Publication #372

Applying the Natural Variability Concept: Towards Desired Future Conditions

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Abstract

Natural resource managers increasingly use the natural variability concept in landscape assessment and planning. Also called the historical range of variability, range of natural variation, and reference variability, the concept was developed by applied scientists and managers seeking a legally and politically defensible reference for setting management goals that sustain ecosystems and conserve biodiversity. This coarse-filter approach argues that restoring or managing ecosystems within the bounds of past structure, composition, and disturbance regimes is most likely to sustain the viability of diverse species. In the Interior Columbia River Basin Ecosystem Management Project, a broad regional assessment, departures from historical (pre-European) vegetation composition were used as one of several criteria for identifying areas of low ecological integrity.

Natural variability is defined as "the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal" (Landres et al. 1999). The natural variability concept can be useful for understanding dynamic ecosystems, for evaluating changes in ecosystems over time, for placing priorities on management actions, and for assessing risk and hazard. A comparison of past natural variability, present conditions, and desired future conditions will provide general direction for ecosystem management. When desired future conditions lie outside of past natural variability, people must accept both the costs of sustaining unprecedented conditions and the increased risk of unpredictable and often unacceptable changes in ecosystems. The magnitude of the departure may determine the degree of difficulty and uncertainty that might be associated with attempting to maintain the system outside of its normal limits.

The natural variability concept can be useful in ecosystem management, but it is not a panacea to solve all problems. When information about past conditions is insufficient, when present conditions are substantially different from past conditions, or when management focus is on isolated reserves, it may be inappropriate to use the natural variability concept as a driving force in ecosystem management. If risk

Aldo Leopold Wilderness Research Institute: Publication # 372

CITATION: Parsons, Russ; Morgan, Penny; Landres, Peter. 2000. Applying the natural variability concept: Towards desired future conditions. In: D'Econ, Robert G.; Johnson, Jacklyn F.; Ferguson, E. Alex. Ecosystem Management of Forested Landscapes: Directions and Implementation; 1998 October 26-28; Nelson, British Columbia, Canada. Ecosystem Management of Forested Landscapes Organizing Committee: 222-237.

and hazard associated with past disturbances are socially or politically unacceptable, it may be inappropriate to manage for the full range of natural variability. In many cases, a narrower range of conditions, or management variability, must be defined to guide management direction to decrease the probability of extreme events that defined the range of past natural variability.

Introduction

In recent years there has been increasing interest in developing an understanding of past ecological conditions for use as a reference in contemporary management. A number of terms such as "natural variability," "range of natural variation," "natural range of variability," "historical range of variability," and "reference variability" have been used for the same concept. As some potential exists for misinterpretation of the terms "historical" and "range," we suggest that the phrase "natural variability" is the most clear, and we will refer to the concept in this way throughout this paper. The purpose of this paper is to present a brief review of the natural variability concept, discuss the utility and appropriate use of the concept, and consider its practical application in ecosystem management with specific attention to the relationship between natural variability and desired future conditions.

Brief Review of the Concept

Definition

The natural variability concept is widely used in natural resource management (e.g., Poff et al. 1997; Skinner and Chang 1996; Brown et al. 1994; Gauthier et al. 1996; Ripple 1994) but must be carefully defined and applied to be successful for specific management scenarios. In this paper we define natural variability as: "The ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal" (Landres et al. 1999).

While the concept can also be used to describe variability in ecosystem processes (e.g., fire frequency and severity, flooding, insect infestations), it is perhaps easier to visualize in terms of ecosystem structure. For example, consider natural variability in the geographical extent of a particular type of vegetation such as old, single-story ponderosa pine (Figure 1). Within the spatial bounds of a particular ecosystem, old, single-story ponderosa pine forest may occupy a portion of the total area over time, depending on dynamic factors such as fire frequency and severity, insect infestations, and climatic variability. To adequately represent past conditions, one must consider the range, mean, and standard deviation, as well as other appropriate

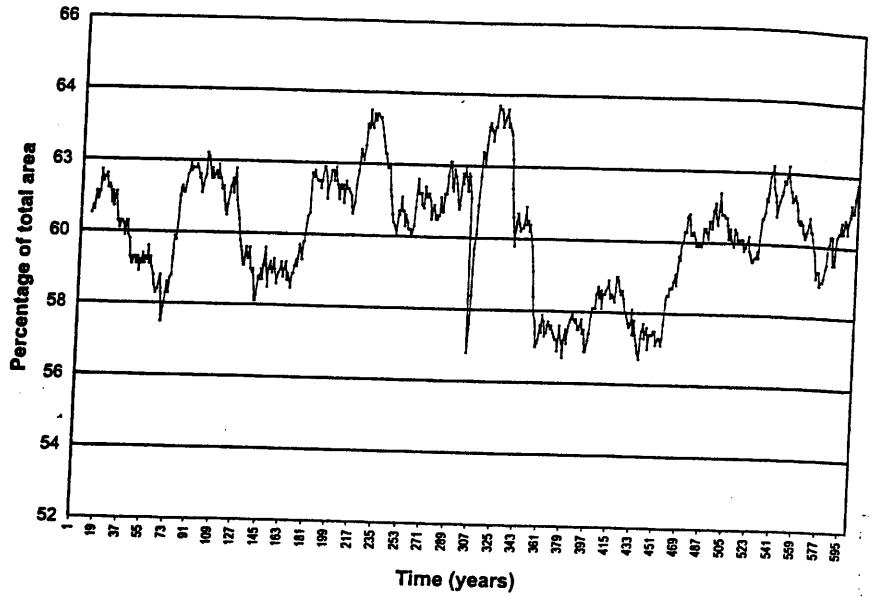

Figure 1. Natural variability over time in the proportion of total ecosystem area occupied by "old growth" ponderosa pine forest (P. Morgan, R.A. Parsons, J. Hauffler, and B. Holt, unpublished data 1998, Natural variability estimates for the Idaho Southern Batholith).

measures, of the percentage of total area occupied rather than the point estimate of area occupied at any given time.

Importance in Ecosystem Management

In today's prevailing climate of litigation, particularly over threatened and endangered species issues, managers need a legally defensible strategy for proactively addressing habitat and population viability. The natural variability concept is a key part of this strategy. This is one reason it is emphasized by United States agencies implementing ecosystem management (Swanson et al. 1993; Morgan et al. 1994; Kaufman et al. 1994; Manley et al.1995; Landres et al. 1999). Developing an understanding of reference conditions is a required critical step in agency protocols for "Ecosystem Management at the Watershed Level" (US Department of Agriculture and US Department of the Interior 1995).

Although the natural variability concept has most commonly been applied when management goals are to restore or maintain historical conditions, it can be useful in almost any management scenario, even when restoration or conservation are not principal objectives. Natural variability is an expression of the natural tendency of a system. Managing natural

systems within the constraints of their natural bounds rather than outside of them will require fewer inputs, because to do so takes advantage of the natural tendency of the system (Allen and Hoeskstra 1992). Thus, even in situations in which the desired condition lies outside the historical bounds, it is useful to know the historical bounds to approximate the departure between desired and historical conditions. The magnitude of the departure will approximate the difficulty that may be encountered in attempting to maintain the system outside of its natural tendency.

The natural variability concept can thus be used for different purposes and towards different management objectives. For this reason, it may provide a common ground for discussion of management issues across ownership boundaries, a key concept in ecosystem management.

Principal Premises Behind the Natural Variability Concept

The natural variability concept is firmly grounded in ecological theory and is based on a number of key premises (Landres et al. 1999):

- Natural variability is a useful reference for evaluating the influence of anthropogenic change in ecological systems including lakes (Smol 1992), commodity production lands (Morgan et al. 1994), and protected areas such as wilderness (Haila 1995).
- Contemporary human influence has diminished the viability of many species adapted to past or historical conditions and processes (Swanson et al. 1994).
- Approximating the variety of historical conditions provides a coarse-filter management strategy that is likely to sustain viable populations of many species about which we know too little (Hunter et al. 1989).
- Working within the bounds of the system as approximated by natural variability is easier, requires fewer external subsidies, and is more cost-effective than trying to sustain unprecedented conditions (Allen and Hoeskstra 1992).
- Analysis over longer time frames and at different spatial scales helps us to understand what constrains and drives ecosystem change (Allen and Hoekstra 1992).
- Disturbances have a strong and lasting influence on species, communities, and ecosystems (White 1979; Sousa 1985) and have been called a "key structuring process" at midscales (i.e., the scale of forest stands) (Holling 1992).
- Variability is important. Reducing spatial variability typically results in declining biological diversity (Petraitis et al. 1989), increased vulnerability to insects, pathogens, or other disturbances (Lehmkuhl et al. 1994), and decreased resiliency to subsequent disturbances (White and Harrod 1997).

Quantifying Natural Variability

Natural variability estimates will be meaningful only if they are developed for well-defined regions with explicit spatial and temporal bounds. The selection of these bounds is extremely important to the overall usefulness of the concept and should be done with great care. Temporal bounds should be defined in such a way as to minimize the influence of long-term climate change (e.g., glacial versus interglacial periods) for the geographic region in question while capturing the natural variability of the conditions being studied. Temporal bounds should be appropriate to management objectives and should consider the degree of past human influence, quality and length of record, presence of exotic species, and known fluctuations in climate. Spatial extent should be determined based on similar factors. As much as possible, natural variability should be assessed for areas over which climatic, edaphic, topographic, and biogeographic factors are relatively consistent (Morgan et al. 1994). In the Interior Columbia Basin Ecosystem Management Project, for example, natural variability was considered within the temporal bounds of the last 2,000 years (Hann et al. 1997), a period in which conditions are believed to have been relatively consistent, both climatically and in terms of Native American influence (Schoonmaker and Foster 1991). Large areas such as regions should be divided into smaller subunits with reasonably consistent biophysical conditions such as subregions (ECOMAP 1993) or potential vegetation types (Hann et al. 1997). Natural variability should then be estimated separately within each subunit.

Once temporal and spatial bounds are defined, it will be possible to quantify natural variability for the area in question. The accuracy and precision of estimates depend on the quantity of data involved, and the degree of confidence data from points and small areas can be extrapolated to larger areas. For example, an understanding of fire history of an area might be built from fire scar and tree ring data at particular locations. As it is rarely possible to develop natural variability estimates based on comprehensive data, some degree of extrapolation or inference will always be involved. For this reason, it is of utmost importance that all assumptions used to construct natural variability estimates be explicitly and carefully stated. Failure to do so may substantially limit the effectiveness and defensibility of the estimates and will obstruct future endeavors to refine them.

Natural variability can be described in a number of ways. For most applications, it is useful to know common statistical estimates of the variables of interest, such as range, mean, median, standard deviation, coefficient of variation, percentiles, and skewness. In analyzing patch dynamics it is useful to describe certain parameters in spatial terms, such as spatial arrangement, sizes and shapes, continuity, and contagion. Disturbance patterns such as fire and flood regimes will need to be described in terms of size and severity, frequency, and spatial distribution.

Range is often used to describe natural variability and to evaluate whether current conditions are beyond the bounds of natural conditions. Different interpretations of the term necessitate that it be clearly explained to avoid confusion. Some researchers may interpret range as a general description of conditions. In statistical terms, however, range refers to the difference between the maximum and minimum values for a given attribute of interest. Extreme events will tend to define the bounds of ecological conditions, but it may be difficult to define spatial and temporal limits for such events. For this reason, we suggest that it is inappropriate to use the range of natural variability *exclusively* as a guide for management decision-making. Range of natural variability will be more useful when considered in conjunction with other parameters such as means, standard deviations, spike values, and trend.

Utility of the Concept

The term *natural variability* has been used in a variety of ecosystems and for a number of purposes, but generally speaking it has been used in two ways: to improve our understanding of ecosystem dynamics and to evaluate changes between the past and the present.

By examining past conditions, we gain an understanding of the processes, driving forces, and overall behavior that characterized a given ecosystem in the past. The natural variability concept has been applied in improving our understanding of old-growth forest ecosystems in the west (Ripple 1994; Camp et al. 1997), mid-west (Mladenoff and Pastor 1993), southwest (Covington and Moore 1997), and northwest (Lesica 1996; Lertzman et al. 1997). It has also been used to better understand processes and dynamics of boreal forest (Gauthier et al. 1996) and of mid-western forest (Baker 1992a). An increased understanding of past conditions can offer insight into contemporary ecosystem conditions.

The natural variability concept has been useful as a framework for evaluating change between the past and the present, particularly in terms of impacts of altered disturbance regimes. In fire ecology, for example, it has been used to evaluate changes in the structure and composition of forest ecosystems resulting from altered fire regimes (Skinner and Chang 1996). In hydrology and limnology, impacts of altered flow regimes have been assessed for the Everglades (Harwell 1997) and for the Colorado River (Poff et al. 1997). It has been used to assess and monitor ecosystem conditions such as eastern deciduous forests (Keddy and Drummond 1996). Such assessments can enable researchers to analyze the type and degree of change and can help identify causes and potential consequences of change. In many cases results of such analyses can be used to direct management. For example, departure from historical conditions has been used to set priorities for management actions (Caprio et al. 1997; Covington and Moore 1994b).

An additional way in which the concept may be useful is in communicating the dynamics of complex ecosystems, a crucial step in developing a common understanding of the behavior of forest ecosystems. An improved understanding of the dynamic nature of ecosystems may help in identifying conflicts between overall ecosystem management goals and specific policies or practices. For example, an understanding that a given ecosystem has a historically higher frequency of fire disturbance may suggest a need for changes in fire management practices (such as increased prescribed burning, understory removal, or limited use of a "let-burn" policy) to manage accumulated fuels.

Appropriate Use of the Concept

The natural variability concept is often viewed as a key concept in ecosystem management. There are conditions, however, in which it may be inappropriate; in such cases, alternative approaches may be more effective.

Circumstances in which the natural variability concept may be inappropriate include the following (Landres et al. 1999).

(1) *When ecosystem functions and components have been substantially altered from historical conditions.* In the sagebrush grasslands of the interior Northwest, a widespread influx of cheatgrass and other exotic annual grasses has greatly altered fire disturbance patterns (D'Antonio and Vitousek 1992). One effect of this change in species composition has been a marked increase in fire frequency to the point that sagebrush, which was maintained because of less frequent fire, is unable to establish itself before the next fire. In the face of increased fire frequency as well as increased competition in growing space, the tendency in the new system is towards elimination of sagebrush and total domination by exotics (D'Antonio and Vitousek 1992), particularly in xeric areas (Tausch et al. 1993). In this case, it is likely that in some areas the system has crossed an essential threshold and can no longer function as before. Crossing such a threshold may result in a new steady state, or relative equilibrium, defined and maintained by its new components and processes (May 1977; Sprugel 1991; Landres 1992; Tausch et al. 1993). When a system has crossed a threshold into a new steady state, it will not naturally return to its former state. Thus it may be inappropriate to apply the natural variability concept until intensive restoration work is done (Wallin et al. 1996).

(2) *When information regarding historical conditions is too limited.* In many cases it is too time-consuming or expensive to get new data. Information on historical spatial patterns is especially difficult to find. If data on historical conditions is insufficient to determine the relationships

between historical components and their functions, the natural variability concept will be of little value. While it may not always be possible to establish quantitative estimates, however, qualitative descriptions can still be valuable.

(3) *When management interest is focused on isolated reserves rather than an entire system.* The natural variability concept is most useful when applied to an entire ecosystem or landscape. In cases in which management interest is restricted to a small fraction of the former landscape, such as an isolated nature reserve in a matrix of agricultural land, it may be unreasonable to assume that all ecosystem processes are intact, even if the protected area in question is apparently unchanged. In extreme cases, conditions within the reserve will be largely influenced by conditions outside the reserve (Saunders et al. 1991). The influence of the surrounding matrix on the reserve will depend on its spatial extent and arrangement and on the relative differences between them (Saunders et al. 1991). Although reserves have traditionally been designed to provide habitat for particular species, they have rarely been designed to include the range of past disturbances, as well as other ecosystem processes (Baker 1992b). Therefore caution should be exercised when applying the natural variability concept to small areas rather than to the whole ecosystem upon which the concept is based.

(4) *When risk and hazard associated with historical ecosystem behaviour is socially or politically unacceptable.* When disturbance events known to have occurred under historical conditions are socially or politically unacceptable (e.g., large floods or catastrophic fires), it may be inappropriate to use the natural variability concept to guide management direction. Other approaches to landscape management will be needed. The natural variability concept, however, may continue to be useful as a component in a management strategy, particularly in assessments of risk and probability of extreme events.

Practical Application: Natural Variability and Desired Future Conditions

As noted above, the concept of natural variability improves our understanding of ecosystem dynamics and provides a framework for comparison between past and present conditions. This comparison can be extended to include desired future conditions, an expression of target conditions preferred by decision makers.

Visualizing Natural Variability and Desired Future Conditions

Past natural variability, present conditions, and desired future conditions can perhaps be best visualized as a plate, a ball, and a bowl (Figure 2). The

range of past conditions, or natural variability, can be considered as a flat surface (the plate) upon which current conditions (the ball) move around owing to the influence of dynamic factors and processes. The plate represents our best estimate of the natural variability of the system in the past; areas outside the plate could be defined as conditions that do not characterize the system in question. Thus, if current conditions (represented by the ball) are forced out of the bounds of the system, rapid and unpredictable change may result. This is analogous to the ball falling off the plate and bouncing in an unknown direction. In some situations the edge of the plate may have very real meaning in that, once conditions leave the known territory of past variability, they may cross a threshold over which return cannot be easily accomplished without intensive management action. Such a phenomenon is theorized to occur when there is a substantial change in species composition and ecosystem function because of invasion by aggressive exotics (Tausch et al. 1993). For example, in forest stands in which blister rust (*Cronartium ribicola*) has eliminated most of the white pine (*Pinus monticola*), Douglas-fir (*Pseudotsuga menziezii*) and grand fir (*Abies grandis*) have increased in abundance. This shift in species composition causes changes in ecosystem function because of higher susceptibility to root disease and differences in efficiency of water use (Byler et al. 1994).

In many cases, past conditions may have exhibited substantial variability. This variability could be represented with a very large plate or platter. Extreme events that defined the range of past variability such as rare, landscape-scale catastrophic fires or floods may be socially or politically unacceptable today. While such events may for all purposes be outside management control, target conditions can still be framed in such a way as to attempt to

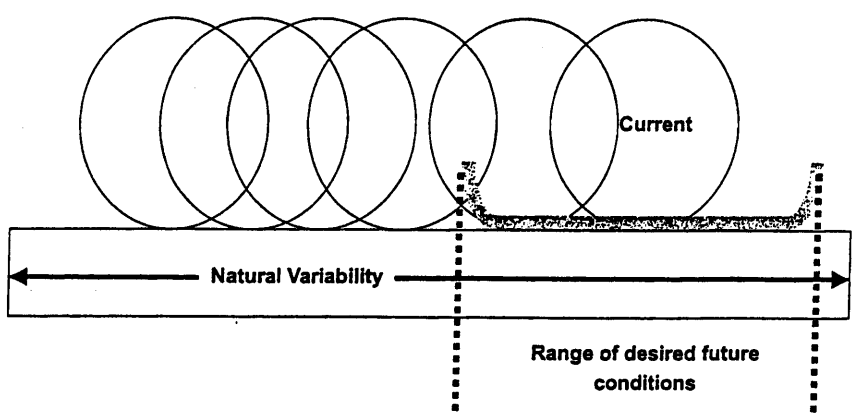

Figure 2. Visualizing natural variability, present conditions, and desired future conditions.

minimize them. Manley et al. (1995) recommend using a subset of the full range of natural variability, or "management variability," as a more practical method for applying natural variability concepts. Management variability will contain the range of permissible desired future conditions. It can be visualized as a bowl in which current conditions continue to move around, but with less total variability than in the past. Setting management targets as a subset of natural variability may allow managers to minimize extreme events while still maintaining ecosystem function.

Using Natural Variability to Guide Management Direction

A comparison of past conditions (characterized by natural variability), present conditions, and desired future conditions can clarify overall management direction (Figure 3). When desired future conditions lie within the bounds of past conditions, as is the case in most wilderness areas and national parks, two general management directions exist. When present conditions are within the bounds of natural variability for the system, management

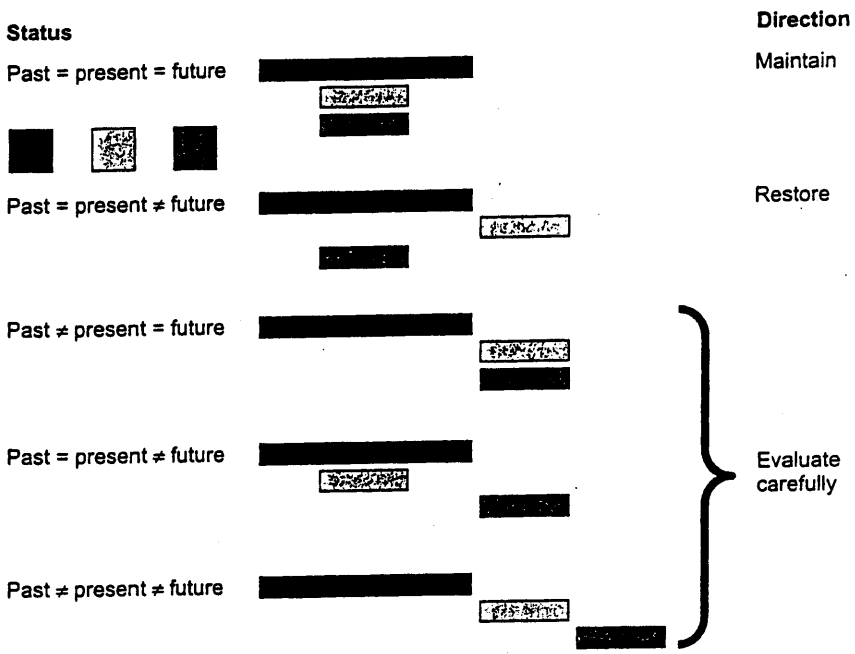

Figure 3. Comparison of past natural variability, current conditions, and desired future conditions and possible combinations of the three. The width of the bars represents the range of conditions for a given variable. Management direction can be clarified by a comparison of the three conditions. For those desired future conditions that lie outside the bounds of the system, the relative departure from past conditions may represent the degree to which unknown and potentially undesirable effects can be expected (from Landres et al. 1999).

direction should be to maintain the system in its current state. When present conditions are outside the natural variability, management direction should be to restore past conditions.

Although maintenance or restoration of past conditions are common management objectives, they are not the only possibilities. In many cases, desired future conditions will lie outside the bounds of natural variability, often for important social or economic reasons. For example, most modern commercial agriculture falls into the realm in which desired future conditions equal present conditions but are different from past conditions (Figure 3). We are able to maintain conditions outside the range of past conditions only through external inputs such as fertilizers, pesticides, and mechanical manipulation (e.g., tillage practices). It is possible as well that desired future conditions may be wholly different from either past or present conditions, such as the conversion of arid lands into reservoirs or golf courses. In these cases, while it is unlikely that components and processes of the original system will be maintained, the natural variability concept can be useful in clarifying the types and magnitudes of external inputs required to maintain the system outside its typical range.

Consider as an example the interior ponderosa pine forest of the western United States. In the past this forest type was characterized by frequent, generally low-intensity surface fires (Covington and Moore 1994a; Morgan 1994). Excluding low-intensity surface fires from the ponderosa pine forests of the inland West has resulted in unnaturally dense stands. These stands, having more ladder fuels and dense canopy cover, are substantially more vulnerable to stand-replacing fire than in the past. Such changes have so altered ecosystem structure and function that catastrophic fire now threatens the sustainability of the forest ecosystem in some places (Covington and Moore 1994a, 1994b). Comparisons of spatial patterns of fires in the southwestern United States have shown that current average fire sizes are three to six times larger than those occurring prior to settlement by Euro-Americans (Barrows 1978; Sweetnam and Betancourt 1990). Habitat for wildlife species such as the flammulated owl (Morgan 1994), northern goshawk, and other species (Covington and Moore 1994a) may be at risk. Current conditions thus lie outside the range of past natural variability.

Returning briefly to our plate, ball, and bowl, the ball is outside of the plate. The issues of catastrophic fires and potential species loss in this forest type are analogous to the uncontrolled bouncing of the ball outside the normal bounds of the system. If management objectives are to restore this forest to its past conditions, fires should be a part of management practices to support and maintain ecosystem processes and species dependent on fire disturbances.

If management objectives are to maintain the system in its current state, it will be necessary to accept the costs (external subsidies) and consequences (potential impacts) associated with maintaining the system outside of its normal range. Costs will include those for higher fire suppression; consequences will include potential long-term damage to streams, soils, aesthetics, commodity production, and higher risk to property and human safety due to increasingly likely crown fires (Covington and Moore 1994b). Thus, unless strong justification can be made for desired future conditions outside of the system bounds, management direction should attempt to restore past system conditions. This could include active management practices such as thinning from below, prescribed fire, and periodic tree harvest (Keane et al. 1990). The shape and bounds of the bowl, or range of desired future conditions, will be defined by the collective effect of the different management actions.

It is important to note that natural variability does not provide a step by step set of instructions for managers. It can be used to guide general management objectives, or overall policy, but not to define what a desired condition might be nor the detail of how to achieve such a condition (Millar 1996). Identifying desired future conditions and the means for achieving them should be based on operational, economic, and social realities of the management region in question. Haufler et al. (1996) recommend balancing human needs with those of other species by choosing desired future conditions that depart from natural variability only where needs of other species are met. Spatial allocation of such needs, such as setting aside some areas for particular purposes, offers one way to resolve conflicts.

Setting Priorities on Management Actions and Evaluating Risk

In addition to its potential use in identifying overall management direction appropriate to specified management objectives, the natural variability concept can be used in other ways. When natural variability estimates are made for a geographic region, the types, severities, and frequencies of disturbances are described. This information can be manipulated to systematically place priorities on management actions and evaluate risk and hazards caused by fire disturbance. At Sequoia and Kings Canyon National Park in California, for example, current conditions were compared to historic fire regimes to generate a map of departures, quantified as multiples of the natural fire return interval. This information was then used in conjunction with locations of important resources and areas of high visitor frequency to set priorities for management actions such as prescribed burns (Caprio et al. 1997). Information on the spatial distribution of fire origins was used to generate a probability-based risk assessment to classify geographic areas by likelihood

of fire starts (fire risk), which could then be evaluated in terms of potential difficulty in fire suppression (fire hazard) (Caprio et al. 1997).

Conclusions

The natural variability concept has developed from several different disciplines toward a common need for coherent management direction across ownership boundaries and for different management objectives. Because of its interdisciplinary origins and flexible application, it is increasingly useful in ecosystem management. In addition to generating increased understanding and better communication of the dynamics of natural systems, it is useful in providing general direction to management and in assessing risk and hazard.

A certain danger exists with this tool, however. Because of the wide flexibility and generality of the concept, the potential exists for misapplication. It is highly recommended that users critically examine the situation to which the natural variability concept is to be applied. In some cases, the natural variability concept will be of limited use, particularly when present conditions are substantially different from those in the past or when information on past conditions is insufficient. If managers decide to use the natural variability concept, we recommend that the geographic and temporal extent used to define natural variability be thoroughly researched and carefully assigned and that assumptions used in building the estimates be explicitly stated so that their merits and impacts can be evaluated.

Acknowledgments

We appreciate financial support from the University of Idaho and the Boise Cascade Corporation.

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