

TOWARD AN UNDERSTANDING OF FIRE HISTORY INFORMATION¹

Carl N. Skinner²

Abstract: *An increased emphasis on interdisciplinary ecosystem management has emerged in recent years. As a result, natural resource managers have been compelled explicitly to consider the ecological role of and physical potential for fire in management of California ecosystems. Fire history data provide information on the long-term dynamics of fire in these ecosystems. Several types of potential sources exist: paleoecological studies, tree-ring studies, historical accounts, and twentieth-century data. Each type of data has its own advantages and limitations.*

Paleoecology studies that consider variations in charcoal and pollen over time can provide insight on the long-term occurrence of fire over thousands of years. Tree-ring studies provide detailed (though usually site-specific) accounts of fire occurrence over hundreds of years. Historical accounts are mostly anecdotal accounts and photographs of conditions and events in the nineteenth and twentieth centuries and provide very little quantitative data. Thus, they can be difficult to interpret. Twentieth-century data are often quite detailed but provide information primarily for the period of organized fire suppression. No single source provides a complete view of past fire regimes. The most comprehensive view comes from considering all of the above information sources.

Key words: *fire history, ecosystem management*

INTRODUCTION

In the past few years, an increased emphasis on integrated ecosystem management has developed (e.g., Manley et al. 1995). This emphasis has helped to highlight the need for greater understanding of ecosystem dynamics and disturbance processes in natural resources management (e.g., Swanson et al. 1994). Despite total yearly precipitation, California's Mediterranean climate, characterized by cool, wet winters and warm, dry summers, provides for a pronounced annual drought period in most ecosystems. This pattern of summer drought ensures that large portions of California annually experience conditions where fires can easily ignite and spread. As a result, fire has long been recognized as one of the more important processes in most California ecosystems (Pinchot 1899; Leiberg 1902; Wickstrom

1987; Martin and Sapsis 1992; Blackburn and Anderson 1993; Skinner and Chang 1996). To provide adequately for the long term health of many California ecosystems, the historical fire regime (i.e., the characteristic fire frequencies, severities, and landscape patterns) must be an important and explicit consideration in natural resources planning.

It is well established that, through affecting vegetation, fires indirectly influence hydrologic processes -- e.g., flooding, sedimentation, water yield, and water quality (Wells 1982). The patterns of fire severity and resulting effects on vegetation across watersheds or landscapes influence the magnitude of effects on the hydrologic processes. High-intensity fires covering large areas, characteristic of many wildfires today, will usually result in more pronounced variation in the hydrologic processes than low-intensity fires that only minimally alter vegetation and soil cover (Agee 1993). Fire history can provide important information on the long-term processes and development of watersheds we are currently concerned with managing.

The predisposition of Mediterranean-type ecosystems to fire obligates managers to consider the characteristics of fires that influenced long-term development of California ecosystems when developing long-range management objectives and goals. Evaluating the likely success of attaining long-term natural resource goals is problematic without a consideration of the physical and biological potential for fire and its ecological function in California environments (Skinner and Chang 1996). If fire history information is ignored, there is a risk of setting ecological goals that have no historical precedent and may ultimately be unattainable.

SOURCES OF FIRE HISTORY INFORMATION

Fire histories can be developed from a variety of sources: e.g., charcoal accumulations in sediments, fire evidence in tree rings, historical accounts, and written records (twentieth-century data) (Patterson and Backman 1988). Each of these data sources has its own advantages and limitations regarding spatial and temporal detail, accuracy, and potential application (table 1).

Paleoecological Evidence of Fire

Paleoecology studies show us that environmental change (e.g., climate, vegetation, fire regime) is continual and unpredictable (Johnson et al. 1994). Studies of paleo-vegetation suggest that modern vegetation assemblages are transient, continually responding to various environmental varia-

¹Published in *Proceedings of the Sixth Biennial Watershed Management Conference*. S. Sommarstrom, editor. Water Resources Center Report No. 92. University of California, Davis (1997).

²Geographer, Pacific Southwest Research Station, USDA Forest Service, 2400 Washington, Redding, CA 96001

**COMPARISON OF SOME PROPERTIES OF THE VARIOUS SOURCES
OF FIRE HISTORY INFORMATION**

Table 1.

Source	Data Gathered Specifically to Record Fire History	Time Range	Temporal Resolution	Spatial Resolution	General Information Provided
Paleoecology Studies	Sometimes	1,000s+ Years	Low	Low	General trends in fire importance inferred from the co-variation of pollen and charcoal
Tree-ring Evidence	Yes	100s to 1,000s Years	High	High	Fire dates - location - sometimes estimated area burned / severity
Historical Accounts	Incidental	19 th & 20 th Centuries	Snapshots	Usually unknown	Description of conditions or fire behavior at a specific place and time
Twentieth-Century Data	Yes	20 th Century	High	High	Fire dates - location - area burned - sometimes severity

tions (Davis 1986; Sprugel 1991; Woolfenden 1996). Vegetation assemblages have often existed in the past that have no modern analogs (Davis 1986; Woolfenden 1996). Yet, the analysis of charcoal and pollen concentrations in cores from lake bottoms and meadows have shown that fire has been a continuing process in most California environments throughout the Holocene (e.g., Davis et al. 1985; Smith and Anderson 1992).

The relative importance of fire under various paleo-climates and vegetation assemblages can be inferred through the association of changing charcoal concentrations with variation in pollen spectra representing vegetational communities (e.g., Edlund and Byrne 1990). Additionally, possible influences of human activities on past fire regimes and vegetation have also been suggested from paleoecological studies (Anderson and Carpenter 1991). Nevertheless, these data generally present us with low-resolution, temporal trends in fire regimes coupled with long-term variation in climate and vegetation. Only a few such studies, none from California, have been published that present relatively high-resolution fire history (e.g., Clark and Royall 1995; Millsbaugh and Whitlock 1995).

Fire Evidence Recorded in Tree Rings

For information concerning fire occurrence before the twentieth century, evidence of fires recorded in tree rings generally provides the most accurate long-term record. Ability to develop fire history from fire scars is limited to areas with large woody plants (usually trees) that attain ages of a century or more and can survive to record fires as patterns in growth rings. Little information is left following fires in herbaceous or shrub communities because of heavy consumption and the fact that plant parts that are not consumed above ground are often killed. Several agents may cause scars in trees (e.g., insects, pathogens, logging, animals, etc.), and care must be used to differentiate fire scars (Agee 1993). Besides the more commonly used fire scars, tree rings may record a variety of other types of evidence associated with past fires. Examples are growth suppressions, missing or very small rings, growth releases, traumatic resin ducts, etc. (e.g., Brown and Swetnam 1994). To be considered evidence of fires, the latter types of evidence should be associated with tree rings of years that nearby trees recorded fire scars.

Differential Susceptibility to Fire Damage. Considerable variation exists among tree species in their susceptibility to scarring or other forms of fire damage. Some species, such as lodgepole pine (*Pinus contorta* ssp. *murrayana*) with thin bark, are easily damaged and often killed by even low-intensity fires (nomenclature follows Hickman 1993). Other species, such as mature Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) with very thick, insulating bark, may require more intense fire just to cause scars. Additionally, though

fire resistance generally increases with age, differentials exist in ages at which the various species develop greater fire resistance (Skinner and Chang 1996). Moreover, once scarred, trees will generally record subsequent fires more easily unless the scar has completely healed or closed (Agee 1993). The various species also appear to heal over fire scars at differential rates. Thus, different tree species vary in their ability to record fires. For example, it is usual for sites that have both ponderosa pine (*P. ponderosa*) and Douglas-fir to have recorded very different fire histories between the two species. The older ponderosa pines will often have large open fire wounds (catfaces). These trees are commonly good recorders of fires and usually exhibit several fire scars. In contrast, having catfaces is unusual for the old Douglas-firs, even on the same sites, since the fire scars often quickly heal over. Thus, with the lack of open wounds, Douglas-firs usually do not scar as readily and may provide a conservative record of past fires. Caution should be used when comparing fire histories among sites occupied by different species.

Distribution of Fires in Time. Most fire history studies attempt to describe how often fires occurred in the study area within the period that has sufficient evidence for fire history reconstruction. These temporal patterns are usually described either as fire frequencies (number of fires per unit time) or fire return intervals (FRI = time between successive fires) for a specified area (see Romme 1980). Fire-history studies usually report the mean or median FRI. However, Swetnam (1993) found that over many centuries the temporal patterns of FRIs can change markedly in concert with climatic variation. He found that fire frequencies may be more influenced by long-term trends of temperature rather than moisture. This suggests that past patterns of FRIs, though important for our understanding of the long-term role of fire, may not always be directly applicable to current climatic patterns (e.g., Stine 1996). Thus, the range of FRIs is also very important and can provide important information regarding the development of species composition and age structures of forests (Caprio and Swetnam 1995; Skinner and Chang 1996). Managers should consider the range of FRIs when developing fire management plans (especially prescribed fire programs) to be more likely to produce desired results while avoiding undesirable effects (Caprio and Swetnam 1995).

Several methods have been developed to detect fire frequencies and FRIs. Generally, the occurrence of fires can be determined either by cross-dating (Fritts and Swetnam 1989) or by estimating correspondence among years of fire evidence in tree rings (Arno and Sneek 1977). Cross-dating uses recurring patterns in the tree rings to adjust for missing or false growth rings. The calendar year and often the season of fires that occurred hundreds and even thousands of years ago can be determined using the cross-dating technique (Swetnam 1993). Without cross-dating, the exact year of a fire cannot be determined.

The correspondence method uses the apparent number of years between fire scars to adjust the alignment of fire scars among samples so that scars in different samples appear to correspond (Arno and Sneek 1977). This method can provide fire history information relatively quickly as it is less time consuming than cross-dating. Additionally, the correspondence method can be used for sites where trees do not cross-date well. However, despite the care taken with this method, the years of the resulting fires are still estimates and could vary by one to three years from the exact year. It is common for fires that occurred within a year or two of other fires to be lumped together using this method. As a result, the correspondence method often underestimates the number of fires within the period of the fire scar record. Nevertheless, for the purposes of the land manager, this method will often provide sufficiently accurate estimates of fire return intervals (Madany et al. 1982).

Sample Gathering Methods. A variety of methods have been used for sample gathering and data collection. Methods include collecting increment cores from fire scarred trees (Barrett and Arno 1988), sawing wedges or partial cross-sections from fire scarred trees (Arno and Sneek 1977), counting rings between scars on stumps in the field (Morrison and Swanson 1990), and collecting full cross-sections from stumps or logs for laboratory analysis (Stokes 1980). The first two of the above methods are most commonly used for collecting samples from living trees. These methods are useful primarily where trees display catfaces or open fire wounds. In stands dominated by trees that heal rapidly, often no indication about where samples should be collected is apparent. The latter two methods are generally used for collecting samples from dead trees and can be used wherever sound wood is available.

These methods vary considerably in their potential to produce accurate, comprehensive fire histories. The increment core method is probably the most difficult to apply properly. It generally requires several cores to be taken from each tree to detect multiple fires and requires cross-dating for any reasonable estimating of fire dates (Barrett and Arno 1988; Sheppard et al. 1988; Means 1989). Collecting wedges or partial cross-sections is much more efficient where allowed. Provided the wedge is deep enough to show the full extent of each fire scar, a more comprehensive record of fires can generally be developed (Arno and Sneek 1977). However, this method will not detect fires recorded elsewhere on the circumference of the tree. Some individual fires may be recorded on only one side of a catface. Therefore, the best methods for detecting a more thorough record of fires use full cross-sections of the trees (Stokes 1980). In this way, fires recorded on only one side of catfaces can be found as well as fires recorded elsewhere on the tree. Additionally, fire scars buried in trees that have healed over completely can be discovered. Laboratory analysis employing cross-dating techniques of carefully prepared full cross-sections provides for the most accurate and comprehensive fire

histories (Stokes 1980). Partial cross-sectioning can often be done without major damage to the tree. However, full cross-sectioning will either kill the tree or requires samples be taken from dead material (e.g., stumps, logs).

Spatial Scale. Fire histories from tree-ring analysis generally fall into three types: 1) single tree samples, 2) composites of multiple trees within a specified site area (Dieterich 1980a, 1980b), and 3) composites of multiple sites for landscapes (Morrison and Swanson 1990). The single tree sample is usually considered the most conservative record of past fires since all fires passing through a stand may not have scarred the single sample (Dieterich and Swetnam 1984). A more comprehensive record of fires is usually provided by compositing evidence from multiple trees from the site of interest (Agee 1993). It is important that the spatial extent of the sampled area along with the time span of the record is noted to provide for comparison of sites from different areas for the various forest types. Skinner and Chang (1996) provide a table summarizing many fire history studies including their spatial and temporal reference for forests of the Sierra Nevada, Cascade Range, and Klamath Mountains.

Landscape-scale studies, in addition to fire-scar data, may include data to describe species composition, stand structures, and tree age classes. Such studies allow estimating extent of fires, patterns of fire severity and stand initiation, long-term stand development processes, and dynamics of the vegetative mosaics. Landscape-scale fire-history studies were originally designed to describe the dynamics of age classes and coarse-grain vegetative mosaics in regions characterized by high-severity, stand-replacing fires (e.g., Heinselman 1973; Johnson and Gutsell 1994). In California, these methods may be useful for developing fire history in chaparral and other shrub lands. However, the horizontal spatial patterns in the forests of California, which were predominantly influenced by low-to-moderate severity fires, are commonly complex and of fine-grain (Chang 1996; Franklin and Fites-Kaufmann 1996; Skinner and Chang 1996). To be useful for understanding fire regimes in California forests, landscape-level studies must be designed to describe the spatial complexity associated with varying fire severity and its influence on the development of the fine-grain spatial patterns as well as the broader-scale landscape patterns.

Only a few landscape-level studies have been completed in California forest areas due to the time and costs involved (e.g., Kilgore and Taylor 1979; Taylor 1993; Caprio and Swetnam 1995; Solem 1995). However, a few additional studies are underway in the Cascade Range and the Klamath Mountains and will become available soon.

Most fire history studies available for California are single-tree or single-site composites of fire return intervals. These latter studies tell us a lot about how fire may have affected forests at a very localized level or how often fire may have passed over a given site within a forest type. Nevertheless,

to understand better how fire dynamically affected landscape-level elements of interest, such as aquatic and riparian environments, vegetational related dynamics, wildlife habitat, and air quality, more landscape-level fire history studies will be necessary (Skinner and Chang 1996).

Historical Accounts

Historical accounts provide a rich background of information to help our understanding of the past influences and uses of fire. A variety of sources have provided historical accounts of fires, their behavioral characteristics, associated vegetation conditions, and Native American uses of fire. These sources include diaries of early settlers and trappers, newspaper stories, dated photographs, surveyors' notes, and journals of ethnographers and botanists (e.g., Sudworth 1900; Leiberg 1902; Barrett 1935; Wickstrom 1987; Blackburn and Anderson 1993).

Interpretation of anthropological accounts and more recent ethnographic work suggests that fire was an important tool used by Native Americans to manage their environment (Wickstrom 1987; Lewis 1993; Anderson and Moratto 1996). Additional perspectives on past fire in California forests comes from many historical accounts (e.g., Pinchot 1899; Sudworth 1900; Leiberg 1902). These accounts often characterized fire as low intensity surface burns and described associated vegetation conditions as commonly rather open with a considerable component of grasses and herbaceous plants. Other historical accounts also describe great variety in the conditions found from place to place with some forests described as quite dense and difficult to travel through (e.g., Leiberg 1902; Cermak and Lague 1993).

Some vegetation types have characteristic fire regimes (Kilgore 1981; Agee 1993; Skinner and Chang 1996). Knowledge of historical vegetation cover can be used to infer the past role of fire. Such information can be found in early forest surveys (e.g., Sudworth 1900; Leiberg 1902) and historical photographs (e.g., Gruell 1994).

A major drawback of historical information is that it is almost entirely anecdotal. Except for some maps and a few early forest surveys (e.g., Sudworth 1900, Leiberg 1902), rarely are any quantitative data associated with historical information. The lack of quantitative data leaves open to interpretation terms such as 'dense,' 'open,' 'severe,' 'damage,' 'common,' or 'extensive' among others. An example is seen in some diverging interpretations of Powers' (1877) description of the use of fire by Native Americans in the southern Sierra Nevada. Barrett (1935: page 22) concludes that fire was not an important tool affecting the landscape because fire was not stated to have been used for purposes other than the gathering of grasshoppers. In contrast, Wickstrom (1987: page 6) states that Native American burning described by Powers (1877) for gathering grasshoppers helped to keep "... the underbrush burned out and the woods

more open and park-like."

The anecdotal accounts are very important for giving us glimpses of fire behavior characteristics and associated vegetation conditions of the past. However, unaccompanied by quantitative data, anecdotal accounts alone can provide only a sketchy view to the past. Nevertheless, when used with fire scar information developed from tree rings, historical accounts can help to provide a more thorough picture of the past influences and uses of fire.

Twentieth-Century Data

Twentieth-century data are primarily records of fires kept by the various resource and fire management agencies. The time included in these records varies by agency and location. For example, the U.S. Forest Service and National Park Service have records of fires that have occurred since the early 1900s. However, these records are more complete for the second half of the century. The California Department of Forestry and Fire Protection has relatively complete records for state and private lands beginning about 1981.

Twentieth-century data provide information about fires during the period of active fire suppression. As such, these data can provide information about size and locations of fires. They can provide such information as the types of places that may be more likely to burn under recent management practices (e.g., McKelvey and Busse 1996). Records available for some more recent fires may give information on effects of fires that burned under more severe conditions. However, very little, if any, information about the ecological role of fire is provided by these data since these fires all occurred during the period of organized fire suppression. Generally, fires that have burned under lower intensities were easily suppressed and account for a small proportion of total burned area. In contrast, high-intensity fires, being more difficult to suppress, account for the great proportion of the total acres burned. Before the development of organized fire suppression, fires burning under low- and moderate-intensity conditions would likely have accounted for a much greater proportion of the total acres burned (Skinner and Chang 1996).

DISCUSSION

Taken alone, each of the above types of fire history information provides a portion, either directly or indirectly, of the history of fire for a given area of interest (Table 1). Together, they can provide a more comprehensive picture of fire history and help to make sense of information that sometimes appears to be conflicting.

Unfortunately, often only one or two of these types of information sources are available to land managers for a given location. The order in which they are likely to be available from most to least common is 1) twentieth-century data, 2)

2) historical accounts, 3) tree-ring, fire-scar studies, and finally 4) paleoecological studies. When data are not available, land managers often extrapolate the implications of fire history information, especially tree-ring studies and paleoecological studies, from areas where work has been done to other areas that are thought to be environmentally similar. This, of course, has pitfalls.

Though to the manager it may seem painfully slow, our knowledge of fire history is continually being advanced by the various means described above. Many questions remain to be explored, especially at the landscape scale of fire environment interactions. It is hoped that this discussion will help provide managers with an understanding of sources for fire history information.

ACKNOWLEDGMENTS

I am grateful for the comments and suggestions of Stephen F. Arno, William F. Laudenslayer, David J. Parsons, and C. Phillip Weatherspoon which greatly improved the original manuscript.

REFERENCES

- Agee, J. K. 1993. *Fire Ecology of Pacific Northwest Forests*. Island Press, Washington, D.C.
- Anderson, M. K., and M. J. Moratto. 1996. Native American land use practices, and ecological impacts. pp. 187-206 In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II, Assessments and Scientific Basis for Management Options*. Centers for Water and Wildland Resources, University of California, Davis. Wildland Resources Center Report No. 37.
- Anderson, R. S., and S. L. Carpenter. 1991. Vegetation change in Yosemite Valley, Yosemite National Park, California, during the protohistoric period. *Madroño* 38: 1-13.
- Arno, S. F., and K. M. Sneek. 1977. *A method for determining fire history in coniferous forests of the mountain west*. USDA Forest Service, Intermountain Research Station, Ogden, UT, General Technical Report INT-42.
- Barrett, L. A. 1935. A record of forest and field fires in California from the days of the early explorers to the creation of the forest reserves. Unpublished report to the Regional Forester. On file at Pacific Southwest Research Station, Redding, CA.
- Barrett, S. W., and S. F. Arno. 1988. *Increment borer methods for determining fire history in coniferous forests*. USDA Forest Service, Intermountain Research Station, Ogden, UT. General Technical Report INT-244.
- Blackburn, T. C., and K. Anderson, editors. 1993. *Before the Wilderness: Environmental Management by Native Californians*. Ballena Press, Menlo Park, CA.
- Brown, P. M., and T. W. Swetnam. 1994. A cross-dated fire history from coast redwood near Redwood National Park, California. *Canadian Journal of Forest Research*. 24: 21-31.
- Caprio, A. C., and T. W. Swetnam. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. pp. 173-179. In: J. K. Brown, R. W. Mutch, C. W. Spoon, R. H. Wakimoto (technical coordinators) *Proceedings: Symposium on Fire in Wilderness and Park Management*. USDA Forest Service, Intermountain Research Station, Ogden, UT. General Technical Report INT-GTR-320.
- Cermak, R. W., and J. H. Lague. 1993. Range of light - range of darkness: the Sierra Nevada 1841- 1905. Unpublished report on file USFS Pacific Southwest Regional Office, San Francisco, CA.
- Chang, C. 1996. Ecosystem responses to fire and variations in fire regimes. pp. 1071-1099. In: *Sierra Nevada Ecosystem Project: Final report to Congress. Volume II: Assessments and Scientific Basis for Management Options*. Centers for Water and Wildland Resources, University of California, Davis. Wildland Resources Center Report No. 37.
- Clark, J. S., and P. D. Royall. 1995. Particle-size evidence for source areas of charcoal accumulation in late Holocene sediments of eastern North American lakes. *Quaternary Research*. 43:80-89.
- Davis, M. B. 1986. Climatic instability, time lags, and community disequilibrium. pp. 269-284. In: J. Diamond and T. S. Case (editors). *Community Ecology*. Harper & Row, New York.
- Davis, O. K., R. S. Anderson, P. L. Fall, M. K. O'Rourke, and R. S. Thompson. 1985. Palynological evidence for early Holocene aridity in the southern Sierra Nevada, California. *Quaternary Research*. 24: 322-332.
- Dieterich, J. H. 1980a. *Chimney Springs forest fire history*. USDA Forest Service. Rocky Mountain Research Station, Fort Collins, CO. Research Paper RM-220.
- _____. 1980b. The composite fire interval - a tool for more accurate interpretation of fire history. pp. 8-14 In: M. A. Stokes, J. H. Dieterich (technical coordinators). *Proceedings of the Fire History Workshop*. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. General Technical Report RM-81.

- Dieterich, J. H., and T. W. Swetnam. 1984. Dendochronology of a fire-scarred ponderosa pine. *Forest Science*. 30: 238-247.
- Edlund, E. G., and R. Byrne. 1990. Climate, fire, and late Quaternary vegetation change in the central Sierra Nevada. pp. 390-396 In: S. C. Nodvin, T. A. Waldrop (technical coordinators). *Fire and the Environment: Ecological and Cultural Perspectives*. USDA Forest Service, Southeastern Research Station, Asheville, NC. General Technical Report SE-69.
- Franklin, J. F., and J. A. Fites-Kaufmann. 1996. Assessment of late-successional forests of the Sierra Nevada. pp. 627-661. In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II: Assessments and Scientific Basis for Management Options*. Centers for Water and Wildland Resources, University of California, Davis. Wildland Resources Center Report No. 37.
- Fritts, H. C., and T. W. Swetnam. 1989. Dendroecology: a tool for evaluating variations in past and present forest environments. *Advances in Ecological Research*. 19:111-188.
- Gruell, G. E. 1994. Understanding Sierra Nevada forests. California Forest Products Commission, Sacramento.
- Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research*. 3:329-382.
- Hickman, J. C., editor. 1993. *The Jepson Manual: Higher Plants of California*. University of California Press, Berkeley.
- Johnson, C. G., Jr., R. R. Clausnitzer, P. J. Mehringer, and C. D. Oliver. 1994. Biotic and abiotic processes of eastside ecosystems: the effects of management on plant and community ecology, and on stand and landscape vegetation dynamics. In: P. F. Hessburg (editor). *Eastside Forest Ecosystem Health assessment. Volume III: Assessment*. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-322.
- Johnson, E. A., and S. L. Gutsell. 1994. Fire frequency models, methods and interpretations. *Advances in Ecological Research*. 24:239-287.
- Kilgore, B. M. 1981. Fire in ecosystem distribution and structure: western forests and scrublands. pp. 58-89. In: *Proceedings of the Conference: Fire Regimes and Ecosystem Properties*. H. A. Mooney, T. M. Bonnicksen, N. L. Christensen, J. E. Lotan, and W. A. Reiners (technical coordinators). USDA Forest Service, Washington, D. C. General Technical Report WO-26.
- Kilgore, B. M., and D. Taylor. 1979. Fire history of a sequoia-mixed conifer forest. *Ecology*. 60:129-142.
- Leiberg, J. B. 1902. *Forest conditions in the northern Sierra Nevada, California*. USDI Geological Survey, Government Printing Office, Washington, D.C. Professional Paper No. 8, Series H, Forestry, 5.
- Lewis, H. T. 1993. Patterns of Indian burning in California: ecology and ethnohistory. pp. 55-116 In: T. C. Blackburn and K. Anderson (editors). *Before the Wilderness: Environmental Management by Native Californians*. Ballena Press, Menlo Park, CA.
- Madany, M. H., T. W. Swetnam, and N. E. West. 1982. Comparison of two approaches for determining fire dates from tree scars. *Forest Science*. 28:856-861.
- Manley, P. N., G. E. Brogan, C. Cook, M. E. Flores, D. G. Fullmer, S. Husari, T. M. Jimerson, L. M. Lux, M. E. McCain, J. A. Rose, G. Schmitt, J. C. Schuyler, and M. J. Skinner. 1995. *Sustaining Ecosystems: A Conceptual Framework*. USDA Forest Service, Pacific Southwest Region, San Francisco, CA. R5-EM-TP-001.
- Martin, R. E., and D. B. Sapsis. 1992. Fires as agents of biodiversity: pyrodiversity promotes biodiversity. pp. 150-157. In R. R. Harris, D. E. Erman (technical coordinators), and H. M. Kerner (editor). *Proceedings of the Symposium on Biodiversity of Northwestern California*. University of California, Berkeley. Wildland Resources Center Report No. 29.
- McKelvey, K. S., and K. K. Busse. 1996. Twentieth-century fire patterns on Forest Service lands. pp. 1119-1138 In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II, Assessments and Scientific Basis for Management Options*. Centers for Water and Wildland Resources, University of California, Davis. Wildland Resources Center Report No. 37.
- Means, J. 1989. Estimating the date of a single bole scar by counting tree rings in increment cores. *Canadian Journal of Forest Research*. 19:1491-1496.
- Millsbaugh, S. H., and C. Whitlock. 1995. A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *The Holocene*. 5:283-292.
- Morrison, P. H., and F. J. Swanson. 1990. *Fire History and Pattern in a Cascade Range Landscape*. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-254.

- Patterson, W. A., III, and A. E. Backman. 1988. Fire and disease history of forests. pp. 603-632 In: B. Huntley and T. Webb III (editors). *Vegetation History*. Kluwer Academic Publishers. Dordrecht, The Netherlands.
- Pinchot, G. 1899. The relation of forests and forest fires. *National Geographic*. 10:393-403.
- Powers, S. 1877. *Tribes of California*. University of California, Berkeley, Reprinted 1976.
- Romme, W. 1980. Fire history terminology: report of the ad hoc committee. pp. 135-137. In: M. A. Stokes and J. H. Dieterich (editors). *Proceedings of the Fire History Workshop*. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. General Technical Report RM-81.
- Sheppard, P. R., J. E. Means, and J. P. Lassoie. 1988. Cross-dating cores as a nondestructive method for dating living, scarred trees. *Forest Science*. 34: 781-789.
- Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. pp. 1041-1069. In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II, Assessments and Scientific Basis for Management Options*. University of California, Centers for Water and Wildland Resources, Davis. Wildland Resources Center Report No. 37.
- Smith, S. J., and R. S. Anderson. 1992. Late Wisconsin paleoecologic record from Swamp Lake, Yosemite National Park, California. *Quaternary Research*. 38:91-102.
- Solem, M. N. 1995. *Fire history of the Caribou Wilderness, Lassen National Forest, California, U.S.A.* M.S. thesis. The Pennsylvania State University, State College PA.
- Sprugel, D. G. 1991. Disturbance, equilibrium, and environmental variability: What is 'natural' vegetation in a changing environment? *Biological Conservation*. 58:1-18.
- Stine, S. 1996. Climate, 1650-1850. pp. 25-30. In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II, Assessments and Scientific Basis for Management Options*. University of California, Centers for Water and Wildland Resources, Davis. Wildland Resources Center Report No. 37.
- Stokes, M. A. 1980. The dendrochronology of fire history. pp. 1-3. In: M. A. Stokes, J. H. Dieterich (technical coordinators). *Proceedings of the Fire History Workshop*. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. General Technical Report RM-81.
- Sudworth, G. B. 1900. Stanislaus and Lake Tahoe Forest Reserves, California, and adjacent territories. pp. 505-561 In: *Annual Reports of the Department of Interior, 21st Annual Report of the U.S. Geological Survey, Part 5*. Government Printing Office, Washington, D.C.
- Swanson, F. J., J. A. Jones, D. O. Wallin, and J. H. Cissel. 1994. Natural variability -- implications for ecosystem management. pp. 80-94. In: M. E. Jensen and P. S. Bourgeron (editors). *Eastside Forest Ecosystem Health Assessment. Volume II: Ecosystem Management: Principles and Applications*. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-318.
- Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. *Science*. 262:885-889.
- Taylor, A. H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. *Canadian Journal of Forest Research*. 23:1672-1678.
- Wells II, W. G. 1982. Hydrology of Mediterranean-type ecosystems: a summary and synthesis. pp. 426-430. In: C. E. Conrad and W. C. Oechel (technical coordinators). *Proceedings of the Symposium on Dynamics and Management of Mediterranean-type Ecosystems*. USDA Forest Service, Pacific Southwest Research Station, Berkeley. General Technical Report PSW-58.
- Wickstrom, C. K. R. 1987. *Issues Concerning Native American Use of Fire: A Literature Review*. USDI, National Park Service, Yosemite National Park, Yosemite Research Center, Yosemite, CA. Publications in Anthropology No. 6.
- Woolfenden, W. B. 1996. Quaternary vegetation history. pp. 47-70. In: *Sierra Nevada Ecosystem Project: Final Report to Congress. Volume II, Assessments and Scientific Basis for Management Options*. Centers for Water and Wildland Resources, University of California, Davis. Wildland Resources Center Report 37.

Skinner, C. N. 1997. Toward an understanding of fire history information. Pages 15-22 in S. Sommarstrom, editor. What is watershed stability? A review of the foundation concept of dynamic equilibrium in watershed management. Centers for Water and Wildland Resources, University of California, Davis, Water Resources Center Report No. 92.

WHAT IS WATERSHED STABILITY?

*A review of the foundation concept of Dynamic Equilibrium
in watershed management*

PROCEEDINGS OF THE SIXTH BIENNIAL WATERSHED MANAGEMENT CONFERENCE

October 23-25, 1996
Cal/Neva Resort Hotel, Lake Tahoe, California/Nevada

Sponsored by the
WATERSHED MANAGEMENT COUNCIL



Edited by
Sari Sommarstrom

**CENTERS FOR
WATER AND
WILDLAND
RESOURCES**



**UNIVERSITY OF CALIFORNIA
WATER RESOURCES CENTER REPORT NO. 92
ISBN 1-887192-06-9
APRIL 1997**