Developing an Ecological Foundation for Management of National Forest Giant Sequoia Ecosystems

by

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Abstract: A strategy for the protection, preservation, and restoration of national forest giant sequoia groves is being formulated using a conceptual framework for ecosystem management recently developed by Region Five of the USDA Forest Service. The framework includes physical, biological, and social dimensions. The array of ecosystem elements and their associated environmental indicators within each of these dimensions is almost endless. Key ecosystem elements, environmental indicators, and reference variability are discussed in this paper. These key elements and associated indicators are thought to be adequate to define and control management activities designed to protect, preserve, and restore national forest giant sequoia groves for the benefit of present and future generations. The key ecosystem elements selected for practical application are: 1) attitudes, beliefs, and values; 2) economics and subsistence; 3) stream channel morphology; 4) sediment; 5) water; 6) fire; 7) organic debris; and 8) vegetation mosaic. Recommendations are made for the attributes of environmental indicators that characterize these elements.

This paper is condensed from a more detailed analysis titled “An Ecological Foundation for Management of National Forest Giant Sequoia Ecosystems” (Piirto and Rogers, 2000).

Giant Sequoia Management in the USDA Forest Service

Introduction

Since their discovery by settlers in 1852, giant sequoia trees (and *Sequoiadendron giganteum* [Lindl.] Decne.) *Sequoia gigantea*[1] have fascinated people throughout the world (Figures 1 a,b). Early exploitation by commercial interests led to many laws and administrative decisions designed to protect the groves where these magnificent wonders of nature are found (Piirto, Rogers, and Bethke 1997, and Tweed 1994).

In 1990 the Sequoia National Forest was party to a mediated settlement agreement (USDA Forest Service 1990) which established goals for giant sequoia management: to protect, preserve, and restore the groves for the benefit of present and future generations. In 1992 President Bush issued a proclamation that indirectly validated these goals and made them national in scope. Of the approximately 75 naturally occurring giant sequoia groves (Figure 2), 43 are found on national forests; most of the remainder are found in national parks (Rundel 1972a, Willard 1995, Rogers 1998). Portions of nine groves are in private ownership. All of the naturally occurring giant sequoia groves are found on the west slope of the Sierra Nevada mountains in California.

Management Goals

Although the mediated settlement agreement (USDA Forest Service 1990) does not elaborate on the meaning of protect, preserve, and restore, the presidential proclamation (Bush 1992) does provide a context from which meanings useful for management purposes can be derived. In the proclamation President Bush declared: "Naturally occurring old-growth giant sequoia groves... are unique national treasures that are being managed for biodiversity, perpetuation of the species, public inspiration, and spiritual, aesthetic, recreational, ecological, and scientific values." Among other things, he proclaimed: "The designated giant sequoia groves shall be protected as natural areas with minimum development."

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[1] The common name, giant sequoia, and the scientific name, *Sequoia gigantea* (Lindl.) Decne., rather than *Sequoiadendron giganteum* (Lindl.) Buchholz, will be used in this paper. Justification for this is documented in Davidson (1972) and Piirto (1977).

Scope and Context of this Paper

Common sense and ecological literature (Fullmer, et al. 1996) suggest the goals of protect, preserve, and restore are not independent of each other. Restoring giant sequoia ecosystems to conditions that resulted from centuries of adaptation to their environment appears to be the best way to protect them in the present, and to assure their preservation (or more appropriately, perpetuation) in the future. This paper provides a scientific foundation upon which management decisions affecting these goals can be based. The foundation is developed in five steps:

1. **Define the ecosystem management process** as it applies to national forest giant sequoia groves. Ecosystem management combines the social, physical, and biological dimensions of the environment in a holistic way that is particularly appropriate to the goals described above.
2. **Identify elements that are key to the function of giant sequoia ecosystems.** This is the second step of the ecosystem management process. It identifies processes (i.e., fire and water), components (e.g., plant species), and structures (arrangement of components) that are important in characterizing giant sequoia groves.
3. **Identify indicators** of the key elements.
4. **Describe how measures of those indicators can vary** within naturally functioning giant sequoia ecosystems.
5. **Provide practical guidance on how to apply the principles** developed above. This is the context, along with certain qualifications, that is necessary for the practical application of the principles developed in this paper.

Ecosystem Management in the US Forest Service

Forest vs. Ecosystem Management

Forest management helps people achieve their goals for forests. It seeks to produce results that meet landowner expectations, whether the owners are public or private. Leuschner (1984) states: "Forest management in the broadest sense, integrates all of the biological, social, economic, and other factors that affect management decisions about the forest." As defined by Manley et al. (1995) ecosystem management is "the skillful, integrated use of ecological knowledge at various scales to produce desired resource values, products, services and conditions in ways that also sustain the diversity and productivity of ecosystems. This approach blends the physical, biological, and cultural/social needs" (Figure 3).

There appears to be no difference between the two approaches to the management of wildland natural resources, at least at the philosophical level. So, if the concept of ecosystem management brings anything new it is simply a reminder that all the elements of an ecosystem are interconnected, and viewing them otherwise leads to faulty assumptions about the consequences of management actions. Former Chief of the Forest Service, Dr. Jack Ward Thomas, expressed this thought when he said: "It is time to consider land use in a broader context than a series of single-use allocations to address specific problems or pacify the most vocal constituencies" (Thomas 1993).

Concepts of Ecosystem Management

Rhetoric abounds, but literature describing the actual practice of ecosystem management is scant. Manley et al. (1995) is a pioneering effort by field-oriented practitioners to put the concepts of ecosystem management to work on the ground. The result is a practical process for implementing ecosystem management in a well defined and systematic way. The process deals with five basic conceptual questions: 1) How did the ecosystem evolve? 2) What is sustainable? 3) What do we want (within the limits of sustainability)? 4) What do we have? 5) How do we move conditions from what we have to what we want?

These questions change the focus from output driven project planning which asks: "What do we need to mitigate because of our actions?", to outcome driven planning which asks: "What do we want to create with our actions?"

The process developed by Manley et al. (1995) involves 14 steps to be applied at the landscape level:

Step 1--select a landscape to analyze

Step 2--select key ecosystem elements and their environmental indicators

Step 3--derive recommended management variability for the indicators

Step 4--define desired condition

Step 5--determine existing condition

Step 6--compare desired condition to existing condition

Step 7--identify opportunities to approach desired condition

Step 8--list potential projects (possible management practices)

Step 9--project selection, prioritization, and scheduling

Step 10--NEPA Analysis and disclosure

Step 11--line officer decision

Step 12--project implementation

Step 13--monitoring and feedback

Step 14--possible forest plan adjustment (adaptive management).

These steps finally provide a systematic and administratively feasible approach to ecosystem management.

Connecting Science to Ecosystem Management

Sustainable ecosystems require that the integrity of their components, structures, and processes (the three general types of elements) be maintained through time and space. This requires a reasonable understanding of how these ecosystems evolved and developed into their present state. Landscape conditions within all ecosystems are dynamic, thus measures of their elements change over time and space, but within certain limits. An understanding of this "range of variability" is critical to ensuring the sustainability of these ecosystems. Science will play a key role in providing that understanding (Piirto, Rogers, and Bethke 1997).

Selecting Key Ecosystem Elements

Ecosystem management in Region 5 of the USDA Forest Service is guided by the concepts and principles established in "Sustaining Ecosystems - A Conceptual Framework" (Manley et al. 1995). This work includes a lengthy list of ecosystem elements that could be helpful in defining and controlling the management actions in national forest giant sequoia groves. Many others could be added to the list, but if all were used in practice the administrative task would become hopelessly complex. It is therefore necessary to concentrate on just the "key" ecosystem elements (Holling

1992). These are the ones that broadly represent the ecosystem, are influenced by management decisions, and are reasonably well understood (Figure 3).

Key elements were chosen from the list of ecosystem elements supplied by Manley et al. (1995) with supplementation from various other sources. Piirto and Rogers (2000) describe the rationale with which key elements were selected from the Atmospheric, Cultural/Social, Hydrologic, and Terrestrial hierarchies. For giant sequoia ecosystems the selected key elements are shown in Table 1.

Environmental Indicators

Once key ecosystem elements are identified, the next step is to determine what environmental indicators will be used to assess them. From a practical administrative point of view the selected indicators should be affected by management actions, change over relatively short periods of time, be feasible to measure either directly or indirectly, and be useful in describing desired conditions. Of the many environmental indicators recognized by Manley, et al. (1995), only a few appear to meet all of these criteria. Piirto and Rogers (2000) describe how the environmental indicators summarized in Table 1 were chosen.

Reference Variability

Environmental indicators are to an ecosystem manager what an engine temperature gauge is to an automobile driver. Environmental indicators are a measure of ecosystem performance, and they often warn of danger at the extremes of their range. Just as the automobile engine temperature can range from below freezing on a cold day to the boiling point of the engine coolant on a hot one, environmental indicators also range between extremes. This range is referred to as reference variability, natural range of variability, or historic range of variability.

Manley et al. (1995) elaborate as follows: "Reference Variabilities represent the full distribution of values for environmental indicators including infrequent and extreme events (e.g., severe floods, high intensity wildfires, etc.). The role of these more extreme disturbances in maintaining ecosystem processes is not well understood, but their importance for biological elements is a well-accepted notion." A desirable and more closely defined operating range is usually found between the extremes. This range is referred to as the recommended management variability (RMV). Again Manley et al.

(1995) elaborate: "The entire Reference Variability distribution is important and should be realized, for biological elements, over long-term, evolutionary temporal scales. However, planned management activities should not normally seek to replicate extreme values of the distribution if they will occur naturally." Under most conditions, properly designed and executed management actions should be able to maintain environmental indicators within the RMV, and by so doing minimize the risk of extreme events that would jeopardize ecosystem sustainability and resiliency (Figure 4).

The recommended management variability for any ecosystem must take into account the influence of climate on forest community development (Patterson and Prentice 1985). Over long periods of time climates do change dramatically. However, even with similar climate regimes there is substantial variation in the composition within and between the giant sequoia groves. Stephenson (1996) states in the context of the biological dimension: "...It therefore seems reasonable to conclude that a variety of different grove structures, not a single predictable grove structure, probably occurred during periods that shared similar climates." Such variation can also be expected in the cultural/social and physical dimensions as well.

Indicators for the key giant sequoia ecosystem elements are discussed in detail in Piirto and Rogers (2000). Because the vegetation mosaic is of paramount importance to both users and managers, indicators for it will be discussed here.

Vegetation Mosaic Ecosystem Element

The vegetative pattern in giant sequoia groves is made up of a variety of gaps and patches. Many authors recognize this mosaic pattern as being an important attribute of the groves (Bonnicksen and Stone 1981, 1982 a,b; Stephenson et al. 1991; Stohlgren 1993 a,b). Huntington (1914) noted that giant sequoia trees generally grow in groups of a half a dozen trees of the same age forming a circle. Stephenson et al. (1991) report that the Parker, Senate, House, and Founders groups in Giant Forest range in size from 0.1 hectares (0.25 acres) to 0.2 hectares (0.5 acres) with 5 to 20 large giant sequoia trees of similar age. They further report that the largest cohort of giant sequoia regeneration caused by prescribed fire in Sequoia and Kings Canyon National Park is about 4 hectares (10 acres) with patchiness of giant sequoia regeneration being a function of patchiness of fire disturbance. The distribution of other vegetation follows a similar pattern. Bonnicksen and Stone (1981, 1982 a,b) report that existing aggregations in Redwood Mountain Grove range in size from 135 to 1600 square meters (0.03 to .395 acres) with most overstory aggregations generally less than 800 square meters (0.20 acres).

The forest mosaic as depicted by Bonnicksen (1982 a,b and 1993 a,b) is illustrated in Figure 5. The boundaries of gaps and patches in giant sequoia groves are characterized as being diffuse, often without sharp edges with many gaps having living trees that survived the effects of fire disturbance (Demetry and Duriscoe 1996). This is important in that restoration work must focus both on gap and patch development and vegetation condition within the adjacent matrix areas. It is critical to realize that in the natural or "ancient" forest only a few patches (on the scale of a fraction to a few acres) may be dominated by large, old trees. However, large, old trees will be scattered throughout the forest matrix (on a scale of hundreds of acres) giving the entire landscape an "old growth", "ancient forest", or "late seral stage" character.

Gap and patch size indicator.

Demetry and Duriscoe (1996) studied fire-caused gaps as part of the research needed for ecological restoration of Giant Forest Village in Sequoia National Park. They analyzed the vegetation response in 18 gaps of three different sizes that were created by prescribed fire within the last 15 years. The gaps ranged in size from 0.067 hectares (0.16 acres) to 1.17 hectares (2.89 acres).

Stephenson et al. (1991) and Stephenson (1994) reported even-aged patches ranging in size from 0.03 to 0.4 hectares (0.08 to 1.0 acres). The minimum size of gap leading to successful recruitment of giant sequoia appeared to be around 0.1 hectares (0.25 acres), to the nearest order of magnitude. Gaps larger than 10 hectares created by avalanches or single or repeated fires are reported as being a rare occurrence within most presettlement giant sequoia groves (Fry 1933, 1948; Stephenson et al. 1991; Caprio et al. 1994; Stephenson 1994, 1996).

Stephenson (personal communication: 1998) speculates that perhaps two thirds of all gaps in presettlement times were less than one half acre in size. Based on work in the Redwood Mountain

Grove, Bonnicksen (1993 a,b) states that even-aged groups of trees in ancient forests were generally less than 0.2 acres in size. However, the gaps from which these groups developed were probably larger than that (Stephenson 1987). Available information suggests that most gaps created by natural causes within giant sequoia groves probably ranged from 0.1 to 3 acres in size as shown in Figure 6. This figure is constructed from an estimate of presettlement distribution of gaps of different sizes based on work by Stephenson (personal communication: 1998) and Bonnicksen and Stone (1978, 1982a).

Recommendation

Most gaps and patches of vegetation that arise from them, should be on the order of 0.2 acres. The recommended management variability should range from 0.1 to 2.0 acres (Figure 6).

Gap and patch frequency indicator.

No empirical data exists to verify the exact amount of area within a giant sequoia grove that was disturbed during any given period in presettlement times. However, some clues to this question can be gained from Bonnicksen and Stone's (1982 a,b) work. They estimated that in 1890 the Redwood Mountain Grove contained 7 percent of the area in aggregations dominated by bare soil (gaps), 6 percent grass and forbs, 10 percent seedling trees (trees less than 3 meters in height), 19 percent brushland, and 17 percent saplings (trees between 3 and 10 meters in height). These conditions suggest that about 13 percent of the area was subject to recent disturbance (the bare soil, grass and forb aggregations). Stephenson (personal communication: 1998) suggests gaps created within a given decade probably occupied significantly less than 10 percent of the landscape. This is consistent with the 7 percent bare soil area estimated by Bonnicksen and Stone (1982 a,b). Bonnicksen and Stone (1982 a,b) also estimate that 15 percent of the area was dominated by pole-size trees (trees between 10 and 35 meters in height), 9 percent by mature trees (greater than 35 meters in height but less than 1.2 meters in diameter breast height), 10 percent by large mature trees (greater than 35 meters in height and greater than 1.2 meters in diameter breast height), and 7 percent was occupied by rock or unclassified vegetation (Figure 7).

Recommendation

- Recently created gaps in the forest canopy (less than 10 years old), other than sites with unproductive soils, should occupy 1-10 percent of the grove area.
- Early seral stage patches (vegetation 10-20 years old) should dominate on 30-40 percent of the grove area.
- Mid-seral stage patches (20-150 years old) should dominate on 40-50 percent of the grove area.
- Patches of late seral stage vegetation (greater than 150 years old) should dominate on 10-20 percent of the grove area.

Consideration should be given to the fact that gap and patch boundaries tend to be diffuse and that remnants of seral stages other than the dominant one can occupy portions of a gap or patch. There can be "young" understory vegetation in late seral patches, and "old" overstory in early seral patches, and various other combinations within a given gap or patch.

Plant community indicator.

According to Rundel (1971) giant sequoia groves are differentiated from adjacent mesic habitats in the mixed conifer forest only by the presence of giant sequoia. Other plant species in giant sequoia groves probably vary in abundance in response to the same conditions that promote the giant sequoia. Pacific dogwood *(Cornus nuttallii)*, for example, is a moisture-loving plant. It frequently seems to be more prevalent in giant sequoia groves than the surrounding forest. It appears that there have been no changes in the dominant trees species present in giant sequoia groves when compared to presettlement times, but there have been dramatic changes in density, age structure, and the overall vegetation pattern (Stephenson 1996).

There is general agreement that the absence of fire in most of the giant sequoia groves has resulted in an increase of white fir, reduced regeneration of giant sequoia and pines, and reduced density of shrubs and hardwoods (Hartesveldt and Harvey 1967, Kilgore and Taylor 1979, Harvey et al. 1980, Bonnicksen and Stone 1982 a,b). Bonnicksen and Stone (1982 a,b) found that the proportion of the area occupied by conifer aggregations has increased from 49 percent in 1890 to 63 percent in 1977. The number of aggregations dominated by white fir increased from 27 percent in

1890 to 37 percent in 1977. However, Bonnicksen's work has been criticized by Stephenson (1987) who points out a probable bias toward underestimating the amount of white fir in 1890, particularly in the overstory.

Considerable information is available on tree stocking density for the mixed conifer forest in general (Dunning and Reineke 1933), but little is available for how it combines with the giant sequoia component within giant sequoia groves. Stephenson (1994) discusses age distribution and Stohlgren (1991, 1992, 1993 a,b) discusses basal area and tree distribution of giant sequoias within selected groves. Rundel (1971) provides valuable information on basal area and frequency of occurrence by major tree species within groves. All of these studies are contemporary; the data include changes that have occurred during the past 100-150 years of "settlement". Nevertheless, they do provide a basis for speculating on how the presettlement groves may have been structured.

Stohlgren's data (1991), for example (Figure 8), shows that over 90 percent of the existing giant sequoia basal area is in trees larger than about 60 inches in diameter. Trees of this size were almost certainly well established at least 100 years ago, and probably persisted with about the same mortality that would be expected even with the periodic low intensity fires of presettlement times. Thus, except for perhaps 10 percent of the total basal area, contemporary basal area distribution for giant sequoias appears to be a reasonable representation of the presettlement distribution. For the part of the range that represents structure development during settlement times, one can speculate that the basal area in larger trees (say between 30 and 60 inches in diameter) probably over-represents presettlement times because these trees did not experience significant thinning by fire. On the other hand basal area in the smaller trees is probably under-represented because seedlings were not being established in the undisturbed, closed canopy forest (Stephenson 1994).

Rundel (1971) provides data on basal area distribution (relative dominance) by species in four groves. However, these data may not give a close approximation to presettlement conditions because, compared to giant sequoia, less of the mixed conifer basal area persists from presettlement times. Willard (1995) provides anecdotal data that helps with the interpretation of mixed species within giant sequoia groves. He analyzed 23 sets of cruise data taken in five groves between 1908 and

1936. (All but five of the sets were taken in 1908.) Giant sequoia ranged from 57 to 87 percent of the total merchantable board foot volume, the average being 73 percent. Although cruise procedures are unknown it is almost certain that the basal area proportion of giant sequoia was less than the cruise proportion. This is because cruise volume is a function of basal area times height, and the giant sequoia trees that account for most of the basal area are taller than most mixed conifers. Thus for the same volume, giant sequoias require less basal area than the mixed conifers. Some of this difference, which could be on the order of 40 to 50 percent, could be offset by breakage estimates used by the cruisers. They surely estimated greater breakage, and hence a proportionally lower net volume, than in the mixed conifers. If Willard's giant sequoia volume proportion is reduced by, say, 10 percent to compensate for giant sequoia height and breakage differences, Willard's data corroborates Rundel's very well. Rundel's (1971) data on four groves averages 65 percent dominance (basal area) for giant sequoia, Willard's (based mostly on 1908 data) would estimate 63 percent on average. Surprisingly, it appears that contemporary relative dominance by species is similar to presettlement times. This probably is not true for the mixed conifer forest in general where there has been significantly more disturbance. However, even here McKelvey and Johnston (1992) estimate only a 10-20 percent shift toward white fir dominance.

However, the same cannot be said about relative density (numbers of trees per acre). In contemporary groves Rundel (1971) shows that giant sequoias number between 5 and 11 percent of the total trees present, with white fir making up between 54 and 85 percent of the total. Many scientists suggest that there were many more young giant sequoias and fewer white fir trees in presettlement times (Hartesveldt and Harvey 1967, Rundel 1971, Kilgore and Taylor 1979, Harvey et al. 1980, Bonnicksen and Stone 1982 a,b). Muir (1961) corroborates this suggestion with anecdotal observations such as: "On a bed of sandy ground 15 yards square, which had been occupied by four sugar pines, I counted ninety-four promising seedlings, an instance of sequoia gaining ground from its neighbors. Here also I noted eighty-six young sequoias from 1 to 50 feet high on less than half an acre of ground that had been cleared and prepared for their reception by fire." Willard (1995) does not have corroborating evidence from cruise data. However, it is safe to say that young giant sequoias (seedlings to trees perhaps 30 inches in diameter) were relatively more abundant and other species, primarily white fir, were less abundant in presettlement times.

Recommendation (plant species)

Intuition suggests that for ecosystem resilience and stability the array of plant species currently existing (other than exotics) should be maintained. Until better information is available, no other species should be introduced and seeds for giant sequoia planting within a grove should come from trees within that grove (Fins and Libby 1982, Fins and Libby 1994). Until more is known about their presettlement distribution, the abundance of shrubs and herbaceous plants should be allowed to vary according to their natural propagation following natural or management induced disturbance. Based on work done by Rundel (1971), Stohlgren (1991), and Willard (1995):

- Within groves giant sequoias should occupy approximately 55-75 percent of the total basal area and should make up at least 10 percent of the total number of trees.
- The mixed conifer component within groves should contain 25-45 percent of the total basal area, white fir being the dominant species. Incense-cedar, sugar pine *(Pinus lambertiana)*, ponderosa pine *(Pinus ponderosa)*, and black oak *(Quercus kelloggii)* are also important components of most groves, but even in combination should rarely occupy more than 20 percent of the total basal area.
- Less common associates of the mixed conifer component include Jeffrey pine *(Pinus jeffreyi)*, Douglas-fir *(Psuedotsuga menziesii)*, red fir *(Albies magnifica)*, Pacific yew *(Taxus bervifolia)*, Pacific dogwood, California hazel *(Corylus cornuta* var. *californica)*, white alder *(Alnus rhombifolia)*, Scouler willow *(Salix scouleriana)*, bigleaf maple *(Acer macrophyllum)*, bitter cherry *(Prunus emarginata)*, and canyon live oak *(Quercus chrysolepis)*. No recommendations for these species are made at this time, other than to recognize their legitimacy.

Recommendation (plant density)

As discussed above, estimating a reasonable recommended management variability for plant densities (trees per acre by size and species) is highly problematical, at least in the smaller size classes. For sustainability on a scale of 10's or 100's of acres, though, it is obvious that to account for mortality each smaller size class must have progressively more members than the preceding one. Table 2 illustrates one such distribution for giant sequoia. It is based on Stohlgren's (1991) work for the larger sizes with intuitive estimates for the smaller sizes. To simplify practical application in the field Table 3 condenses Stohlgren's complete set of data given in Table 2 and depicted graphically in Figures 9 and 10. For other tree species it is assumed that they will be distributed in a similar (uneven-aged) fashion. Guldin (1991) provides one approach for defining the relationships between size (as a proxy for age), number of trees, and basal area per acre. By combining the work of Rundel (1971) and Stohlgren (1991) one can conclude that average basal area stocking for groves should be on the order of 210 square feet per acre for giant sequoia and 110 square feet per acre for other species. (Note: These figures include the basal area of trees that exist in the forest as a result of fire suppression in the last century. However, the contribution of these trees to total basal area is relatively small, as shown in Figure 8, especially in the case of giant sequoia, because most of the basal area is accounted for in trees older than 100 years.)

Interpretation and Application

Overview

The information provided in this paper is intended to serve as an ecological foundation for site-specific grove management planning. It is expected that scientific principles and methods will be applied to monitor management activities that are based on what is presented here. As scientists add to the body of giant sequoia knowledge, and as monitoring provides feedback on the short- and long-term effects of management actions, adaptive management will create a strong link between science and management of national forest giant sequoia ecosystems. The purpose of this section is to provide a context for the practical application of the preceding.

Completing the Ecosystem Management Process

This paper has concentrated on giant sequoia ecosystems, their elements, associated environmental indicators, and reference variability. These are critical variables in the process of ecosystem management planning, but identifying and quantifying them only completes three steps out of the 14-step process discussed by Manley et al. (1995). The context in which ecosystem elements and environmental indicators are applied in practice must take into account all 14 steps in the planning process with significant emphasis on Steps 1 and 14 (landscape to analyze and adaptive management).

Selecting the Landscape Area

The first step in the Manley et al. (1995) ecosystem management process is to select a landscape for analysis. The focus of this paper has been on grove ecosystems, the boundaries of which are defined by the outermost giant sequoia trees within the groves. The paper does not attempt to deal with external influences. However, it is obvious that the ecosystem management process must take into account the larger landscape of which the groves are a part. An approach to defining the ecologically rational zone of influence for giant sequoia groves should definitely take into account two of the key elements identified in this paper: fire and water (Rundel 1972b, Anderson 1995, University of California 1996). Using this approach, and with only rudimentary knowledge of fire behavior and hydrology, leads to the conclusion that sub-watersheds that contain the groves should be the landscape of concern. More specifically, fire influence is of concern in those portions of the sub-watershed that lie below the grove, and water influence is of concern for those portions that lie directly above.

Management Caveats

The following observations are intended to assist with the practical application of the information presented in this paper:

- Recommended management variability (RMV) includes a range of values within reference variability that implies a high degree of resilience and sustainability for the ecosystem. RMVs must often describe mid-range values under the assumption that the extremes should be rare and will occasionally exist whether or not there is a deliberate attempt to create or maintain them.
- Allowing indicators to routinely exist at extremes, or outside the range of variability, probably decreases ecosystem resilience and sustainability in most cases. In rare cases such as the realized expectation indicator, values at the extreme can be very desirable.

- The need for management action (management opportunity) is indicated by a difference between existing condition and RMV.
- Part of the variation within reference variability is random (e.g., mortality is influenced by weather pattern during a particular fire event), and part is systematic (e.g., species composition is influenced by aspect and elevation). Deciding where to operate within RMV therefore requires a knowledge of the physical and biological landscape as well as the cultural/social context in which management decisions are made.
- Sustainability of range-wide grove attributes is not necessarily dependent on sustainability of individual grove attributes (e.g., it may be acceptable, or even desirable, for one grove to be deficit in an attribute if another grove is surplus). In fact, for certain attributes this is very much the way things work in nature. Not all giant sequoia groves are going to have trees as large as the General Sherman. Therefore, any proposal to correct the difference between RMV and existing conditions in a specific grove should consider whether or not it is important to take into account the existing conditions in all the other groves.
- In the social dimension be wary of the interpretation of the "limit of acceptable change". Regardless of scientific validity, diverse values and cultural inertia will allow change to happen only so fast.
- The concept of ecosystem management is new and some of the scientific information requires verification. Therefore, in the application of RMVs developed in this paper, common sense in relation to known science and site-specific conditions should prevail.

Concluding Comments

The key ecological elements, environmental indicators, and the quantification of indicators presented in this paper must be subject to frequent review and revalidation. Members of the Giant Sequoia Ecology Cooperative (USDA 1996) should be an integral part of this adaptive management process.

Not seeing the forest for the trees has been a common expression in forestry. We have observed through this work that our past and present efforts to classify vegetation and ecosystems often masks our view of the finer scale of diversity that exists within these types.

We have also learned through this work process that the restoration and maintenance of healthy forest ecosystems cannot simply focus on process. Rather, an understanding of structure and process at both the landscape (coarse) and plant aggregation (fine) scales is essential.

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References Cited

Anderson, M.A., Graham, R.C.; Alyanakian, G.J.; Martynn, D.Z. 1995. Late summer water status of soils and weathered bedrock in a giant sequoia grove. Soil Science 160(6): 415-422.

Bonnicksen, T.M.; Stone, Edward C. 1978. An analysis of vegetation management to restore the structure and function of presettlement giant sequoia-mixed conifer forest mosaics. Unpublished final report to the USDI National Park Service, Sequoia and Kings Canyon National Parks, California.

Bonnicksen, Thomas M.; Stone, Edward C. 1981. The giant sequoia-mixed conifer forest community characterized through pattern analysis as a mosaic of aggregations. Forest Ecology and Management 3(1980/81): 307-328.

Bonnicksen, Thomas M.; Stone, Edward C. 1982a. Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. Ecology 63(4): 1134-1148.

Bonnicksen T.M.; Stone, Edward C. 1982b. Managing vegetation within U.S. national parks: a policy analysis. Environmental Management 6(2): 101-102.

Bonnicksen, Thomas M. 1993a. Restoring ancient giant sequoia forests. An electronic publication. Department of Forest Science; College Station: Texas A&M University.

Bonnicksen, Thomas M. 1993b. Ancient forests of the Sierra Nevada. Unpublished speaker's notes for an industry sponsored economic summit.

Bush G. 1992. Giant sequoia in national forests. A proclamation by the President of the United States. 1992 July 14; 1 p.

Caprio, A.C.; Mutch, L.S.; Swetnam, T.W.; Baisan, C.H. 1994. Temporal and spatial patterns of giant sequoia radial growth response to a high severity fire in A.D. 1297. Unpublished contract report to the California Department of Forestry and Fire Protection, Mountain Home State Forest.

Davidson, J.G.N. 1972. Pathological problems in redwood regeneration from seed. Berkeley: University of California; Ph.D. dissertation.

Demetry, Athena; Duriscoe, Daniel M. 1996. Fire-caused canopy gaps as a model for the ecological restoration of giant forest village. Unpublished report to Sequoia and Kings Canyon National Parks, National Park Service, USDI.

Dunning, D.; Reineke, H. 1933. Preliminary yield tables for second-growth stands in the California region. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Technical Bulletin No. 354. 24 p.

Fins. L.; Libby, W.J. 1982. Population variation in *Sequoiadendron*: seed and seedling studies, vegetative propagation, and isozyme variation. Silvae Genetica 31(4): 102-110.

Fins. L.; Libby, W.J. 1994. Genetics of giant sequoia. In: Aune, Phil, technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 65-68.

Fry, W. 1933. The giant sequoia avalanche. Sierra Club Bulletin 18: 118-120.

Fry W.; White, J.R. 1948. Big trees. Revised enlarged edition. Palo Alto: Stanford University Press; 126 p.

Fullmer, D.G.; Rogers, R.R.; Manley, J.D.; Stephenson, L.L. 1996. Restoration as a component of ecosystem management for giant sequoia groves in California. In: Pearson, D.L., Klimas C.V., editors. Proceedings of the Society for Ecological Restoration conference, The role of restoration in ecosystem management; 1995 September 14-16; Seattle, WA. Society of Ecological Restoration, Madison, WI, 109-115.

Guldin J.M. 1991. Uneven-aged Bdq regulation of Sierra Nevada conifers. Western Journal of Forestry 6(2): 27-32.

Hartesveldt, R.J.; Harvey, H.T. 1967. The fire ecology of sequoia regeneration. Proc. Tall Timbers Fire Ecol. Conf. 7:65-77.

Harvey, H. Thomas; Shellhammer, H.S.; Stecker, R.E. 1980. Giant sequoia ecology, fire and reproduction. USDI National Park Service, Scientific Monograph Series No. 12. Washington, DC.

Holling C.S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecological Monographs 62(4): 447-502.

Huntington, E. 1914. The climatic factor as illustrated in arid America. The Carnegie Institute of Washington, Publication No. 192, Washington, DC.

Kilgore, Bruce M.; Taylor, D. 1979. Fire history of a sequoia-mixed conifer forest. Ecology 60(1): 129-142.

Leuschner, W.A. 1984. Introduction to Forest Resource Management. New York: John Wiley and Sons, Inc.; 298 p.

McKelvey, Kevin S.; Johnston, James D. 1992. Historical perspectives on forests of the Sierra Nevada and the Transverse Ranges of southern California: forest conditions at the turn of the century. In: Verner, J.; McKelvey, K.S.; Noon, B.R.; Gutierrez, R.J.; Gould Jr., G.I.; Beck T.W., technical coordinators. The California spotted owl: a technical assessment of its current status.

Gen. Tech. Rep. PSW-GTR-133. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 225-246.

Manley, P.N.; Brogan, Gary E.; Cook, Carolyn; Flores, Mary E.; Fullmer, Donald G.; Husari, Susan; Jimenson, Thomas M.; Lux, Linda M.; McCain, Michael E.; Rose, Judy A.; Schmitt, Gary; Schuyler, John C.; Skinner, Michael. 1995. Sustaining Ecosystems-A Conceptual Framework. San Francisco, CA: USDA Forest Service Pacific Southwest Region. Report No. R5-EM-TP-001.

Muir, J. 1961. The mountains of California. Garden City, New York: Doubleday and Company; 300 p.

Patterson III, W.A.; Prentice, I.C. 1985. Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs. Quarternary Research 23: 87-108.

Piirto, D.D. 1977. Factors associated with tree failure of giant sequoia. Berkeley: University of California; 155 p. Ph.D. dissertation.

Piirto, Douglas D.; Rogers, R.R.; Bethke, M.C. 1997. Communicating the role of science in managing giant sequoia groves. In: Murphy, Dennis; Loftus, Nelson, technical coordinators. Proceedings of the National Silviculture Workshop; 1997 May 19-22; Warren, PA. Gen. Tech. Rep. GTR-NE-238. Radnor, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 48-57.

Piirto, Douglas D. and Rogers, R.R. 2000. An ecological foundation for management of national forest giant sequoia ecosystems. Berkeley, CA: USDA Forest Service Pacific Southwest Region. Gen. Tech. Rep. (in press).

Rogers, Robert. 1998. An unpublished report of all known giant sequoia groves. Address inquiries to R. Rogers, c/o USDA Forest Service, Sequoia National Forest, Porterville, CA.

Rundel, P.W. 1971. Community structure and stability in the giant sequoia groves of the Sierra Nevada, California. The American Midland Naturalist 85(2): 478-492.

Rundel, P.W. 1972a. An annotated list of the groves of Sequoiadendron giganteum in the Sierra Nevada--Pt. I. Madrono 21(5): 319-328.

Rundel, P.W. 1972b. Habitat restriction in giant sequoia: the environmental control of grove boundaries. The American Midland Naturalist 87(1): 81-99.

Stephenson, N.L. 1987. Use of tree aggregations in forest ecology and management. Environmental Management 11(1): 1-5.

Stephenson, N.L. 1994. Long-term dynamics of giant sequoia populations: implications for managing a pioneer species. Gen. Tech. Rep. PSW-151. Forest Service, U.S. Department of Agriculture.

Stephenson, N.L. 1996. Ecology and management of giant sequoia groves. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chap. 55. Davis: University of California, Centers for Water and Wildland Resources.

Stephenson, N.L.; Parsons, D.J.; Swetnam, T.W. 1991. Restoring natural fire to the sequoia-mixed conifer forest: should intense fire play a role. Proceedings of the 17th Tall Timbers Fire Ecology Conference, High Intensity fire in Wildlands: Management Challenges and Options; Tallahasse, FL. Tall Timbers Research Station. 321-337.

Stohlgren, Thomas J. 1991. Size distributions and spatial patterns of giant sequoia in Sequoia and Kings Canyon National Parks. Davis: University of California; 300 p. Ph.D. dissertation.

Stohlgren, Thomas J. 1992. Resilience of a heavily logged grove of giant sequoia (*Sequoiadendron giganteum*) in Kings Canyon National Park, California. Forest Ecology and Management 54: 115-140.

Stohlgren, Thomas. J. 1993a. Spatial patterns of giant sequoia *(Sequoiadendron giganteum)* in two sequoia groves in Sequoia National Park, California. Can. J. For. Res. 23: 120-132.

Stohlgren, Thomas J. 1993b. Intraspecific competition (crowding) of giant sequoias *(Sequoiadendron giganteum)*. Forest Ecology and Management 59: 127-148.

Thomas, Jack Ward. 1993. Forest management approaches on the public lands. Albright Lecturer speech. University of California, Berkeley.

Tweed, William. 1994. Public perception of giant sequoia over time. In: Aune, P.S., technical coordinator. Proceedings of the symposium on giant sequoias: their place in the ecosystem and society; 1992 June 23-25; Visalia, CA. Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 5-7.

University of California, Centers for Water and Wildland Resources. 1996. Sierra Nevada ecosystem project, final report to Congress, vol. I, assessment summaries and management strategies. Davis: University of California, Centers for Water and Wildland Resources.

USDA Forest Service. 1990. Sequoia National Forest Mediated Settlement Agreement. Unpublished administrative document, Porterville, CA.

USDA Forest Service. 1996. Grant sequoia memorandum of understanding (MOU) for the giant sequoia ecology cooperative. Copies of the MOU agreement can be obtained from the USDA Forest Service, Sequoia National Forest, 900 West Grand Avenue, Porterville, CA.

Willard, Dwight. 1995. Giant sequoia groves of the Sierra Nevada, a reference guide. Self published. Address inquiries to D. Willard, P.O. Box 7304, Berkeley, CA 94707.

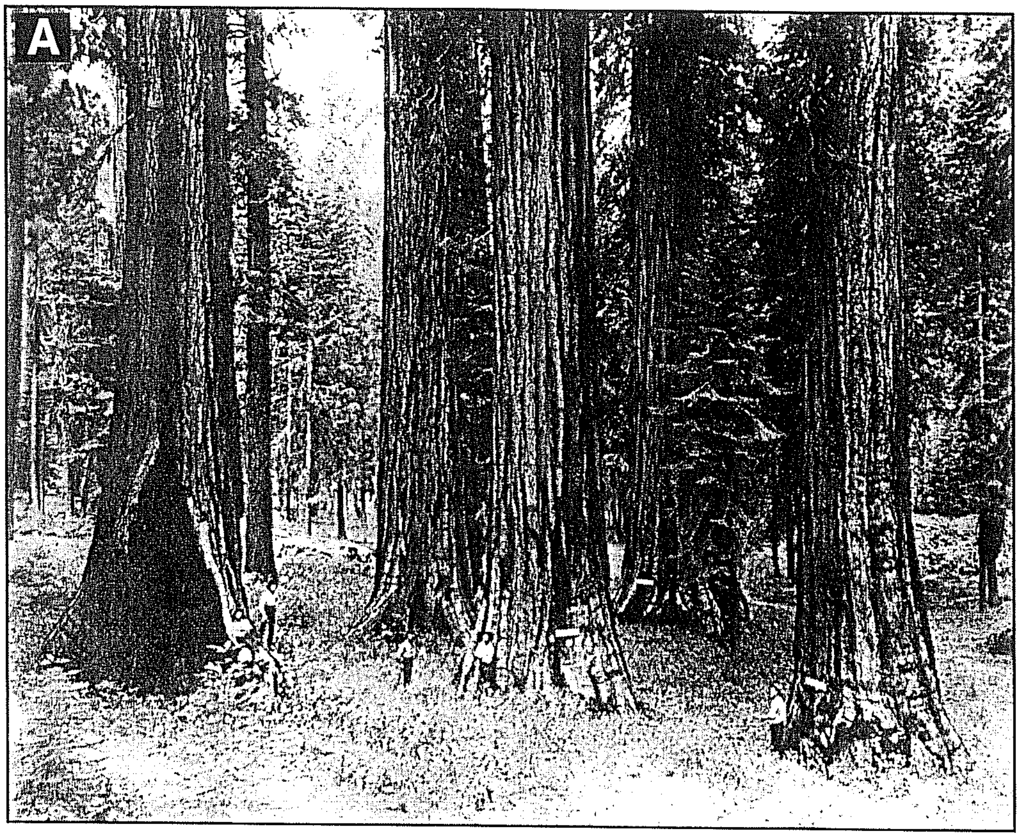

Figure 1a

The Confederate Group of giant sequoias in Mariposa Grove, Yosemite National Park. Note the signs that give each large tree an individual name.

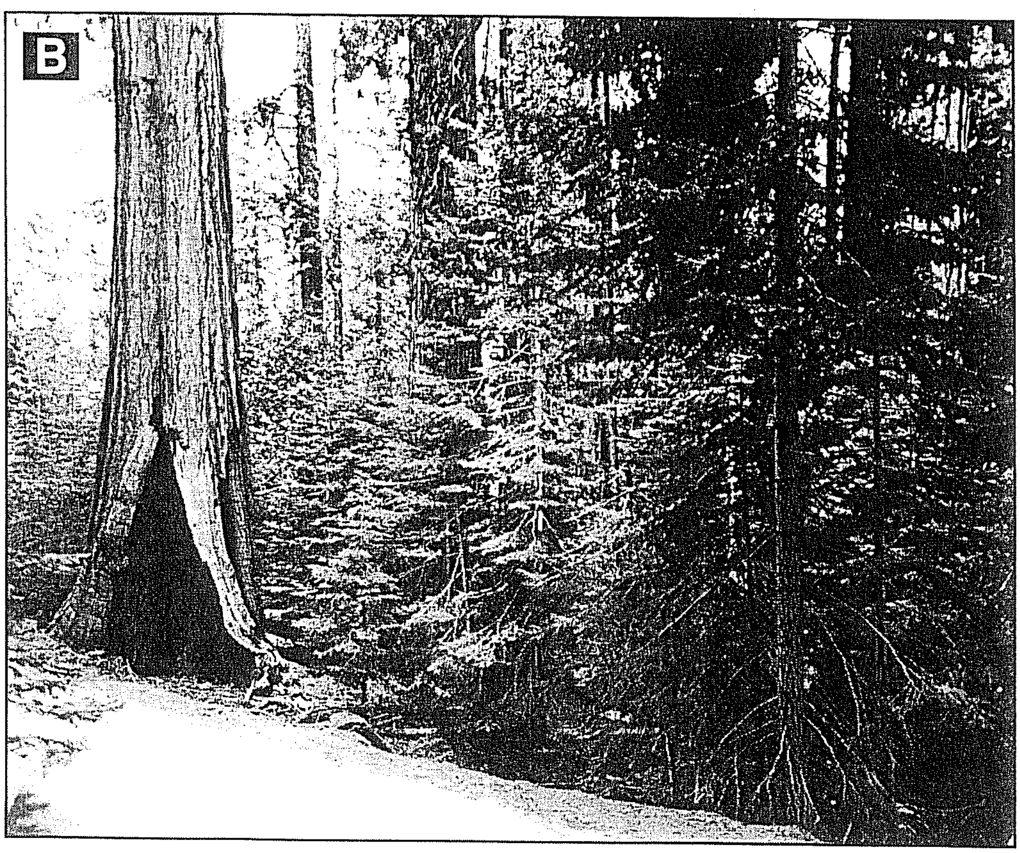

Figure 1b

By 1970, in the absence of frequent surface fires, a dense thicket of white firs grew at the base of the sequoias. Such thickets provide fuels that could conduct fire high into the sequoias. *(Photographs courtesy of Bruce M. Kilgore, National Park Service.)*

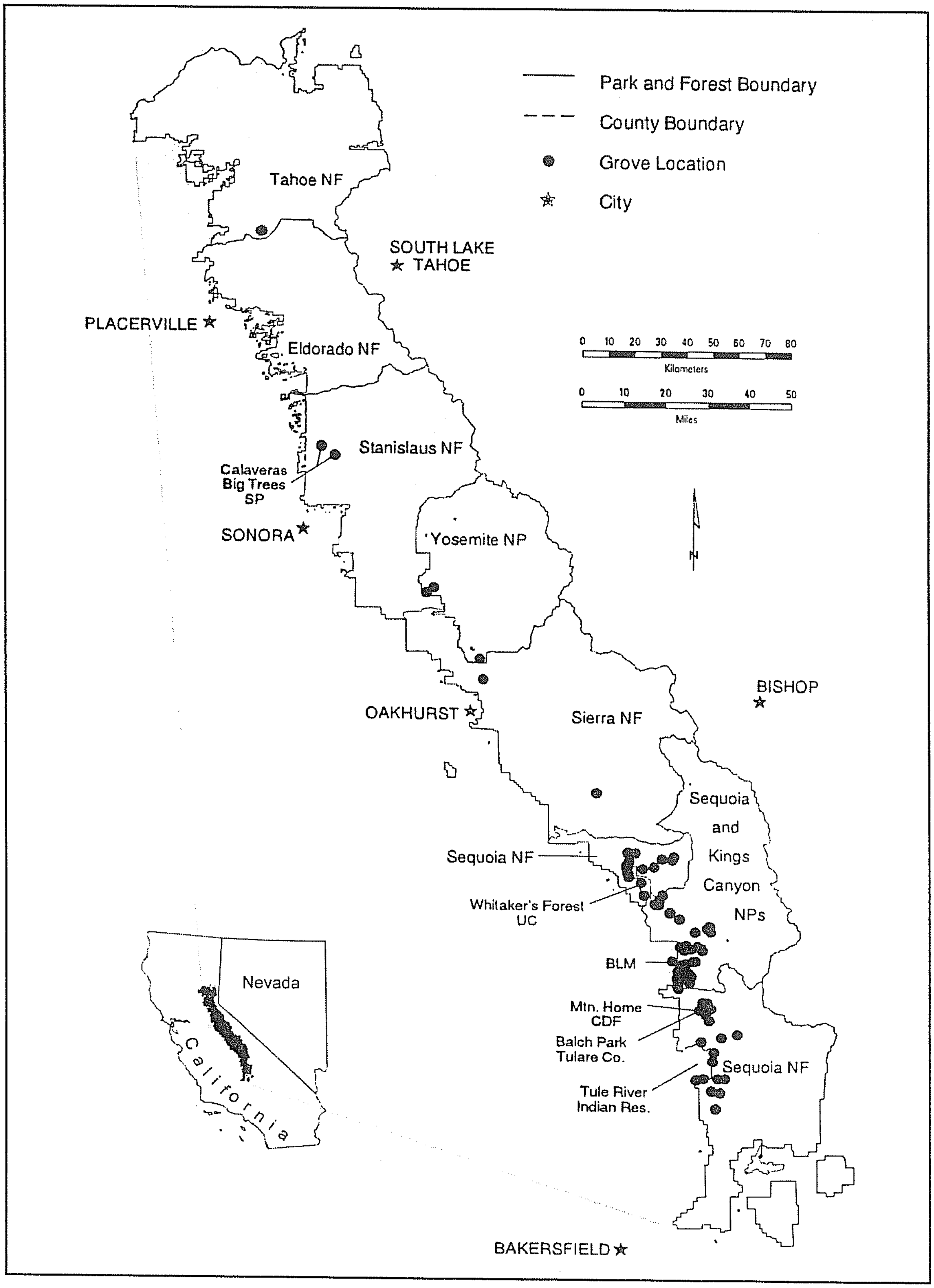

Figure 2 Locations of giant sequoia groves in the Sierra Nevada *(University of California 1996)*.

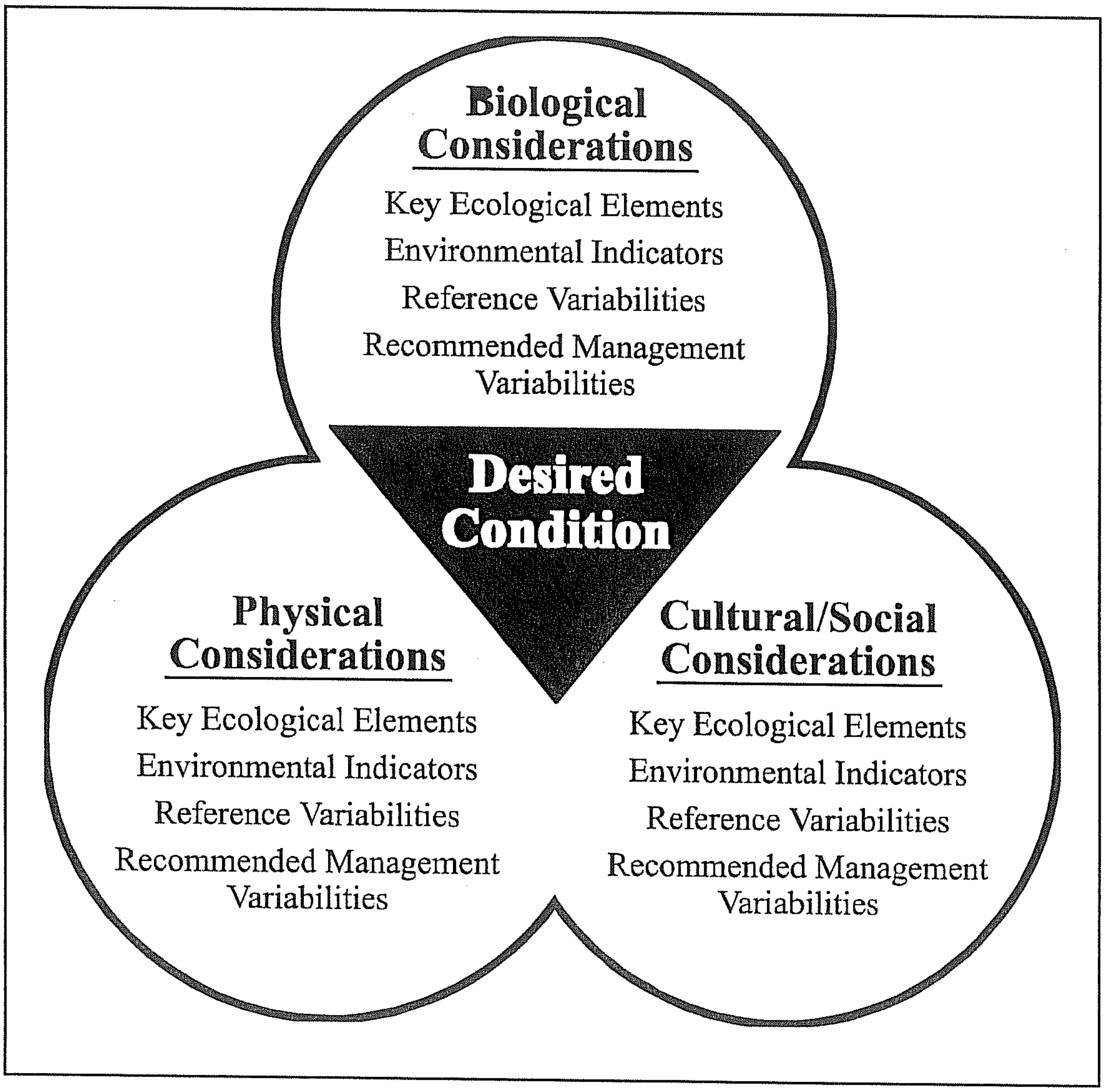

Figure 3 The USDA Forest Service Pacific Southwest region approach to ecosystem management. Biological, cultural/social, and physical considerations are integrated to arrive at a desired condition *(Manley et al. 1995)*

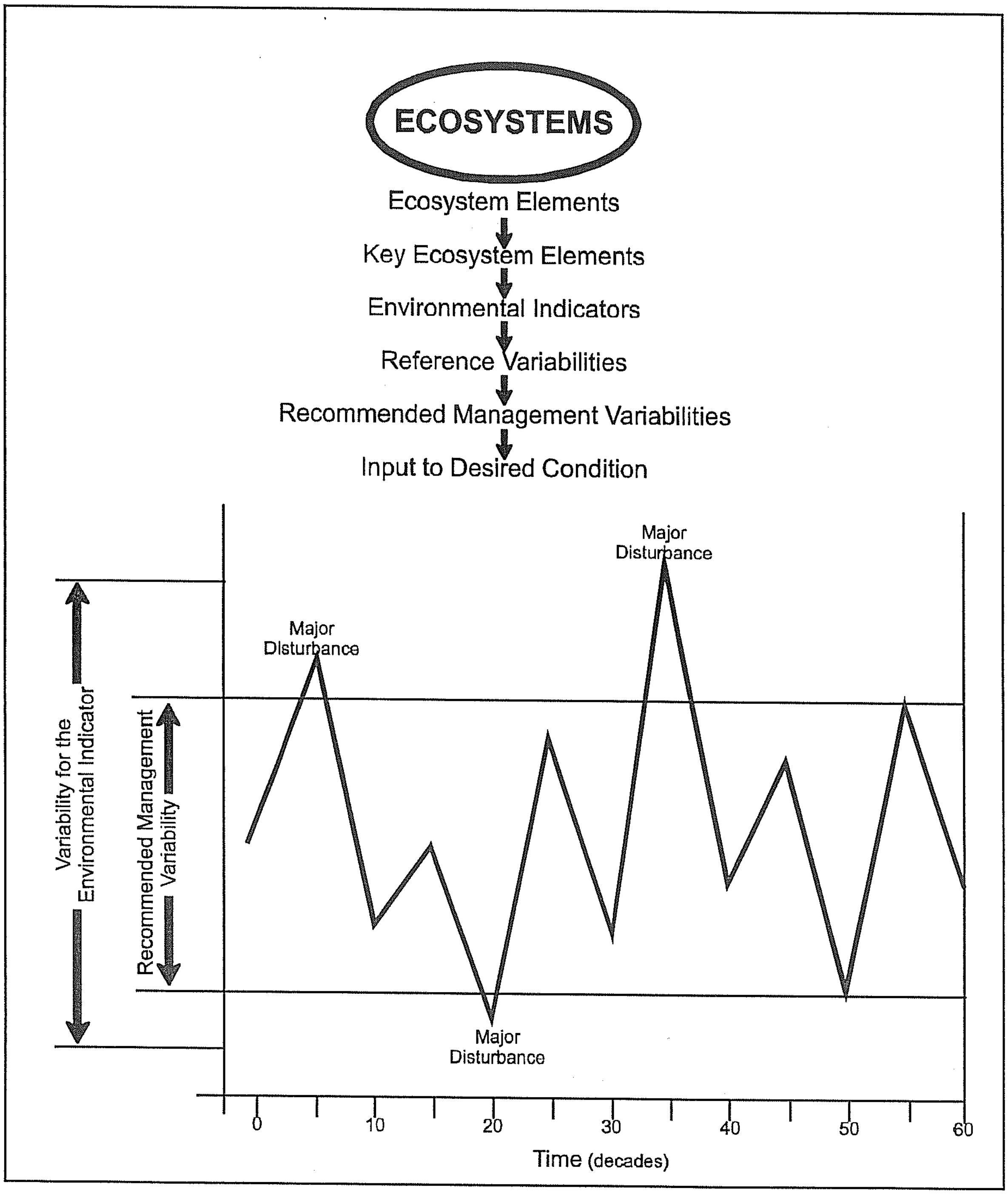

Figure 4 Relationships between ecosystem elements, indicators and recommended management variability *(Manley et al. 1995)*

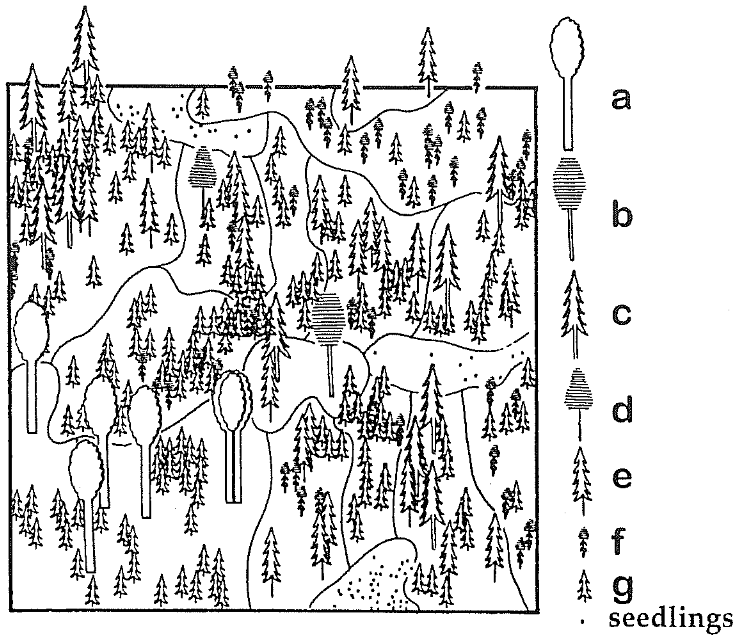

Figure 5 Sequoia grove structure and dynamics can be understood in terms of a mosaic of forest gaps and patches. This schematic diagram shows the location of trees in a 50 m x 50 m (164 ft x 164 ft) section of the Redwood Mountain Grove, unburned for about a century. Lines are meant to accentuate the forest mosaic by delimiting patches of relatively uniform forest structure and composition, though it is clear that patch boundaries are not always distinct and their designation can be somewhat arbitrary. *The tree symbols represent:*

- **a- giant sequoias greater than 35 m (115 ft) tall**
- **b- sugar pines greater than 35 m tall**
- **c- white firs greater than 35 m tall**
- **d- sugar pines 10 to 35 m (33 to 115 ft) tall**
- **e- white firs 10 to 35 m tall**
- **f - sugar pines 3 to 10 m (10 to 33 ft) tall**
- **g- white firs 3 to 10 m tall**
- **● - seedlings**

For clarity, the tree symbols are reduced in size relative to the plot, lending a somewhat open appearance to the stand. *Adapted from Bonnicksen and Stone [1982a], with permission of the Ecological Society of America.)*

Gap Size and Frequency Indicators

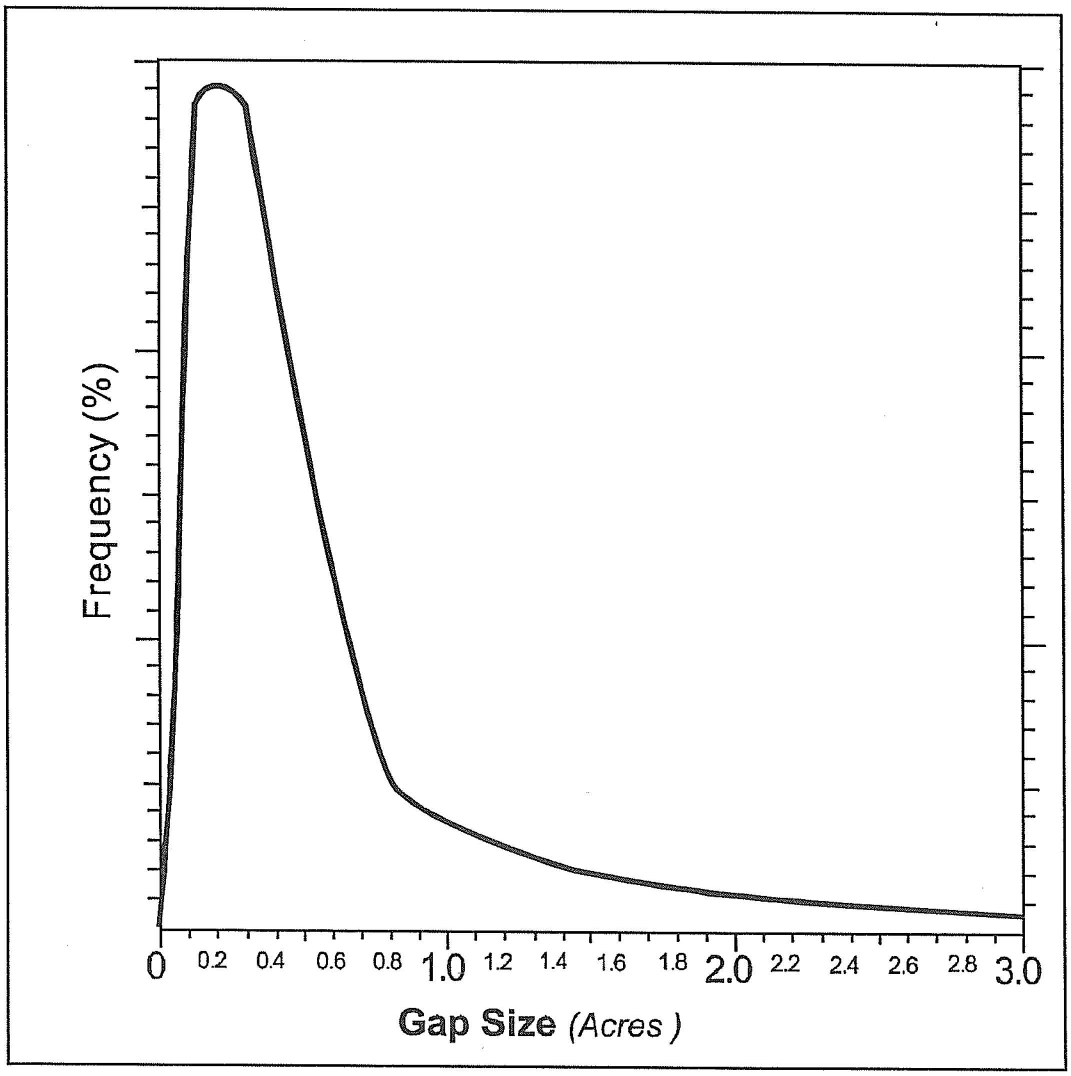

Figure 6 The **gap size and frequency indicators** for the Vegetation Mosaic ecosystem element. An approximation based on anecdotal data provided by Stephenson (1998) and empirical data in Bonnicksen and Stone (1981, 1982), Stephenson (1991, 1994, 1996), Caprio et. al. (1994), Demetry and Duriscoe (1996). Even though two-thirds of all presettlement gaps were probably less than 0.5 acres, they accounted for only one-third of all gap area.

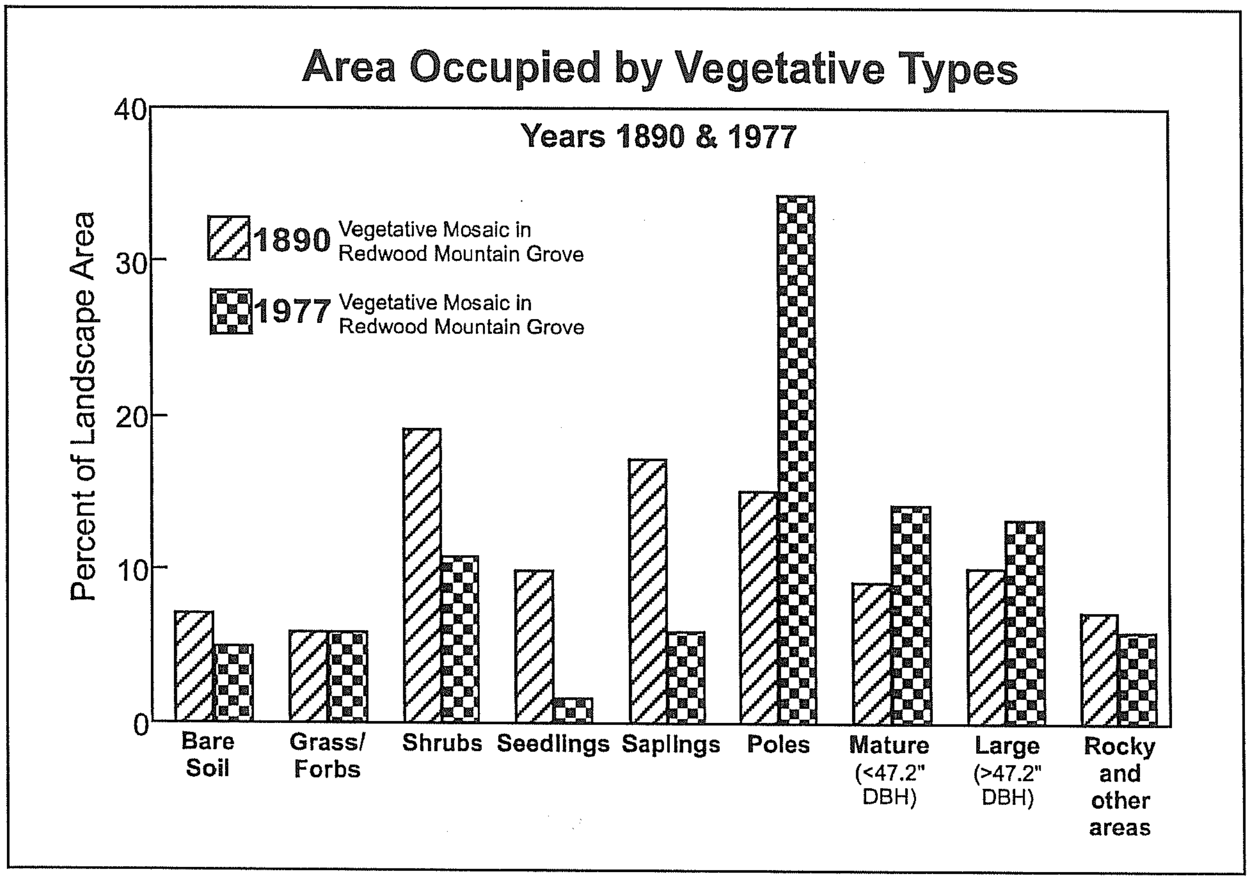

Figure 7 The plant community indicator of landscape area for the Vegetation Mosaic ecosystem element based on empirical data provided by Bonnicksen and Stone (1982) for Redwood Mountain Grove. Illustrated in this figure is the estimated amount of landscape area occupied by different vegetation types. A similar shift in vegetation types has been anecdotally observed for other national forest giant sequoia groves.

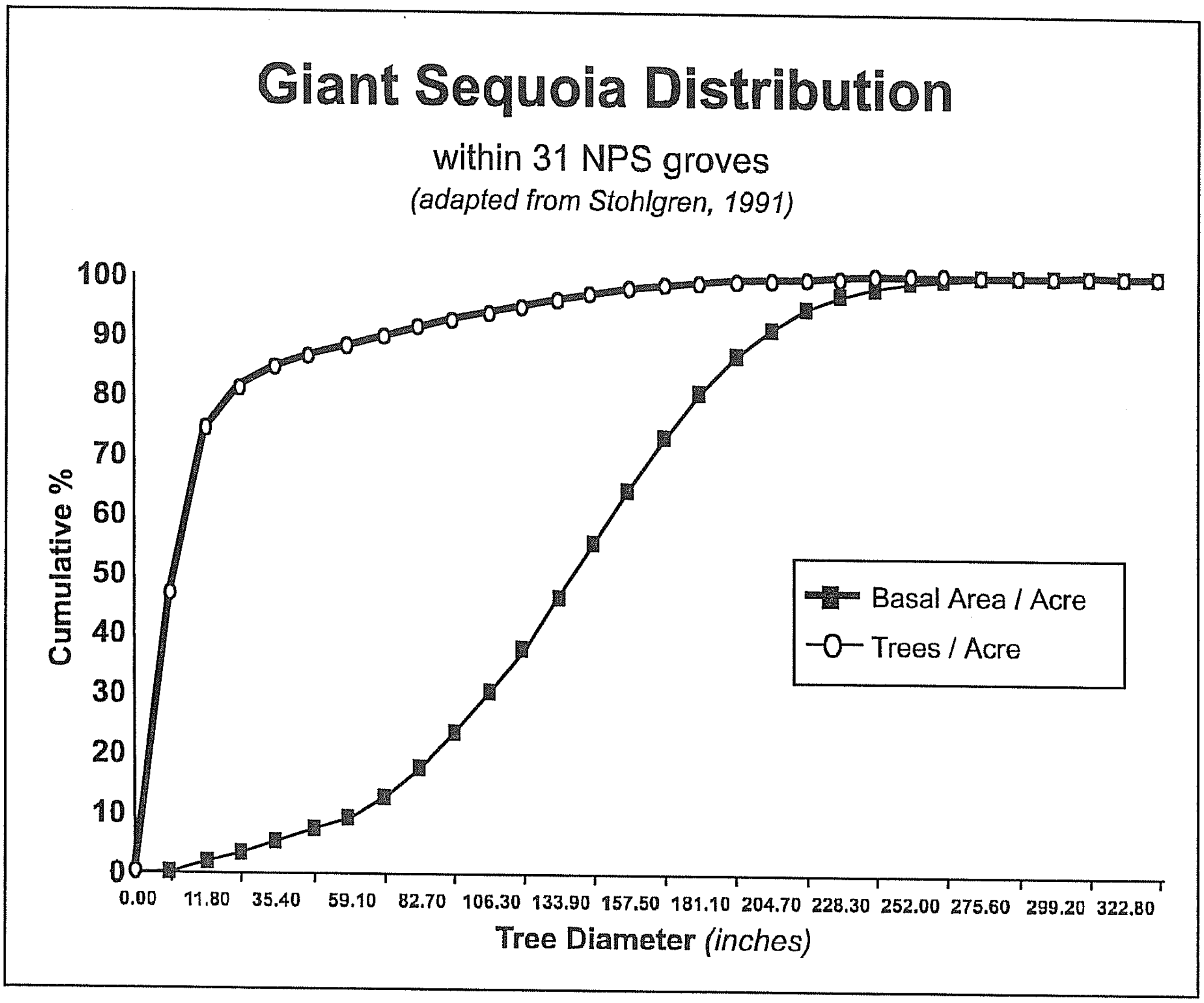

Figure 8 Distribution of giant sequoia trees as expressed by numbers of trees and basal area per acre.

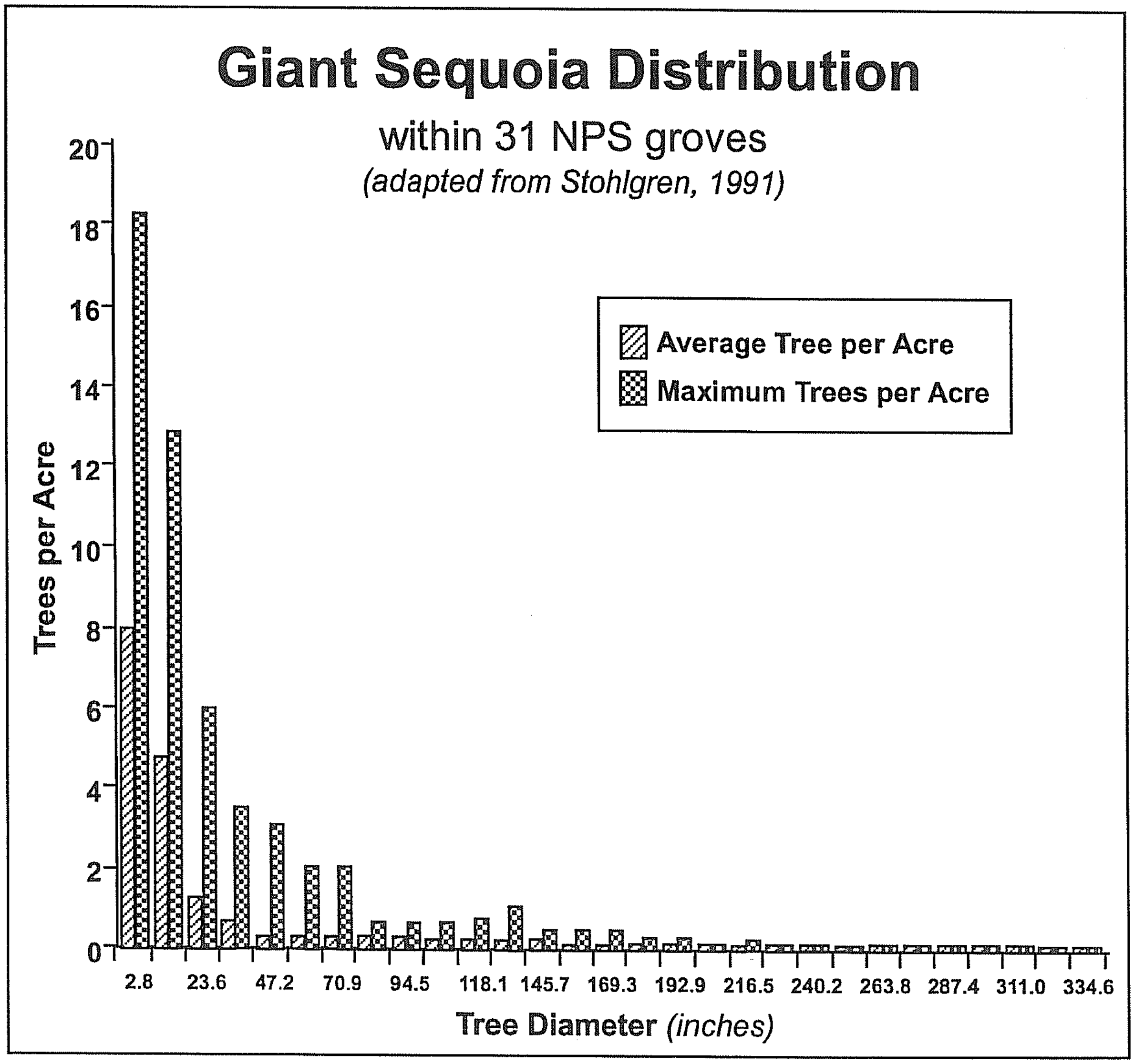

Figure 9 Distribution of giant sequoia trees as expressed by numbers of trees per acre.

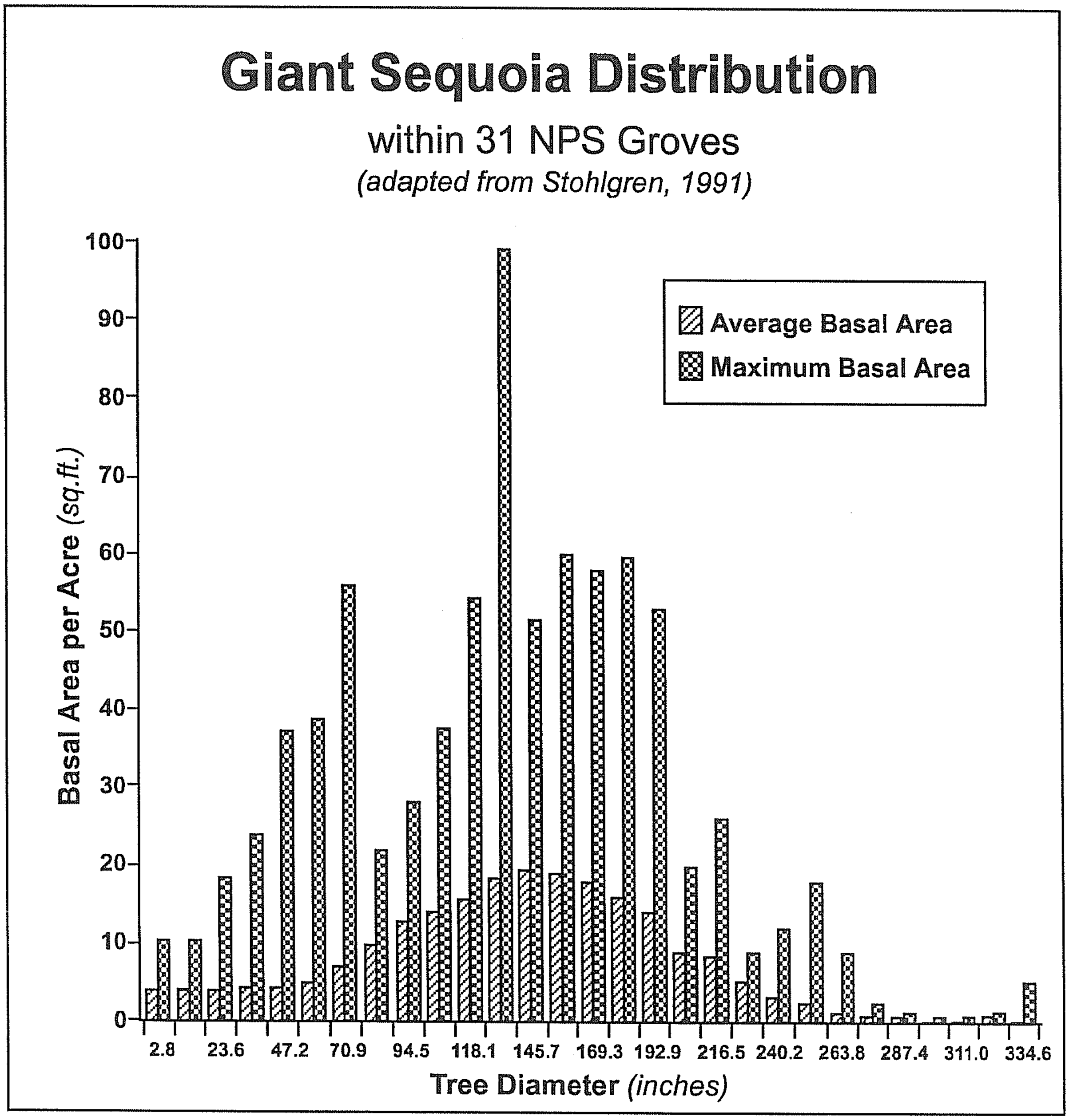

Figure 10 Distribution of giant sequoia trees as expressed by basal area per acre.

Table 1

Recommended Environmental Indicators for National Forest Giant Sequoia Groves

ECOSYSTEM ELEMENTS	RECOMMENDED ENVIRONMENTAL INDICATORS
Attitudes, Beliefs, and Values	• expression of realized expectations • recognition and incorporation of diverse values and beliefs
Economics and Subsistence	• resource uses • financial feasibility
Stream Channel Morphology	• sinuosity, confinement, and gradient (Rosgen channel types)
Sediment	• vegetative bank protection (upper banks) • cutting (lower banks) • deposition (lower banks) • scouring and deposition (channel bottom) • percent stable material (channel bottom)
Water	• drainage density • surface distribution • concentration
Fire	• severity • return rate (i.e., fire return interval)
Organic Debris	• weight of down material • distribution of down material • snag density

Vegetation Mosaic	• gap and patch size
	• gap and patch frequency
	• plant community
	    • plant species
	    • plant density

Table 2

Reference Variability for Number of Giant Sequoia Trees (TPA) and Basal Area Per Acre (BA/Acre)[1]

Diameter Class *(inches)*	Average Trees/Acre	Range of Trees/Acre	Average BasalArea/Acre *(sq. ft.)*	Range of BasalArea/Acre *(sq. ft.)*
2.8	7.9	0.0 to 18.2	0.3	0.0 to 0.8
11.8	4.6	0.1 to 12.8	3.5	0.1 to 9.8
23.6	1.2	0.2 to 5.9	3.7	0.6 to 18.0
35.4	0.6	0.1 to 3.4	3.8	0.5 to 23.4
47.2	0.3	0.0 to 3.0	3.9	0.0 to 37.0
59.1	0.3	0.1 to 2.0	4.8	1.0 to 38.5
70.9	0.3	0.0 to 2.0	6.9	0.0 to 55.4
82.7	0.3	0.0 to 0.6	9.6	0.0 to 21.3
94.5	0.3	0.0 to 0.6	12.4	0.0 to 27.6
106.3	0.2	0.0 to 0.6	13.6	0.0 to 37.4
118.1	0.2	0.0 to 0.7	14.9	0.0 to 53.9
133.9	0.2	0.0 to 1.0	17.8	0.0 to 98.9
145.7	0.2	0.0 to 0.4	19.2	0.0 to 51.1
157.5	0.1	0.0 to 0.4	18.8	0.0 to 59.7
169.3	0.1	0.0 to 0.4	17.3	0.0 to 57.5
181.1	0.1	0.0 to 0.3	15.3	0.0 to 59.3
192.9	0.1	0.0 to 0.3	13.4	0.0 to 52.3
204.7	<0.1	0.0 to 0.1	8.5	0.0 to 19.6
216.5	<0.1	0.0 to 0.2	7.8	0.0 to 25.9
228.3	<0.1	0.0 to 0.1	4.7	0.0 to 8.5
240.2	<0.1	0.0 to 0.1	2.9	0.0 to 11.6
252.2	<0.1	0.0 to 0.1	1.9	0.0 to 17.5
263.8	<0.1	0.0 to 0.1	0.8	0.0 to 8.9
275.6	<0.1	0.0 to 0.1	0.4	0.0 to 1.8
287.4	<0.1	0.0 to 0.1	0.2	0.0 to 0.9
299.2	<0.1	0.0 to 0.1	0.1	0.0 to 0.5
311.0	<0.1	0.0 to 0.1	0.1	0.0 to 0.3
322.8	<0.1	0.0 to 0.1	0.2	0.0 to 0.8
334.6	<0.1	0.0 to 0.1	0.1	0.0 to 4.8

[1] The average and range of values shown are based on studies completed by Hammon et al. (1964, 1970, 1975, 1976), Western Timber Service (1970), Stohlgren (1991) for 31 national park giant sequoia groves containing 30 or more giant sequoia trees.

Table 3
Recommended Management Variability (RMV) for Giant Sequoia Trees[1]

DBH Size Group *(inches)*	Average Trees/Acre	RMV for Trees/Acre Range	Average Basal Area / Acre *(sq. ft.)*	RMV for Basal Area /Acre Range *(sq. ft.)*
0.1 to 5.9	7.9	10 to 40[2]	0.3	0.2 to 0.6
5.9 to 17.7	4.6	5 to 20[2]	3.5	0.5 to 1.5
17.7 to 29.5	1.2	2 to 10[2]	3.7	1.0 to 4.0
29.5 to 65.0	1.2	1 to 4	12.5	4.0 to 16
65.0 to 112.2	1.1	1 to 2[3]	42.5	14 to 41
112.2 to 187.0	0.9	0 to 2[3]	103.3	0 to 119
>187.0	0.1	0 to 2[3]	41.1	0 to 331
TOTAL	17		206.9	

[1]Recommended management variabilityis based on a complete giant sequoia tree inventory of 31 national park groves with more than 30 giant sequoia trees present (Hammon et al. 1964, 1970, 1975, 1976; Western Timber Service 1970; Stohlgren 1991). Original grove size estimates used by Stohlgren were modified to reflect current information. Stohlgren estimated 8,277 acres (3,351 hectares), current estimates show 9,665 acres (3,913 hectares) in the 31 national park groves. This difference in size affects per hectare and per acre calculations and explains why numbers shown here do not correspond directly to Stohlgren's per hectare values.
[2]Probable range needed for sustainability - not substantiated by empirical or other data.
[3]No giant sequoia grove is known to have on average more than 2 trees per acre in these size classes.