100-200 years--which might suggest that only short-term effects (ENSO, succession) need to be considered—in fact, forces that operate over long terms are equally likely to have a role in influencing conditions over the next decade to centuries.

Because cycles of different natures are interacting, the changes we experience at a decadal or century scale are complex, non-linear, and not predictable from short-term fluctuations. No-analog situations likely exist for the near future. Thus, since the 'cyclic' events of plant succession are always superimposed against a backdrop of other change, no two 'cycles' of a sere are likely to be the same because conditions on the earth change. The complex interactions of short and long-term fluctuations (e.g., Fig. 2) mean that the pattern of change at present and in the near future may take many forms (e.g., Fig. 3). The likelihood of background influence on short-order changes depends on both the sensitivity of ecological change as well as the magnitude of background changes. There is evidence that we are in a period of increasing climatic variability: within the last millennium, some scientists find strong evidence that "vegetation was changing more rapidly during the last 1,000 years than at any time since the end of the Pleistocene" (Jacobsen et al. 1987).

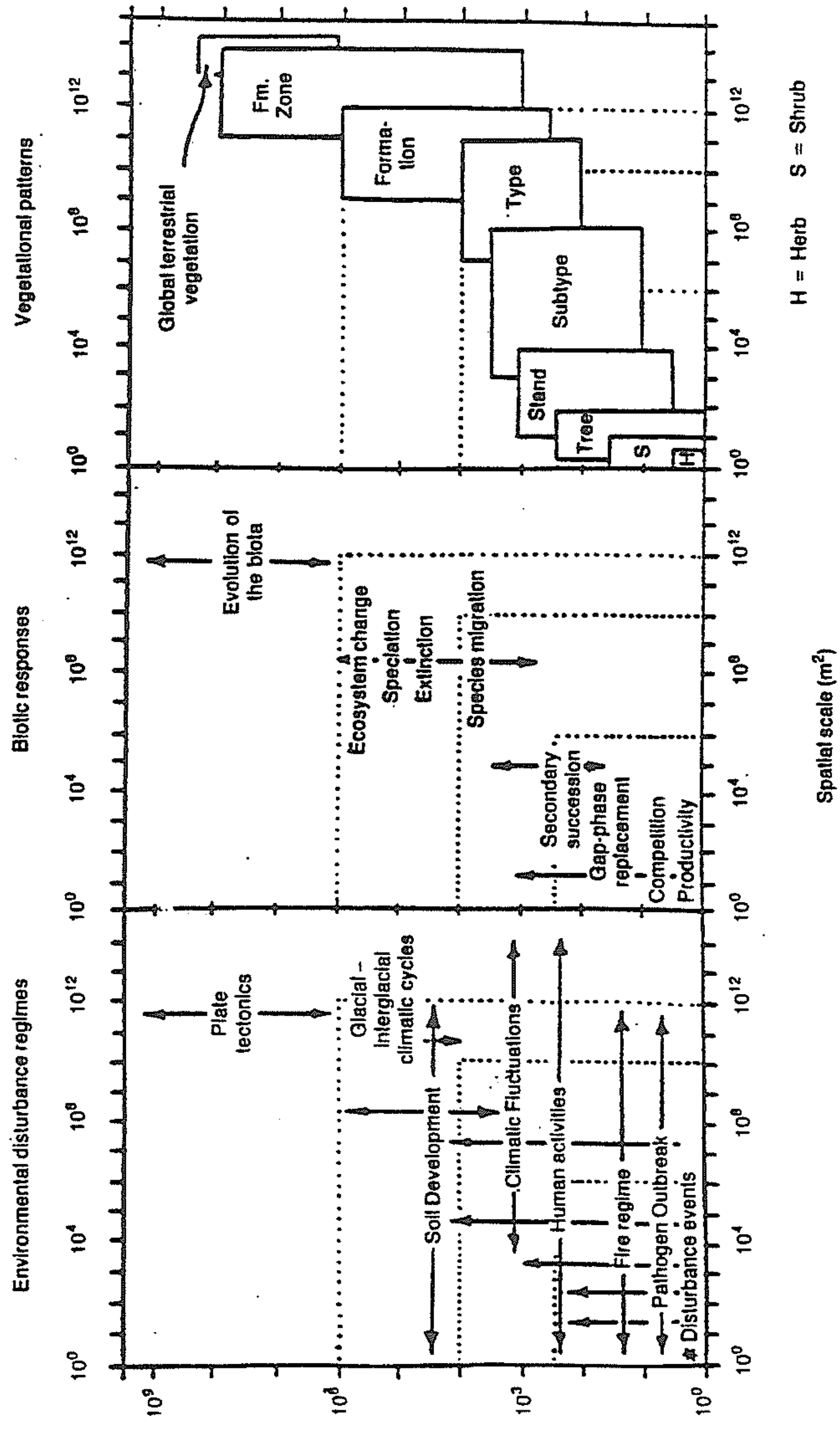

Figure 1. Hierarchic spatial and temporal scales with corresponding response functions. (From: Delcourt & Delcourt 1993.)

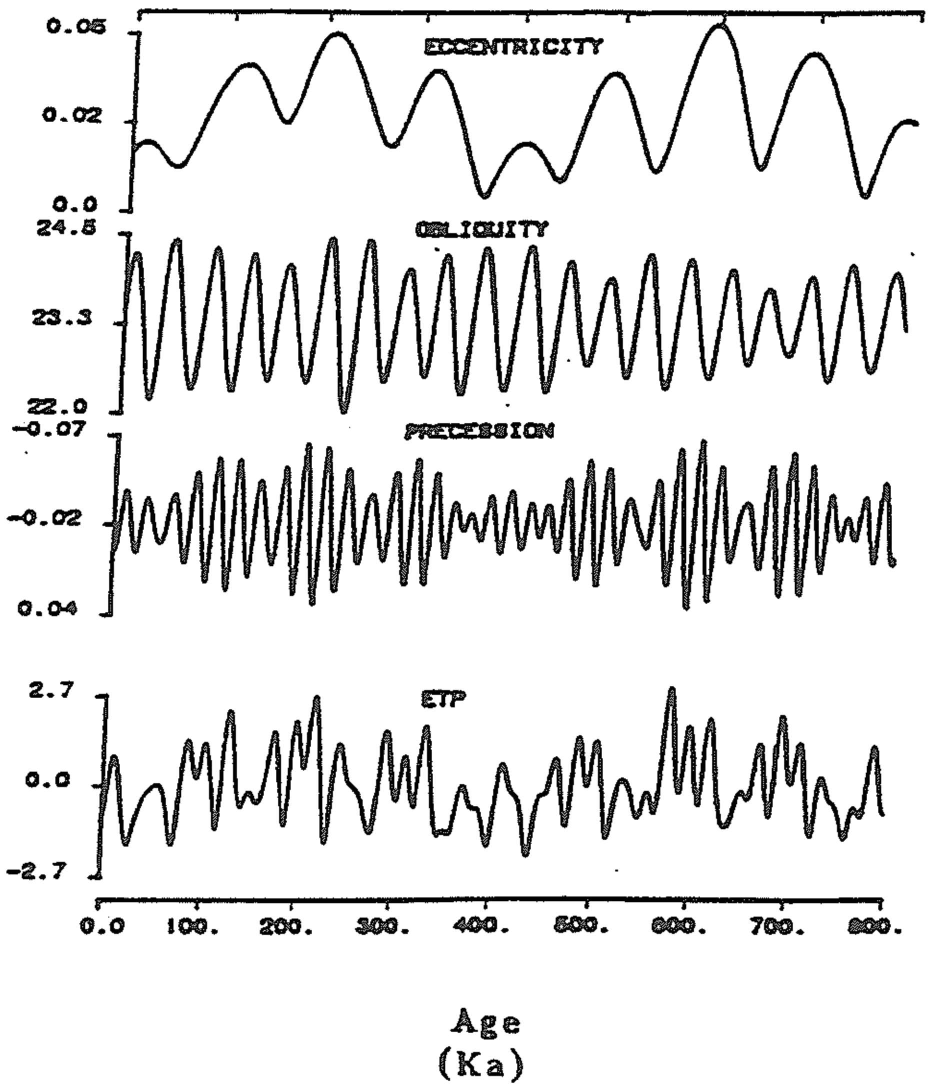

Figure 2. The effect of individual forces combining to produce a singular and constantly changing influence on global environmental conditions is demonstrated here by the so-called Milankovitch forces. Variations in three major components of the earth's orbit around the sun are shown individually (eccentricity, obliquity, and precession) and combined (ETP, shown in units of standard deviation). The composite graph closely parallels the pattern of glacial/interglacial periods in the last 800,000 years indicating the control that the interactions of these three forces has on global climates. (Modified from: Imbrie et al. 1984.)

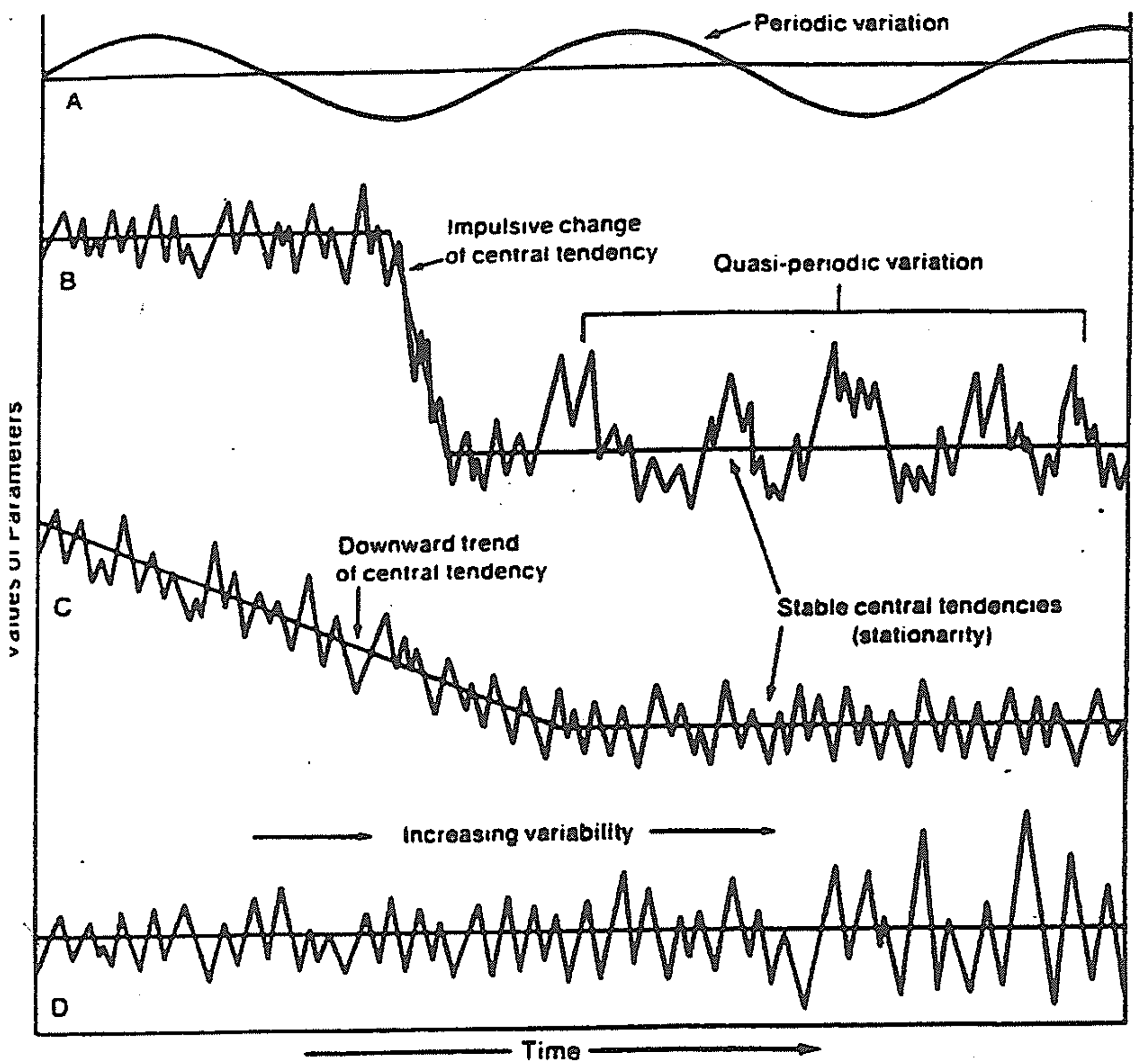

Figure 3. Examples of the range of variability possible in climate variation when forces of different magnitude are combined. The examples demonstrate fluctuations of short-term events and longer-term trends. (From: Hare 1979.)

The occurrence of overlapping temporal processes reminds us that discussions about ecosystem change—disturbance, recovery, succession, adaptation—should always include an explicit declaration of time frame (White & Pickett 1985, Turner et al. 1992, Sprugel 1991). For example, our labeling of a process or event as 'disturbance' is contingent on a time context. What may look like (and be called) a disturbance at a short time scale (e.g., fire) becomes either a routine event or invisible where a higher order pattern dominates at a longer scale (Fig. 3; Vogl 1980, Bradshaw 1988). Conversely, what might seem like a stochastic effect at a short-term (e.g., droughts) may appear as a regular pattern of a longer term fluctuation. Stating the time scale clearly will help mitigate the confusion that discussions about ecosystem change seem to fall into.

Consider the implications of interacting climate and ecological changes to current forest structure in the Sierra Nevada. Relative to average values, the climate of the Sierra Nevada during recent historic periods has been (Stine 1996):

> A.D.1850 - A.D.1970: Abnormally wet and warm, including the wettest half-century in the last thousand years.
>
> A.D.1650 - A.D.1850: Anomalously cold and dry relative to the last 10,000 years, marked by the only glacial advance—the Little Ice Age—known to have occurred in the Sierra since the retreat of Wisconsin glaciers at the end of the Pleistocene.
>
> A.D.900 - A.D.1300: Periods of drought more intensive in degree than experienced in the 20th century and lasting 100-150 years.

Policy and management lessons from this climate record include:

1. Environmental changes (here, climate) of a magnitude significant enough to influence major landscape architecture (e.g., forest structure, species distributions) have occurred at decadal and century levels within the last several thousand years and may well occur in the near future.

2. Forests that are mature now developed under dramatically different climates than those that today's young forests experience. Architectures we see in today's mature forests may reflect adaptations to climates that prevailed during their establishment and which no longer prevail. Conditions in old forests may be inaccurate models for future adapted forests.

3. Ecosystem changes during the last 150 years may reflect natural adjustments to climatic changes as well as successional events or responses to human actions.

4. Forest management (and other resource) practices developed during the last century may be too narrowly tuned to current (late 20th century) conditions and not broad enough to accommodate the range of possible conditions (natural and anthropogenic) of the future.

5. Studying HRVs over only the last 150-200 years may provide inadequate or misleading information.

Most climate scientists agree that the forcing factors which influence global climates interact so complexly that future climate cannot be accurately predicted. Especially at regional scales and for the short term future, directions and magnitudes of change are presently unknowable. However, evidence indicates that climatic variability is increasing. Thus, the most reliable prediction about future climates may be that they will be different from the present.

Discussions about complex changes and lack of predictability may lead to the conclusion that ecosystems change so unexpectedly that our ability to plan is futile. Further, it may lead to the conclusion that biota must be adapted to irregular, potentially rapid and unique change, thus why would historic information be at all useful, or why would biota benefit by a restriction to historic (or 'natural') pattern and process?

To accept these conclusions would be to throw the baby out with the bathwater. Discussions about the relationship of historic to present and future conditions are important for balance—by and large, ecologists have ignored most environmental fluctuations except short-term ecological and physical ones, and thus may misinterpret the historic record and implications to management. The overwhelming evidence from evolutionary studies is that plants and animals adapt to the rate and magnitude of natural changes. Since human effects have the potential to far exceed the rate of natural changes (e.g., see Ehrlich & Wilson 1991), it is valuable to learn what the nature of change has been for local biotas, and what the range of response from biota has been. When we are able to accurately assess these at appropriate time depths, historic patterns by and large have both enough repetition as well as meaningful variance as to be extremely useful for planning at management scales (e.g., Box 1, Box 2).

2. WHAT TIME DEPTH IS RELEVANT FOR ASSESSING HRV?

The discussions above emphasize overlapping scales of natural change. A lesson for using historic information in management planning is to study and understand processes at appropriate time scales (Norton 1992, Allen & Hoekstra 1992).

Horizons for land management attempt to reach forward 100-200 years (sometimes more, although realistically they are constrained by institutional and social forces to fractions of this). Thus, we would like to understand the nature of changes that might occur within this time frame. This includes events with a period shorter than 100-200 years, such as fire disturbance and population dynamics, as well as longer term events that might significantly influence the backdrop of change.

As in other sampling situations, the appropriate time depth for HRV analysis depends partly on how much variability is expected in the processes. The more variable a process, the more time depth is required to accurately estimate variation. Many biotic processes are highly irregular from year to year, as reflected, for example, in population size of annual plants (Table 3, Howald 1996). Fire return intervals are also highly irregular, both in the short (Table 4) and long term (Fig. 4). Fluctuations in vegetation composition are significant enough that even in a continuous pollen record for over several centuries from Lake Tahoe the dramatic anthropogenic impacts on the forest of the early 19th century are not overwhelming (Davis 1996).

Similarly, the longer the time period of an event, the more time depth required to understand the nature of the process. For example, in the eastern Sierra, the Inyo and Mono Craters have been regular and dramatic disturbance events to the surrounding conifer forests and meadows. Cumulatively, they have been active at century levels, and have significantly influenced forest, range, and meadow development in this area for millennia. An adequate understanding of these relationships, however, will take a record of at least several thousand years.

To pick up events that appear unique or rare (higher order disturbances) takes a time scale that will elucidate potential trends. For example, in the Sierra Nevada, climate studies reveal several periods of intensive and extensive droughts (100-150 years long) between A.D. 900 and A.D. 1300, which had dramatic effects on stream, lake, and vegetation structure (Graumlich 1993, Stine 1990, 1994, Hughes & Diaz 1994). Fire patterns (interval, severity, and size) similarly were different during this period (Swetnam 1993). Climate at present in California shows more similarities to these periods than to the intervening Little Ice Age, but many management studies and policies accommodate only process and responses of the last two centuries.

Another approach to determining adequate time period for historic process is to assess variation within that time where climate and landscape conditions are basically modern. Earlier than this (i.e., ages prior to a modern period), conditions may be largely irrelevant to likely short-term futures. Understanding extreme events and variability within the modern period is an important indication of extremes that realistically could be expected in the near future. Defining "modern" is arbitrary, of course. Certainly Holocene (last 10,000 years) is more appropriately modern than the entire Quaternary (last 2.5 million years) since major glacial periods likely are nonanalogous to management scales, although many Quaternary scientists now focus on the last interglacial (prior to the Holocene) as an important proxy for modern biotic responses. Further, the last several millennia are more relevant as modern than the entire Holocene, since the early Holocene warm period seems outside the range of conditions likely to be encountered in the next 100-200 years (Davis et al. 1985, Anderson 1990, Smith & Anderson 1992, Woolfenden 1996). Considering these situations together suggests an appropriate time depth of about 2,000-4,000 years for studying terrestrial HRVs within routine landscape analyses in California.

Although getting too long an historic record is rarely a problem, it follows that including events which occur on a long-period fluctuation (such as major tectonic events, glacial cycles) or occurred deep in time and appear non-analogous to modern conditions would be misleading. That ginkgo or even Port-Orford-cedar, for instance, were present in the Sierra Nevada during the Tertiary (Millar 1996a) and, thus, are within HRVs, is not a defensible argument for reintroducing these species into the range, as climate, topography, and landscapes are now radically different. Including variation that is far beyond what could be expected when developing a desired condition only makes the value of HRV meaningless because it is so wide. Knowledge of long-term historic changes gives deep understanding to the nature of landscape evolution and biotic adaptation, and belongs importantly as a research issue. Rarely, however, would it be necessary on a routine operational basis to extend an historic analysis beyond several thousand years.

Compared to the time lengths that would seem appropriate from a theoretical basis, the recommended periods for analyzing HRVs have been much shorter, attempting to reach 200 years but usually orders of magnitude shorter. For instance HRVs estimated for many variables in the Pacific Northwest used A.D. 1600 as the oldest time, whereas most of the measures were from a much more recent period (PNW 1993). Another recommendation for measuring ecological variation in historic condition was to "roll forests back and compare" to present (Bonnicksen 1994); in other words, "grow" historic forests backward from the trees standing at present. Finally in many restoration projects, "presettlement conditions" are used as a model for the restored conditions. These examples illustrate how time depths considered adequate for HRV continue to be too shallow.

3. CAN ADEQUATE HISTORIC MEASUREMENTS BE MADE AT APPROPRIATE SAMPLE SIZES & TIME DEPTHS?

At an operational level, we do not yet seem to have the capacity to routinely obtain adequate measurements necessary to characterize historic ranges of variability with statistical

Table 3.

Fluctuations in census of Santa Cruz tarplant (*Holocarpha macradenia*) in 22 populations from Contra Costa County, California over 11 years (From: Howald 1996).

Pop no.	1982	1983	1984	1985	1986	1987	1988	1990	1991	1992	1993
1	100	175	1	47	30	250	130	nd	nd	0	0
2	600	1,200	900	2,600	3,000	1,750	5,100	1	1	5	463
3	100	130	25	125	50	300	450	112	15	2	35
4	300	400	400	550	250	100	375	1	nd	1	4
5	60	75	0	50	15	0	0	nd	nd	nd	0
6		300	125	700	700	500	800	nd	nd	nd	4,051
7		130	125	175	100	70	125	0	nd	0	0
8		115	85	34	15	0	15	nd	nd	nd	0
9			250	15	1,200[d]	200	600	nd	nd	nd	nd
10			0	100	100	100	60	nd	nd	0	16
11			400	1,600	275	1,600	4,000	3	3	18	133
12			750	600	1,050	1,200	800	8	nd		047
13			30	750	600	400	700	nd	nd	nd	11
14			2	7	10	nd	nd	nd	nd	nd	nd
15					750	250	300	1	nd	0	5
16					750	700	1,500	10	nd	0	160
17					30	325	500	12	nd	1	0
18					250	400	1,000	12	12	0	20
19					0	0	0	0	nd	0	0
20*					400	400	600	nd	nd	1,500	nd
21[d]					20	1	nd	nd	nd	nd	nd
22[d]						850	3,000	nd	nd	nd	nd

nd = no data *Located on Sobrante Ridge
[d]Located in the San Pablo reservoir watershed

Table 4.

Fire history estimates in and adjacent to the Mammoth to June region.

Mammoth to June area: (From U.S. Forest Service 1995a)

Site 1: mixed red fir/Jeffrey pine
- Mean fire interval: 8 years
- Range: 2-18 years
- Record period: 1703 to 1951 (248 years)
- Number of trees sampled: 11
- Area of sampling: 65ha

Site 2: mixed conifer
- Mean fire interval: 9 years
- Range: 3-19 years
- Record period: 1731-1959 (228 years)
- Number of trees sampled: 9
- Area of sampling: 40ha

Valentine Reserve, adjacent to Mammoth to June area (From: Stephens 1996)

Site 1: Jeffrey pine
- Mean fire interval: 11 years
- Range: 4-21years
- Record period: 1593-1889 (296 years)
- Number of trees sampled: 19
- Area of sampling: 4 ha

Site 2: mixed conifer
- Mean fire interval: 37 years
- Range: 13-87 years
- Record period: 1624-1844 (220 years)
- Number of trees sampled: 11
- Area of sampling: 2 ha

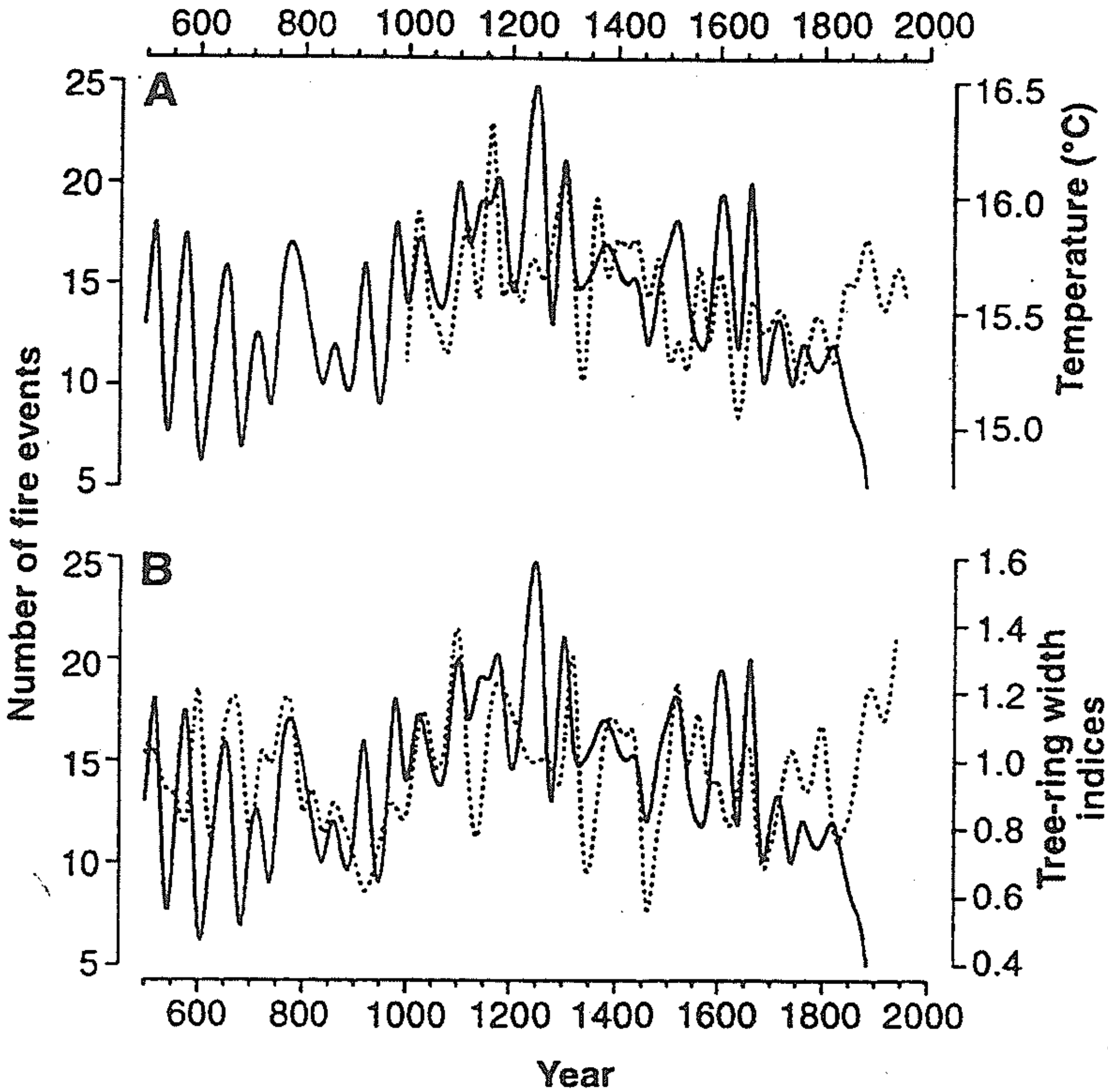

Figure 4. Long-term variation in fire occurrences (solid line, A.D. 550 and 1990) and summer temperature (reconstructed temperatures from tree-ring data) in giant seqouia (A) and bristlecone pine (tree-ring width indices) (B). Increases in fire frequency is indicated during the medieval warm period (c. A.D. 1000-1200) and decreases in the historic period (> 1850) are apparent). (From: Swetnam 1993.)

accuracy (Maser 1990, PNW 1993, Kaufmann et al. 1994). Limitations include lack of funds and priority to do the job adequately; lack of training to design, conduct, and interpret information; lack or paucity of historical data over the time span needed; and inability of current analytical tools to resolve information at the scale needed (Millar 1996b).

Some environmental indicators provide useful historic information; others are intractable (e.g., Table 5). As noted above, where there is high variance in a process (many biological phenomena), large sample sizes are needed to assess HRV with meaningful accuracy. Fire history studies in the Mammoth-June region (Box 1) indicate this. For a record length of 220 years (1624 - 1844) and 11 trees sampled in a mixed conifer type, fire return times averaged 37 years, but ranged from 13-87 years (Table 4). With this variability and small sample size, it is difficult to interpret the mean as well as the range of values. When short term, small samples are compared to situations where detailed long term and quantitative fire data are available, both the means and the annual variability are seen to be tied to both short term weather patterns and long-term climate changes (Fig. 4, Swetnam 1993).

A problem with historic data, especially historic photos, is that they often are thought to indicate presettlement conditions merely because they are old (e.g., late 19th or early 20th C). However, many of these may in fact depict conditions at the height of, or just after, the most drastic anthropogenic events, especially in places like the Sierra Nevada, which suffered extensive land clearing, timber harvest, grazing, and land disturbance from mining quite early (Beesley 1996).

Some biota and ecological processes leave little or no direct trace. For these, historical condition must be estimated from proxies or indicators of their presence. In some cases, this may be quite accurate, for instance where tree-ring patterns can indicate historic stream flow and historic climates. In other cases, such as forest structure (vertical complexity and spatial mosaic), historic patterns must be inferred from an understanding of historic growth rates and disturbance events. Eventually inferences are piled on inferences, for example, when historic animal distributions are inferred from forest structure which are themselves inferred from fire data. Finally there are many basic ecological phenomena for which virtually no proxy or indicator is reliable at the resolution needed. These include historic genetic diversity, invertebrate biota, herbaceous plants, etc. For many of these it is probably best to concede that historic data are too speculative, and they should not be included in HRV analysis.

For some historical phenomena of interest, analytical technology may not be adequate to provide the level of resolution needed. Pollen and packrat midden analysis of historic species distributions are examples. Pollen analyses provide continuous traces of taxa presences, abundances, and distributions. Statistical methods have been developed to improve resolution and interpretation. Although providing excellent sources of historical data, in many important cases, pollen types cannot be identified to species. For example, with a few exceptions, resolution of taxa is impossible below a composite of three families, Cupressaceae, Taxodiaceae, and Taxaceae. If one can make a safe guess of the species present, the limitation is less restricting. Packrat midden macrofossils are identifiable to species, but represent only local and specialized habitats.

4. WHAT IS THE RELATIONSHIP OF HRV TO ECOLOGICAL SUSTAINABILITY?

In some management approaches, HRV is directly tied to sustainability. For example, the handbook for ecosystem management of the Pacific Southwest Region, U.S. Forest Service, states, "if environmental indicators are within reference variability, then the system is judged as sustainable" (Manley et al. 1995). Without trying either to replay the arguments that define ecological sustainability or resolve the debate about whether ecological sustainability even exists, the question can be restated as, how can HRV help in maintaining ecosystems as would have been without significant human impact, if that is desired? Discussions about the nature of ecosystem change imply non-equilibrium conditions for environments and biota adapting to them, and that ecosystems are evolving in non-linear ways (e.g., Kay 1991). Further, given one set of environments over time, there are multiple potential trajectories and endpoints that ecosystem elements (and collectively, the whole ecosystem) could take, depending on initial conditions, disturbance, and the sequence of events over the course of time (Christensen 1990, Allen & Hoekstra 1992, Tausch et al. 1993, Kaufman 1993). If one's definition of sustainability and desired conditions is open enough to embrace these ranges of potential outcomes, then HRV probably gives a reasonable idea of possible futures.

Considerations about multiple environmental indicators pertain here. Relationships among two or more indicators over time are little documented, but ecological correlations among obviously interdependent elements (e.g., Fig. 5) imply that organisms' HRVs may co-vary. The sets of joint conditions that arise among elements over time will have much to do with determining what trajectory an ecosystem takes. The historic--and adaptable--set of combinations may be a small subset of all the combinations possible among individual HRV distributions. Thus, sustainability is probably more related to the unique combination of HRVs than to individual ones. It is also possible that many combinations of values among elements have not occurred naturally, and that these combinations would yield consequences hitherto not experienced by that environment. This could occur even though HRVs of individuals elements are not violated.

Table 5.

Examples of environmental indicators ranked according to their efficiency or feasibility in analysis of historic terrestrial variability, from Mammoth-June Ecosystem Management Project (Millar, 1996b). High ranks indicate that large sample sizes can be obtained from adequate time depths with reliable accuracy to determine actual HRV.

Good (direct)

—fire return intervals

(—plant species composition—family level; planned but funds inadequate to conduct analysis)

Moderate to poor (inferred/shallow time depth)

—prehistoric cultural conditions & uses

—insect- & pathogen-related forest disturbance effects (forest health)

—spatial mosaic of fire effects (patchiness and fire intensities)

—stream/spring flows

—forest structure (vertical and horizontal patterns)

Highly speculative

—wildlife distributions, habitat requirements, and population dynamics

—fisheries

—air quality

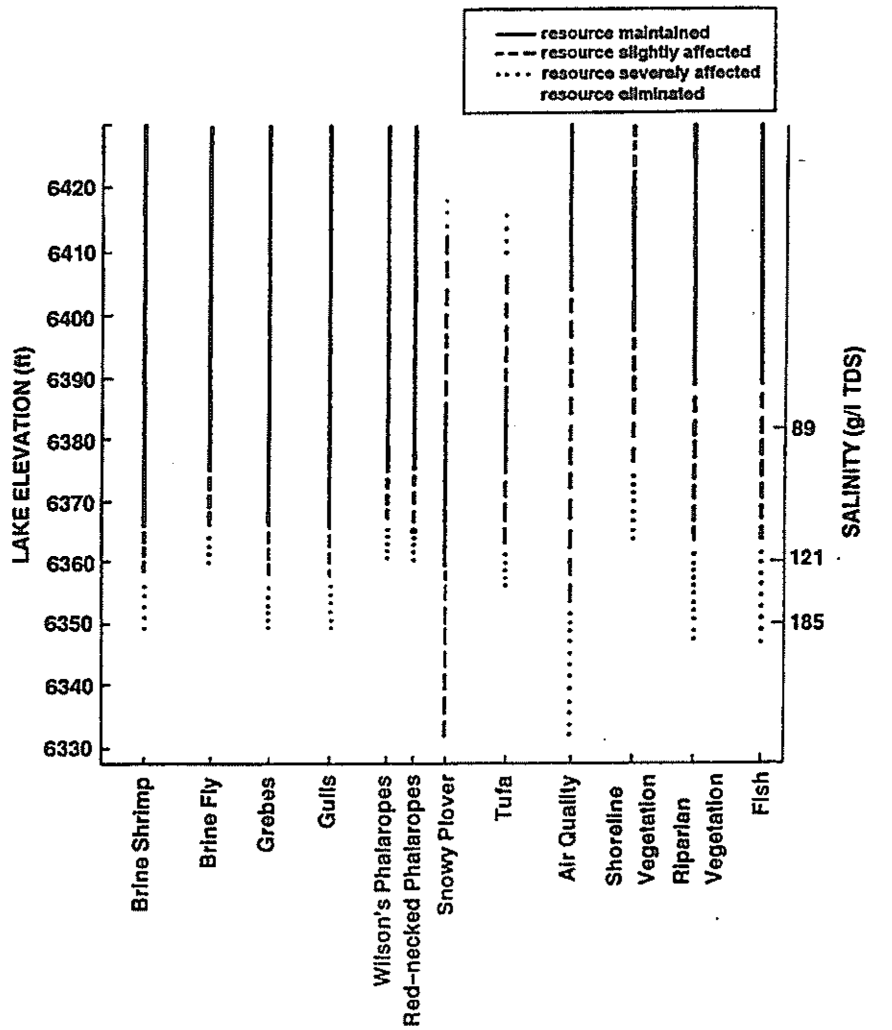

Figure 5. Example of combining multiple environmental indicators into combined DC. Shown are current physiological tolerances; HRVs would likely show a similar pattern. Considering ranges of resources together, a composite DC around 6380-6390 ft was suggested in early Mono Basin deliberations as a sustainable goal. (From: Mono Basin Study Committee 1987.)

5. HOW ARE SOCIAL VALUES INTEGRATED WITH HRV IN DETERMINING DESIRED CONDITIONS?

As mentioned above, I will not take up this important topic except for a brief comment. In determining DC, it will often be the case that social values for individual environmental factors or whole ecosystems are completely outside the HRV. This situation may, for various reasons, be accepted by the decision maker (see examples in Manley et al. 1995), but such cases should be treated as red-flag indicators that significant unforeseen ecological changes may occur.

An example of this is with mountain yellow-legged frog and trout introduced for recreational fishing in the Sierra Nevada. The decline of this high-elevation amphibian native to the Sierra Nevada is linked to predation by introduced fish. Prior to stocking, only a few of the 4000 high Sierran lakes contained native fish; the rest were fishless. Social desire for recreational fishing may overwhelm interests in returning frogs to the lakes, and thus a DC may recommend continued stocking. The decision-maker should be aware not only that this will preclude re-establishment of frogs, but likely lead to further decline and possible extinction for some species, as well as likely impact suites of aquatic invertebrates. The absence of frogs causes ripples in the food chain of which we know little but suspect much (Erman 1996).

Other examples where social values exceed HRV are from the Mammoth-June Case (Box 1),

6. WHAT ARE USEFUL ADAPTATIONS OF HRV CONCEPTS IN ECOSYSTEM MANAGEMENT?

Despite criticisms outlined here, historical information remains one of our most important ecological sources of information for ecosystem planning and management. Without the perspective of spatial and temporal variability in ecosystems, we are merely groping in the dark; we need insights from historical analysis to plan for the future. However, our use of historical information may be more effective with modification. Some of these have been discussed above; others are summarized here.

First is general expectation from HRV analysis. Given the limited relationships of past to future environmental conditions, the nature of ecosystem change, and inaccuracies in describing historical data, a prescriptive use of HRV will often be inappropriate or misleading. Rather than using HRV as a direct set of goals for the future, i.e., tying DC to HRV, it is best to let historic data **inform** the analyst about system behavior and potential management consequences, as was done in the Mammoth-June project (Box 1).

An appropriate use of HRV in planning future management goals and DC is to weight **process** more than **structure**. Emphasis on stems/acre, diameter classes, species diversity/acre, population sizes, etc. in historic analysis and in DC statements puts one in a position to misuse historic data. Rather, emphasis on the role of functions in ecosystems, including disturbance processes of fire, avalanche, insects & disease, flooding, reproduction processes such as mating, establishment, migration, and productivity processes such as decomposition and nutrient cycling will usually be more important. A goal to reintroduce and/or maintain these inherent (historic) ecosystem processes, rather than strictly control ecosystem structures, is more likely to avoid problems associated with uncertainties about ecosystem changes. With this emphasis, structure develops as a response to process rather than being directly prescribed. Further, it is important to remember that ecological processes have variability also. In practice, mean values for processes often become management targets (e.g., mean fire interval lengths), whereas a better approach is to consider their ranges (e.g., range of fire interval lengths).

Emphasizing process rather than structure slightly shifts the underlying approach to management. Rather than attempting to **restore** or **reconstruct** past conditions (by managing within structural HRVs), the goal becomes to **realign** the system to current conditions, trends, and future uncertainties. This shift forces the analyst to start with the ecosystem where it is at present, to identify if possible what ecosystem conditions would have occurred at present without human impact, to recognize that process (presence or absence) is more likely to be a stable factor over time than structure, and to allow process to define the evolving structural conditions for the future.

Other considerations for appropriate use of historical information include: 1) emphasizing environmental indicators that are most amenable to accurate historical analysis, and not trying to speculate on other indicators where information isn't available or is practically unknowable; 2) using appropriate time depths and sample sizes so that HRVs are meaningful; where these cannot be obtained, then clearly declare the limitations on the variance measured; always state time depth and sample sizes for analysis together with HRV (e.g., "a range of historic fire intervals from *a-z* years was determined for a record of *n* trees over *x* years"); 3) develop management goals that fall generally within the intersection of HRVs for multiple indicators rather than single HRVs.

Although DC statements may be written broadly ("habitat for species *x* exists in adequate amounts to maintain current populations"), equally often they emphasize limited views of the future, or very narrow ranges of conditions ("4-6 snags per acre"). This suggests that the possibility of multiple ecosystem pathways, unexpected events, major interactions among elements, and threshold events are not really accepted by managers or the public. DC statements that recognize **ranges** of outcomes and not just **singular** states as acceptable are more realistic.

For indicators where historic information cannot be obtained, the approach to defining a management goal (DC) may be quite different. For instance, in determining goals for forest structure, rather than guess at HRVs, the DC may be (rather than to manage within HRV) to attain healthy, resilient stands that are able to reproduce and withstand regular stresses.

A few other notes about HRV and DC. When environmental elements are far out of HRV (e.g., a century of fire suppression in the west; introduced fish in previously fishless alpine lakes; dammed rivers; exotic plant invasions), realigning the system or moving toward a DC that is more ecologically native may involve intermediate steps that are intentionally outside HRVs. A DC that allows wildfires to burn may involve intermediate fuel reduction steps of thinning harvests, or managed fires at the "wrong" time of year; restoring stream function in incised channels may involve engineering efforts; stabilizing an endangered species may locally disfavor other key species.

Finally, it should be obvious that situations where current conditions exceed HRV do not always call for change or action. There may be many times when current conditions and trajectories are satisfactory, for either ecological or social values, despite being quite different, either in individual element or collectively, from historic conditions. Historic conditions are best considered a yardstick and informant to understanding current and future management.

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BOX 1
THE MAMMOTH-JUNE ECOSYSTEM MANAGEMENT PROJECT

The Mammoth-June Ecosystem Management Project (MJEMP) of the Inyo National Forest, California (U.S. Forest Service 1995a, 1995b), was an early attempt in the Sierra Nevada to follow the new regional landscape-analysis framework for ecosystem management (Manley et al. 1995). Analysis of historic and existing conditions is central to developing desired conditions in the approach. The Sierra Nevada Ecosystem Project reviewed the MJEMP as a case study focusing on the role of historic information in ecosystem management (Millar 1996b). The following is a brief introduction to this project and the lessons learned from it.

Lying between the resort towns of Mammoth Lakes and June Lake, Mono County, CA, the 36,000 acres known as the Mammoth-June (MJ) area are dominated at lower elevations by Jeffrey pine, red-fir, and mixed-conifer forests. Higher elevations rise to cliffs and peaks of the Sierra crest. The MJ area has been the focus of continuing public controversy over developed versus undeveloped uses: grazing, timber harvest, firewood cutting, geothermal development, offroad vehicle use, alpine skiing, nordic skiing, wilderness appreciation, scientific study, and ecological reserves.

The analysis was conducted over three years by an Inyo National Forest interdisciplinary team. The team began by identifying environmental indicators that represented key compositional, structural, and process elements of the MJ landscape (Table 1). Inventories of existing conditions and analyses of historic condition were conducted on these indicators. Time depth for historic 'analyses' varied from a few years to several hundred years. Recorded monitoring information was available for only a few indicators, for example, 7 years of streamflow data. With a few exceptions, assessment of historic condition was stated without a time depth, was very general, and represented vague guesses at how different conditions were prior to human disturbance. Only fire history, and to some degree, historic forest composition, were the result of attempts at quantitative reconstruction.

After completion of data collection and analysis of historic variation, as well as an extended social analysis and public input period, the team developed draft statements of DC for the area. These were developed for two scales of the landscape for the primary vegetation types (example, Table 2) and for specific high-interest areas within these types. The DCs were intended to integrate HRV and social values.

The MJEMP case study demonstrated that historic information, either about a specific time or about the range of conditions over an historic period, is extremely difficult to obtain or measure within the budgets, timelines, and training of national forest staff. Most of the information obtained was highly inferential; mostly qualitative; localized, and extrapolated from point sources (pictures, a few locations); mostly short-range; and mostly shallow in total time-depth. Some quantitative historic data were inferred on fire frequency from fire-scarred trees and snags, but these provided limited spatial resolution and relatively short time depth (Table 4). Historic wildlife distributions were the most speculative variable to assess, being based on estimates of historic forest habitats, historic use of habitat, and historic disturbance.

Lack of localized, detailed, or adequately old historic information forced the MJEMP to proceed with the analysis somewhat differently than prescribed by the regional guidelines. The MJEMP used inferences on historic information to inform the direction but not the detail of what the desired conditions might be; that is, to suggest the general pathway of change brought about by the interaction of desired ecosystem processes. The team did not try, in the DC, to mimic detail of past structure or composition, nor to build the desired condition from highly inferred estimates of historic conditions. Instead, it sought to assure that historic natural processes (e.g., fire, riparian function, water cycles, aquatic functions) would continue or be reintroduced into the MJ landscape, and focused less on promoting exact structure or composition that resembled historic condition. The guiding philosophy of the desired condition was that processes in the future landscape were, for the most part, the same ones that operated under historic conditions. The challenge remained to infer or estimate the rates, forms and magnitudes of these interacting processes.

BOX 1

THE MAMMOTH-JUNE ECOSYSTEM MANAGEMENT PROJECT (continued)

For some elements, the team chose a desired condition that intentionally contradicted the historic condition. For example, the team felt that the continued reintroduction of Lahontan cutthroat trout (a native of eastside streams but not those in the MJ landscape) was desired, although not historic. Further, the team described a desired future fuels condition that recognized the need to avoid catastrophic fire in the vicinity of the town of Mammoth Lakes. Such a condition would probably require active fuels treatment beyond the historic forest condition on the town side of the MJ landscape. Another example favored public preference for high wildflower diversity in the montane Glass Creek Meadow. Historic analysis of this meadow suggests that it was intensively grazed around the turn of the century. Grazing impacts are inferred to have catalyzed a change in plant species composition and abundance, wherein cattle selected and removed grasses leaving niches open for expansion of less forageable species (wildflower species). Thus, the meadow may have been historically dominated by grasses, but altered to have high forb diversity, which is now preferred by recreational hikers. Although with diminished grazing impact the meadow seems to be reverting to a condition of greater grass abundance, this process is slow and may never revert to presettlement condition due to other environmental changes. The management recommendation is to leave the meadow as it is, rather than actively restore conditions within inferred species' HRVs.

The initial planning process for the MJ area, which followed the directions set out in the 1988 Land Management Plan for the Inyo National Forest, called for development of resource thresholds as well as analysis of cumulative effects. As analysis proceeded in the MJEMP, however, it became clear that thresholds had different meanings among team members. The majority interpretation was that thresholds are quantitative values indicating when major and/or rapid changes of state (forest condition, wildlife viability, fish diversity and productivity, water abundance and quality, soil productivity, plant biodiversity) might occur. They maintained that resource thresholds are highly complex, vary with location in the MJ area, season, management activity, adjacent land use, condition of other resources, and changing weather and climate, and have their own HRVs. The team felt that the data it was capable of collecting could not lead to estimation of quantitative thresholds with defensible accuracy. Rather, they suggested that HRVs would generally indicate the bounds of natural thresholds.

Another interpretation held by the decisions makers viewed thresholds conceptually as management limits. To these team members, thresholds represented the best scientific guess at allowable bounds on activities that could be permitted in an area: if a proposed project does not cause a threshold to be exceeded, then a management action or proposed activity could be considered. As interpreted this way, thresholds are simple, static indicators that provide information to managers about resource capabilities in an area, and define defensible decision space.

After debate, the MJEMP analysis team rejected the notion that fixed and quantitative management thresholds could be determined, and even questioned if they exist for resource conditions in the MJ area. Team members willingly discussed the conceptual and qualitative nature of resource variation and extremes, and potential consequences of extending beyond these extremes, but they would not stand behind numeric values that might be interpreted as thresholds. Many feared that such values would become management targets, and that areas might blindly be managed to threshold values. They emphasized instead an adaptive-management approach, whereby ecosystem elements would be observed and interpreted as an ongoing process, and monitoring intensity would be heightened if extreme values were approached, and case-by-case decisions made.

Box 2.
THE MONO BASIN ECOSYSTEM

The Mono Basin ecosystem, and the complex ecological, management, policy, and legal stories surrounding it, are internationally renowned. Mono Lake, located in the high shrub steppe of eastern California, lies in an enclosed basin at the intersection of the Sierra Nevada and Great Basin biomes. Due to the nearly 1-million-year history as a closed basin, the lake has naturally been highly saline and alkaline. Few biota exist in these extreme conditions; the food chain is highly specialized and adapted. The lake's extremely high productivity is critical to migrant waterfowl. The relatively simple aquatic and adjacent terrestrial ecosystem has been the focus of many long-term scientific studies that have elucidated food-chains relationships as well as physiological requirements and niche breadths for individual taxa. Summaries and detailed analyses of Mono Basin science and policy abound (e.g., Winkler, 1977, Stine 1990, 1991, Mono Basin Study Committee 1987, Wiens et al. 1993, Hart 1996).

The Mono Basin has been the center of study and debate primarily because of the intense social issues surrounding it. Four of the major tributaries that feed the lake have been diverted by the Los Angeles Department of Water and Power since 1940. Over the decades, these diversions caused a precipitous decline in lake level (Fig. 6) with attendant dramatic effects on the lake's food chain. The scientific, management, and political activism that ensued over the years is the cumulative result of trying to understand the essential needs of the ecosystem, and arrive at a balanced solution between ecological and social values.

Among the many reasons the Mono Basin story is exemplary for ecosystem management is that it lays bare those analytical issues of ecosystem assessment that are so difficult to sort out in complex terrestrial systems. This is made possible primarily because lake elevation (related to water volume and hence salinity) is an easily measured, reliable proxy for viability of the main taxa in the trophic web. Further, historic water elevations (and thus biotic HRVs) can be determined over recent centuries and millennia, and these can be compared to effects of water diversions. The precipitous drop in lake elevations caused by the diversions over the past 50 years is several times the magnitude of natural changes in shoreline over the last 120 years (Fig. 6), and near the lowest levels of physiological tolerances of the lake biota (Fig. 5).

Viewed over the longer term, however, the elevation at lowpoint during diversions is not outside the HRV, although near in the lowest end of the distribution. The lake has dropped to slightly lower levels during what are known (from other proxies) to be extensive drought periods (Fig. 7). Each of these lowpoints has dipped near to what has been determined to be a critical elevation not only for the biota but for the lake itself. Due to the lake's geomorphologic conditions, at only slightly lower elevations than the historic lowstands, critical deltaic and lacustrine conditions would be lost at threshold proportions.

Of the complex decisions for the lake's preferred level (i.e., DC) that have resulted from decades-long deliberations, considerations were given to:

—HRV of the lake, in both short and long-terms;
—eco/physical consequences of being near the low end of the historic elevations;
—intersection of physiological tolerances and NRVs for salinity, lake levels;
—food chain consequences;
—level the lake would have been at present without diversion.

The recent decision, mediated over by the State Water Resources Control Board (1994), set the goal for the lake level (DC) as 6392 ft. Information about historic fluctuations in the lake level, causes and consequences of these levels, interactions of various elements at different historic periods, physiological tolerances to differing levels, were central in finding the balance between ecological and social values at Mono Lake.

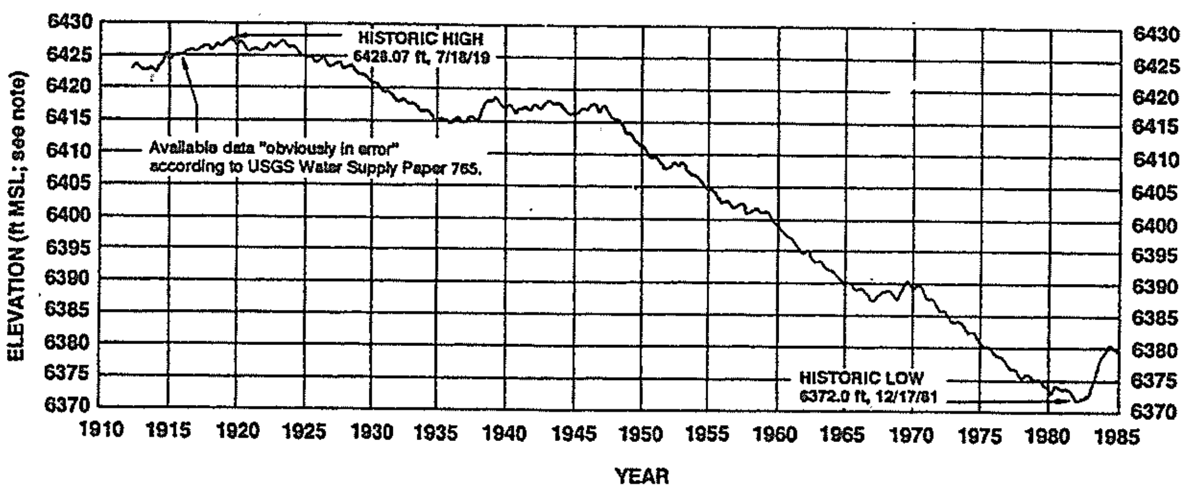

Figure 6. Surface elevations of Mono Lake 1850 to 1985, showing natural decline in lake levels from historic high in 1919, and decline due to water diversions since 1940. Increases in the late 1960s and mid 1980s were due to heavy precipitation that raised the lake level despite diversions. (From: Mono Basin Study Committee 1987.)

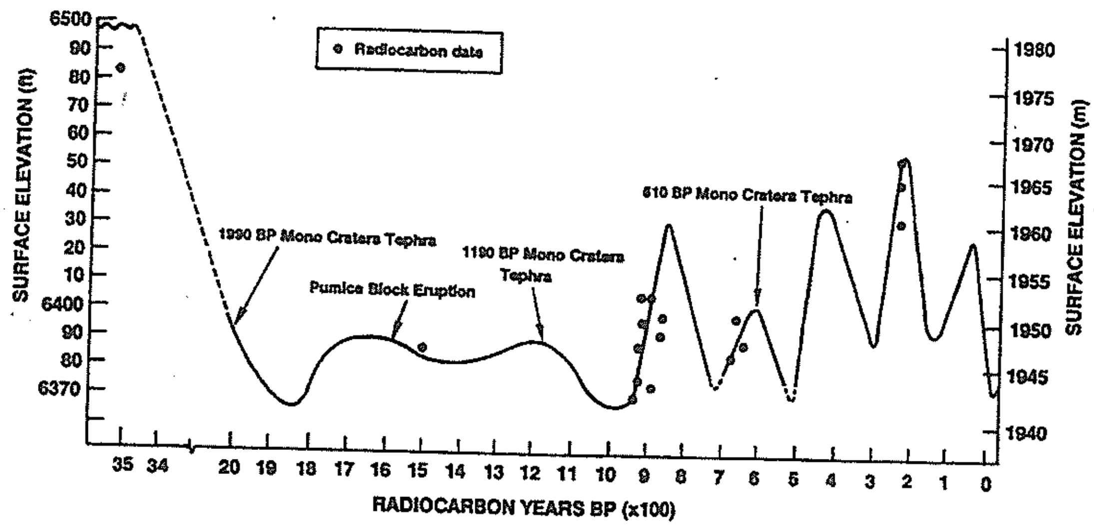

Figure 7. Surface elevations of Mono Lake from 3500 years before present to 1985, showing large fluctuations over century and millenial scales. (In Mono Basin Study Committee 1987.)

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