Forest Changes Since Euro-American Settlement and Ecosystem Restoration in the Lake Tahoe Basin, USA[1]

Alan H. Taylor[2]

Abstract

Pre Euro-American settlement forest structure and fire regimes for Jeffrey pine-white fir, red fir-western white pine, and lodgepole pine forests were quantified using stumps from trees cut in the 19th century to establish a baseline reference for ecosystem management in the Lake Tahoe Basin. Contemporary forests varied in different ways compared to the presettlement reference. Contemporary Jeffrey pine-white fir forests have more and smaller trees, more basal area, less structural variability, and trees with a more clumped spatial distribution than presettlement forests. The mean presettlement fire return interval for the period 1450-1850 for Jeffrey pine-white fir forests was 11.5 years, and most fires (>90 percent) burned in the dormant season, while no fire was recorded in the study area after 1871. Differences in the structural characteristics of contemporary and presettlement red fir-western white pine and lodgepole pine forests were similar to those for Jeffrey pine-white fir forests. However, 19th century logging changed the composition of red fir-western white pine forests, and these forests now have more lodgepole pine than red fir or western white pine. Comparison of contemporary Jeffrey pine-white fir forests with the presettlement reference suggest that restoration treatments should include: (1) density and basal area reduction, primarily of smaller diameter trees, (2) reintroduction of frequent fire as a key regulating disturbance process, and (3) increasing structural heterogeneity by shifting clumped tree distributions to a more random pattern. Restoration treatments in red fir-western white pine forests should include: (1) a shift in species composition by a density and basal area reduction of lodgepole pine, and (2) increasing structural heterogeneity by shifting tree distributions to a more random pattern. In lodgepole pine forests, the restoration emphasis should be: (1) a density and basal area reduction of small diameter trees, and (2) an increase in structural heterogeneity that shifts tree spatial patterns from clumped to a more random distribution. Re-introduction of fire as a regulating process into high elevation red fir-western white pine and lodgepole pine forests may be viewed as a long-term restoration goal.

Introduction

The concepts of reference conditions and the range of natural variability are central to forest management practices being developed under the rubric of ecosystem management (Agee and Johnson 1988, Grumbine 1994, Kaufmann et al. 1994, Overbay 1992). Reference conditions are usually considered the range of historical variability in forest structures and processes at the time of European settlement (Morgan et al. 1994, Swanson et al. 1994). Perspectives that emphasize the management of forests within their historical range of variability evolved from an

---

[1] A version of this paper was presented at the National Silviculture Workshop, June 6-10, 2005, Tahoe City, California.
[2] Department of Geography, The Pennsylvania State University, 302 Walker Building, University Park, PA 16802.

understanding of what presettlement conditions were, and how and why contemporary conditions deviate from them (Covington et al. 1997, Kaufmann et al. 1994, Landres et al. 1999, Morgan et al. 1994, Swanson et al. 1994). Presumably, management for presettlement conditions will maintain important evolutionary and functional linkages between species and reduce the risk of unexpected ecological outcomes such as species extinction (Landres et al. 1999, Moore et al. 1999, Swanson et al. 1994). Identification of reference conditions is therefore an essential step in implementing ecosystem management. Moreover, reference conditions represent a framework for evaluating current ecosystem structures and processes and for designing restoration treatments to change current conditions if they fall outside their historic range of variability (Covington and Moore 1992, Fule et al. 1997, Grumbine 1994, Kaufmann et al. 1994, Morgan et al. 1994, Swanson et al. 1994). In cases where contemporary forest conditions are outside their range of historic variability, the presettlement reference can also be used to identify restoration goals and to develop restoration treatments (e.g., Fule et al. 1997, Moore et al. 1999, Morgan et al. 1994, Swetnam et al. 1999, White and Walker 1997).

In the Sierra Nevada, forests have been dramatically altered by Euro-American land use practices. Forest lands have been logged, grazed, and burned since the mid to late 19th century (McKelvey and Johnston 1992, SNEP 1996, Vankat and Major 1978). Consequently, resource managers need information on presettlement forest conditions where much of the evidence of the forest was removed by 19th or 20th century logging. In the Lake Tahoe Basin, forests were logged soon after initial Euro-American settlement (hereafter presettlement) (Leiberg 1902). Small scale logging to supply timber for local use began as early as 1861 and near clearcut logging occurred between 1873 and 1900 (*fig. 1*) (Lindström 2000, Strong 1984). Contemporary forests became established after logging.

In this paper, reference conditions from well preserved cut stumps on early cut-over lands were used to identify and compare historical and contemporary forest characteristics in the Lake Tahoe Basin as a basis for forest ecosystem management. The specific questions addressed in this study were: (1) What was the historical range of variability in forest structure, i.e., species composition, size structure, spatial pattern, on the east shore of Lake Tahoe, and how is contemporary forest structure different? (2) How did presettlement fire regimes vary spatially and temporally? (3) How can this information be used to guide restoration of forests in the Lake Tahoe Basin towards a presettlement condition?

Study Area

Forests were sampled in a 2900 ha area on the west slope of the Carson Range on the east shore of Lake Tahoe (*fig. 1*). Elevations range from 1910-2666m. The topography of the Carson Range is steep and complex, and variability in elevation and topography exert strong control on the distribution of forest types in the study area. Three forest cover types occur in the area: (1) Jeffrey pine (*Pinus jeffreyi*) forests occur at lower elevations, (2) red fir (*Abies magnifica*) -western-white pine (*P. monticola*) forests occur at mid-elevation, and (3) lodgepole pine (*P. contorta* var. *murrayana*) occupy at high elevations or wet sites within the red fir zone. Climate in the Lake Tahoe Basin is characterized by cold-wet winters and warm-dry summers. Mean monthly temperatures at South Lake Tahoe (1820m) range from -1°C in January to 18°C in July and mean annual precipitation is 78.4 cm. Most precipitation

(86 percent) falls as snow between November and April. The terrain is steep and complex and forests grow on shallow (< 1m), excessively drained, medium acidity soils derived from Mesozoic aged granite (Hill 1975, Rogers 1974). Stands sampled in this study were located where the original forests were nearly clearcut during the Comstock mining era, and where stumps were well preserved. Sampled sites included the observed variability in the density and size-class distributions of well preserved stumps and live trees in each forest type. A total of 20 stands (11 Jeffrey pine, six red fir-western white pine, three lodgepole pine) were sampled in this study.

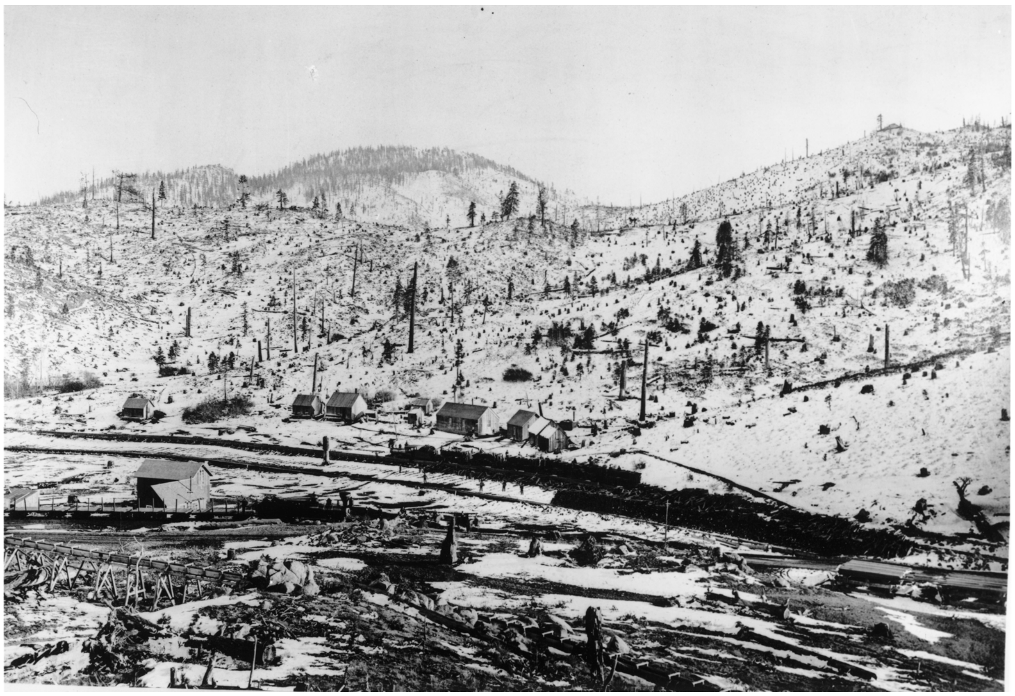

Figure 1—Forest conditions in the study area in 1876 at Spooner Summit in the Carson Range, on the east shore of Lake Tahoe, Nevada (C.E. Watkins). Note the near clearcut logging of the forest and the presence of cut stumps that served as the basis for the reconstruction of presettlement forest conditions in the Carson Range, Lake Tahoe Basin, Nevada.

Methods

Forest Structure and Composition

All forest stands were sampled using 50m X 100m (0.5 ha) plots, and the location (UTM coordinates with a GPS), slope aspect, slope pitch, and elevation of each plot were recorded. All stumps and live trees (stems ≥10 cm in diameter at breast or stump height) within a plot were mapped to the nearest 0.3m by establishing a 10m X 10m grid and then measuring the coordinates (x,y) of each tree from the origin (0,0) of each cell using a metric measuring tape. The species and diameter of each stump (stemwood) or live tree (outside bark at dbh) were then recorded. Bark thickness was added to stump stemwood diameter using bark thickness estimates from inside-outside bark diameter regression equations developed for ponderosa pine (*P. ponderosa*), sugar pine (*P. lambertiana*), and red and white fir (i.e., Dolph 1989, Larsen and Hann 1985, Walters and Hann 1986a). Lodgepole pine has thin bark (<1 cm) (Agee 1993) so bark thickness was not added to lodgepole pine stump diameters.

Stand Age Structure

The age of the post-logging cohort was estimated by coring 9 to 26 of the largest diameter contemporary trees 30 cm above the ground surface in each plot. Cores were sanded to a high polish, their growth rings were cross-dated (Stokes and Smiley 1968), and tree age was assigned based on the calendar year of the inner most ring. The ages of potential presettlement trees, i.e. established prior to 1850, were also determined in each plot. Presettlement trees were distinguished from the post-logging cohort by their height, crown form, large diameter, bark structure and thickness, and highly clumped spatial pattern. All potential presettlement trees were cored, cores were sanded and cross-dated, and their annual growth rings were measured to the nearest 0.01 mm. Total radial growth since the logging date was then subtracted from tree diameter to determine stem diameter on the date the stand was logged. All presettlement stems ≥10 cm on the date of logging were included in presettlement forest reference estimates. The date of logging in each plot was estimated by identifying the dates of sudden increases in radial growth in surviving presettlement trees. Growth releases were identified visually from graphs of a standardized growth index (actual width/mean width) (Veblen et al. 1991), derived from the radial growth measurements of presettlement trees in each plot.

Spatial Patterns

The type, scale, and intensity of spatial patterns of trees in the presettlement and contemporary forest were identified and compared using Ripley's K(t) function (Ripley 1977). Ripley's statistic examines the number of stems around each stem in concentric circles of a given radius (Duncan 1991, Kengel et al. 1997). The number of stems, occurring within a circle of radius t, is compared with the expected number of stems based on a Monte Carlo simulation of a randomly (Poisson) distributed point pattern. This pattern permits detection of significant ($P<0.05$) aggregation or hyper-dispersion in a population. The intensity of pattern is indicated by the magnitude of K(t), and the scale of pattern is determined by the radius of the distance class, which in this case was 3m.

Fire History

Fire occurrence in presettlement Jeffrey pine forests was identified for 13 sites, of about 10 ha each, from fire scars recorded in the annual growth rings of stumps (n=39) and recently dead standing presettlement trees (n=2). Samples were removed from the stumps and live trees with a chainsaw and the tree rings in each sample were cross-dated using standard dendrochronological procedures (Stokes and Smiley 1968). The calendar year of each tree ring with a fire scar lesion in it was then recorded as the fire date. Presettlement fire histories in red fir-western white pine and lodgepole pine forests could not be reconstructed from cut stumps. Stumps with fire scars in them shattered when samples were extracted with a chainsaw. The season of burn for a fire was determined from the position of the fire scar lesion within the annual growth ring, following Baisan and Swetnam (1990): (1) early (first 1/3 of earlywood), (2) middle (second 1/3 of earlywood), (3) late (last 1/3 of earlywood), (4) latewood (in latewood), (5) dormant (at ring boundary). In this area of strongly seasonal precipitation (winter wet, summer dry), dormant fires represent fires that burned in late summer or fall after radial growth ceased for the year, not fires that burned in winter or early spring (Caprio and Swetnam 1995).

Results

Dates of Logging and Forest Age-Structure

Logging dates were determined for 17 of the 20 plots. Four plots were cut in the 1870s, ten were cut in the 1880s, two were cut in the 1890s, and one was cut in 1905. Based on the dates of logging in adjacent plots, the other three plots were probably logged in the 1870s (n=1) and 1890s (n=2).

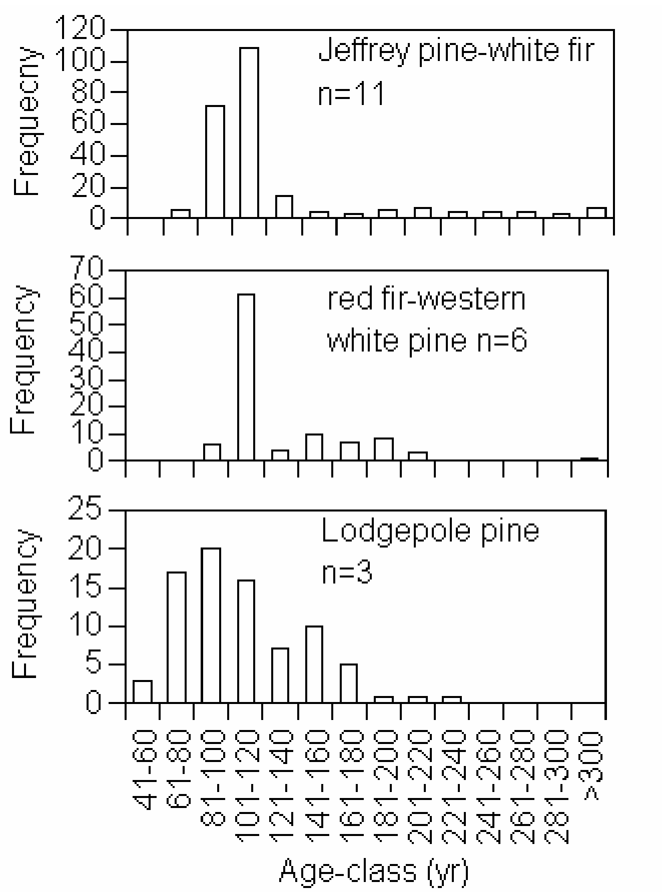

Figure 2—Frequency distribution of aged trees in contemporary forests in 20-yr age-classes, n is the number of plots.

Tree ages in the plots were similar in all forest types. Most trees were 80-120 years old and became established soon after logging (*fig. 2*). There were surviving presettlement trees in the plots but they were not abundant. On average, Jeffrey pine-white fir plots had 9.2 (range 0-44), red fir-western white pine plots had 10.4 (range 0-16), and lodgepole pine plots had 16.6 (range 0-26) trees ha^{-1} >120 years-old.

Forest Structure and Composition

Jeffrey Pine-White Fir Forests

The characteristics of presettlement Jeffrey pine-white fir forests were different than those of contemporary forests (*table 1*, *fig. 3a*). Contemporary forests were more dense, they had greater basal area, and they had different shaped size-class distributions than presettlement forests. There were few presettlement trees <40 cm dsh and contemporary Jeffrey pine, white fir, and red fir trees were smaller in diameter than presettlement trees (*table 1, fig. 3a*).

The spatial patterns of trees were also different in the presettlement and contemporary forest (*table 2*, *fig. 4a*). Presettlement trees >10 cm dsh and >40 cm dsh were clumped at small scales (≤ 9m) in <50 percent of the plots, and they were randomly distributed at larger scales. Large presettlement trees (>40 cm dsh) in a few

Table 1—*Structural characteristics of presettlement and contemporary forest stands on the east shore of Lake Tahoe, Carson Range, Nevada. Density and basal area estimates are for stems >10 cm in diameter.*

	Presettlement				**Contemporary**			
Forest type	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Jeffrey pine-white fir								
Density (trees ha^{-1})								
Jeffrey pine	55	9.7	26	90	297	171.5	132	758
White fir	13	9.7	0	32	38	21.6	8	78
Red fir	1	2.8	0	10	8	19.1	0	68
All	68	22.2	30	114	343	178.7	172	794
Basal area (m^2 ha^{-1})								
Jeffrey pine	19.4	5.3	11.6	29.3	38.9	6.6	23.4	48.1
White fir	5.7	4.1	0	12	5.1	2.8	0.4	11
Red fir	0.4	1	0	2.6	2.4	5.3	0	18.2
All*	25.5	8.1	12.6	38.1	46.4	6.3	28.4	58.7
Diameter (cm)								
Jeffrey pine	68	7.8	54	85.6	38.7	8.5	28.6	52.5
White fir	76.3	27.9	54.8	113	45.4	14.1	25.3	66.4
Red fir	75.5	78.9	56.2	97.2	43.7	12.8	39.2	58.2
All	67.5	8.1	54.7	85.3	39.4	8.8	27.8	52.7
Red fir-western white pine								
Density (trees ha^{-1})								
Red fir	94	32.1	68	142	184	142	14	328
Western white pine	53	17.9	22	74	71	52.4	14	146
Lodgepole pine	14	23	0	58	274	188.8	0	484
White fir					1	1.7	0	4
Jeffrey pine	1	0.7	0	4	3	2.8	0	6
All	162	33.1	118	208	538	259.1	214	842

Basal area (m^2 ha^{-1})								
Red fir	40	9.3	27	53	24	16.9	5.7	50
Western white pine	15.5	6.4	5.8	22.2	6.5	5.1	0.8	13.3
Lodgepole pine	0.3	3.2	0	8.2	17.9	10.5	0	31.6
White fir					<0.1	0.1	0	0.2
Jeffrey pine					0.1	0.1	0	0.3
All	55.8	9.3	40.9	67.8	48.5	15.4	31.7	71.4
Diameter (cm)								
Red fir	73.5	8.1	62.3	80.8	42.1	10.3	31.5	60.7
Western white pine	63.9	9.8	47.3	80.3	32.1	8.3	21.8	41.5
Lodgepole pine	33.8	10.3	27.3	41.5	28.3	5.1	23.2	31.4
White fir					27.6			
Jeffrey pine					20	7.6	16.8	23.1
All	64.9	7.1	56.6	75.1	33.1	5.6	26.7	39.8
Lodgepole pine								
Density (trees ha^{-1})								
Lodgepole pine	171	74	90	234	583	334	202	850
Red fir	12	17.3	0	32	27	3.5	0	76
Western white pine					4	6.9	0	12
White fir					1	1.2	0	2
Jeffrey pine	3	4.7	0	8	2	2.1	0	4
All	186	85.7	98	266	617	366	204	860
Basal area (m^2 ha^{-1})								
Lodgepole pine	55.6	32	29.7	91.4	40.3	14.5	26	55.1
Red fir	1.5	1.4	0	2.3	6.4	11.1	0	19
Western white pine	2.6	4.5	0	7.9	0.3	0.9	0	0.6
White fir					0.4	0.5	0	1
Jeffrey pine					0.1	0.2	0	0.2
All	59.7	87.6	37.6	93.5	47.8	18.9	26.1	59.6
Diameter (cm)								
Lodgepole pine	62.4	7.3	54.5	69.2	29.4	6.6	25.4	36.9
Red fir	59.5	44.2	33.9	85	42.9	17	33.2	52.5
Western white pine	107.3				41.4	21.7	28.8	54
White fir								
Jeffrey pine								
All	62.4	6.4	55	66.4	30.4	5.7	26.1	36.9

plots were clumped at intermediate scales (12-15m). Contemporary trees >10 cm dbh and <40 cm dbh in 90 percent of the plots, in contrast, had clumped distributions at all scales and large (>40 cm dbh) contemporary trees were clumped at all scales in about half the plots.

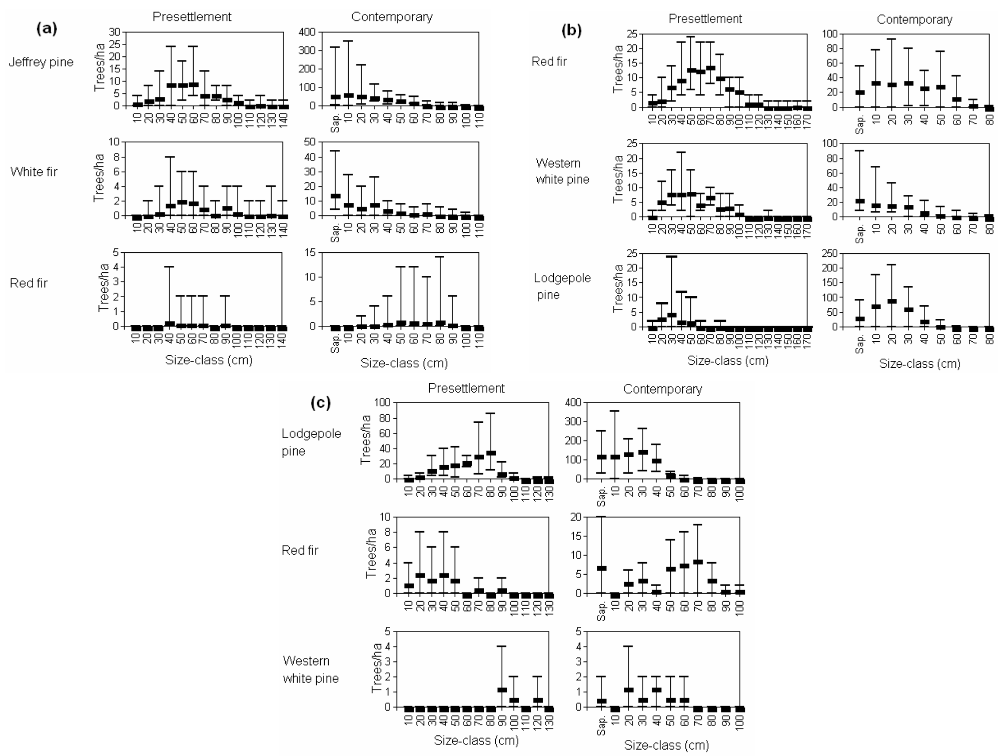

Figure 3—Average density and range of trees (stems ≥10 cm in diameter) and trees and saplings (stems >1.4m tall and <10 cm in diameter) in presettlement and contemporary (a) Jeffrey pine-white fir forest plots (n=11), (b) red fir-western white pine (n=6), and (c) lodgepole pine forest (n=3) forest plots. Note that the scale of the y-axis is not the same on the graphs. Not shown for contemporary forests of red fir-western white pine are Jeffrey pine in the Sapling (mean=0.7, range0-2), 10 cm (mean=1.3, range 0-4) and 30 cm (mean=0.7, range 0-2) size-classes, and white fir in the 20 cm (mean=0.3, range 0-2) and 30 cm (mean=0.3, range 0-2) size-classes. Not shown for contemporary lodgepole pine forests are Jeffrey pine in the 40 cm (mean=0.7, range 0-2) size-class, and white fir in the 30 cm (mean=1.0, range 0-2) size-class.

Red Fir-Western White Pine Forests

The characteristics of presettlement red fir-western white pine forests were different than those of contemporary forests *(table 1*). Presettlement forests were less dense than contemporary forests but basal areas were similar. The composition of contemporary and presettlement forests was quite different. Presettlement forests were mainly red fir and western white pine, while lodgepole pine was present in only two plots. Contemporary forests, on the other hand, have more lodgepole pine than red fir or western white pine, and >50% of the contemporary trees are lodgepole pine. The size-class distributions of the contemporary and presettlement forest were also

Table 2—*Frequency of plots with a clumped distribution (Ripley's K(t), P<0.05) at 3m distance steps for three diameter classes (>10 cm, <40 cm, >40 cm) of stems in presettlement and contemporary forests. Only populations with >13 individuals were analyzed and those that were too small are indicated by a dash (-); n=number of plots.*

Forest type	**Distance (m)**								
	n	3	6	9	12	15	18	21	24
Jeffrey pine-white fir									
Presettlement									
>10 cm	11	4	5	3	1	1	0	0	0
<40 cm	11	-	-	-	-	-	-	-	-
>40 cm	11	5	4	4	3	3	1	0	0
Contemporary									
>10 cm	11	11	11	11	11	11	11	11	11
<40 cm	11	11	11	11	11	11	11	10	10
>40 cm	11	3	6	5	5	5	7	5	5
Red fir-western white pine									
Presettlement									
>10 cm	6	5	4	2	0	1	1	1	1
<40 cm	6	2	1	1	1	1	1	0	0
>40 cm	6	4	2	1	1	0	0	0	0
Contemporary									
>10 cm	6	6	6	0	5	5	6	5	4
<40 cm	6	5	5	5	5	4	4	4	4
>40 cm	6	5	3	3	2	2	2	0	0
Lodgepole pine									
Presettlement									
>10 cm	3	1	3	2	2	2	1	1	1
<40 cm	3	0	0	0	0	0	0	0	0
>40 cm	3	1	1	2	1	1	1	1	1
Contemporary									
>10 cm	3	3	3	3	3	3	2	2	2
<40 cm	3	3	3	3	3	3	3	2	2
>40 cm	3	1	1	0	0	0	0	0	0

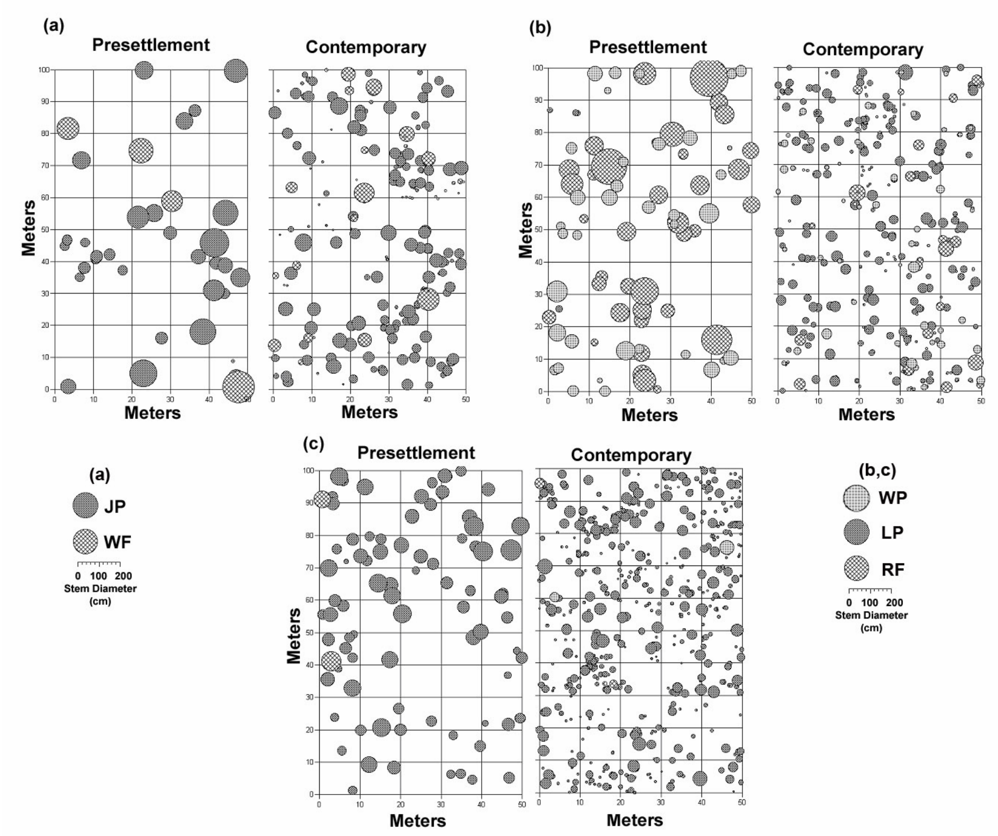

Figure 4—Stem maps of presettlement and contemporary (a) Jeffrey pine-white fir, (b) red fir-western white pine, and (c) lodgepole pine forest in the Carson Range, Lake Tahoe Basin, Nevada. Each pair illustrates stand structure in the same 0.5 ha plot. The plots shown for each forest type had the median presettlement stem density. Species acronyms are: JP-Jeffrey pine, LP- lodgepole pine, RF-red fir, WF-white fir, WP-western white pine.

different and presettlement red fir, western white pine, and lodgepole pine trees were larger than contemporary trees *(table 1*, *fig. 3b*). There were few presettlement trees <30 cm dsh.

The spatial patterns of trees were also different (*table 2*, *fig. 4a*). Presettlement trees >10 cm dsh and >40 cm dsh were most frequently clumped at small scales (<9m), and randomly distributed at larger scales (*table 2*, *fig. 4b*). Small and intermediate sized trees (<40 cm dsh) were usually randomly distributed at all scales. In most contemporary forest plots, all but the largest trees (>40 cm dbh) had a clumped distribution at all scales. Large contemporary trees (>40 cm dbh), in contrast, were most frequently clumped at the smallest scales (3-9m), and they were randomly distributed at larger scales (*table 2*).

Lodgepole Pine Forests

Presettlement lodgepole pine forests were less dense than the contemporary forests but their basal areas were similar (*table 1*). Presettlement trees were also larger than those in the contemporary forest, and they were present in a wider range of size-classes (*fig. 3c*). There were few presettlement stems <30 cm dsh in any of the plots. Spatial patterns of presettlement lodgepole pine trees varied by size class but they were different than for contemporary trees. Presettlement trees >10 cm and >40 cm dsh were clumped at all scales in some plots, and trees <40 cm dsh were randomly distributed at all scales. In contemporary forests, trees >10 cm and trees <40 cm were usually clumped at all scales, but large trees (>40 cm dbh) were mainly randomly distributed (*table 2*, *fig. 4c*).

Fire History in Jeffrey Pine-White Fir Forests

A long history of fire was preserved in Jeffrey pine stumps. One hundred and fifty-six fires were recorded as fire scars in the stumps. The fire record spanned the period AD 1160 to 1871, but only one site recorded fires before 1400. Four sites recorded fires by 1450, so the period 1450 to 1850 was selected as the period for the presettlement period fire disturbance analysis (*fig. 5*). Sample depths >10 percent are generally adequate to analyze temporal variation in fire occurrence in short fire return interval ecosystems (Caprio and Swetnam 1995).

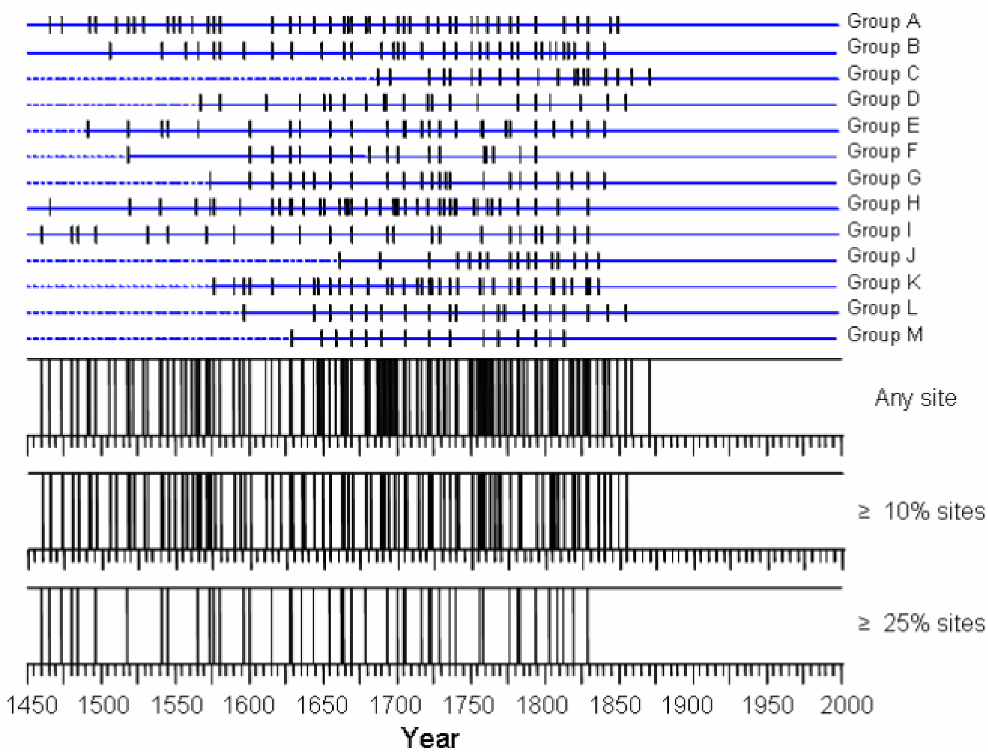

Figure 5—Fire chronology for Jeffrey pine-white fir forests for the period 1450-2000 for the 13 sample sites on the east shore of Lake Tahoe, Carson Range, Nevada. Fire dates are indicated by short vertical lines. The top portion of the graph shows fires record in each of the 13 sample sites. The three composite graphics at the bottom show fires recorded by all, >10% or more, and >25% or more of the sites.

Mean fire interval (MFI) estimates varied with sample area size and the MFI was shorter for the composite chronology for all sites (2.9 years) and longer for site chronologies (11.4 years) (*table 3*). The frequency of fires of different extent was inferred from the number of sites recording a fire. Small fires recorded by one or <10 percent of the sites were the most frequent type of fire and they had the shortest MFI (*table 3*, *fig. 5*). Larger fires recorded by 25 percent or more of the sites were less frequent and had longer MFI.

Table 3—*Fire return intervals statistics (years) for sites (n=13), and for a composite of all sites for the period 1450-1850. WMPI is the Weibull median probability fire interval.*

Type of sample	Number intervals	Mean	Median	WMPI	Std. Dev.	Min.	Max.	Skew-ness	Kurt-osis
Sites	321	11.4	9	9.8	8.6	1	82	2.8	15.6
Site composite									
All fires	135	2.9	2	2.5	2.3	1	12	1.5	2
>10% scarred	98	4	4	3.6	2.6	1	12	0.8	0.2
>25% scarred	45	8.2	7	7.1	5.7	1	23	0.9	0.1

The position of fire scars within annual growth rings indicate that fires burned mainly in the dormant season after trees had stopped radial growth for the year. This pattern suggests that dormant season fires burned in late summer or early fall, since radial growth of Jeffrey pine north of Lake Tahoe (120 km) is complete by late August (Taylor 2000).

Discussion

The structure and composition of forests that now cover the east shore of Lake Tahoe are very different from the pre Euro-American forests. Overall, the original forest was more open, less dense, and was composed of trees that varied widely in diameter. The original forest was removed over a period of 2-3 decades, beginning in the 1870s, to supply timber and cordwood to the Comstock mines in Virginia City, Nevada. A new forest began to establish immediately after stands were logged and forests in the Carson Range are now mostly dense 100-120 yr-old second growth, where trees are relatively small in diameter. This general description of forest changes in the Carson Range since the late 1800s is derived using dendroecological techniques, and it is consistent with written descriptions of the extent and severity of logging in the Lake Tahoe Basin in the 19th century (Leiberg 1902). However, written descriptions do not provide the quantitative data on presettlement forest characteristics needed by managers to design treatments to restore forests to the desired condition. In the case of the Lake Tahoe Basin, the desired condition has been identified by multiple stakeholders as the presettlement condition (Christopherson et al. 1996).

Sites for this study were chosen for conditions that promoted stump preservation to reduce uncertainty in reconstructed forest characteristics caused by disappearance of material. Complete decay, logging, or consumption of woody material by fire can eliminate evidence of the earlier forest (Fule et al. 1997). Small diameter stumps were present on most sites indicating that post-logging consumption of wood was unlikely. Wood decay varies with size and species and, in California forests, fir decays more quickly than pines, and small stems decay more rapidly than large ones (Kimmey 1955, Harmon et al. 1987). Therefore, reconstructed density and basal area estimates may be more reliable for pines than fir, and for large than small trees. Thus, managers should use the reference estimates conservatively in evaluating how contemporary forests deviate from the presettlement conditions, and for developing forest-ecosystem restoration goals.

Comparison of Presettlement and Contemporary Conditions

The presettlement reference conditions identified for the Carson Range can be applied by managers and stakeholders to: (1) evaluate contemporary forest conditions to prioritize management activities, (2) determine the causes of contemporary forest change, and (3) develop treatment strategies to restore highly altered forests to a desired condition (Christopherson et al. 1996, Covington et al. 1997, Kaufmann et al. 1994, Moore et al. 1999, Swanson et al. 1994, White and Walker 1997). Forests on the east shore of Lake Tahoe have a shared history and consequently they share certain common characteristics. They established immediately after near clearcut logging in the late 19th century, and then developed during a long post-logging, fire-free period. Yet, a comparison of presettlement and contemporary forest conditions and fire history suggest that contemporary forests vary in how and why they deviate from the presettlement reference.

Compared to presettlement forests, contemporary Jeffrey pine-white fir forests have smaller trees, less structural variability and, on average, five-fold more trees and nearly two-fold more basal area. The density and basal area change differences are greater in Jeffrey pine-white fir forests than for other forest types because of the key role of frequent fire in shaping presettlement Jeffrey pine-white fir forest structure, and the effect of fire suppression on post-logging stand development. The fire record demonstrates that low severity surface fires burned frequently. These fires maintained low stand density and basal area by thinning seedlings, saplings, and small diameter trees in presettlement Jeffrey pine-white fir forests. Moreover, the most widespread fires occurred during drought years that were preceded by wet years 2-3 years before the drought. Fuel buildup during the wet years appears to have predisposed the landscape to widespread burning during drought. No thinning fires have burned in Jeffrey pine-white fir forests since 19th century logging, and the post-logging fire-free period is unprecedented in length compared to the >400 year record of presettlement fire. Thus, fire regime changes caused by fire suppression have resulted in greater changes in Jeffrey pine-white fir forests from the presettlement condition than for the other forest types.

Fire regimes were not identified for presettlement red fir-western white pine and lodgepole pine forests in the Lake Tahoe Basin, but data on fire regimes for these types of forests elsewhere in the Sierra Nevada and southern Cascades suggest that return intervals are much longer (45-110 years) (Bekker and Taylor 2001, Caprio in press, Pitcher 1987, Taylor 2000). In fact, the 120 year post-logging fire free period may not exceed the longest fire free periods experienced in these forest types during the presettlement period. Consequently, although contemporary forests are denser and less structurally diverse than presettlement forests, the role of logging in these differences is probably more important than fire suppression. The post-logging compositional change in red fir-western white pine forests illustrates this point. Lodgepole pine was a minor component of presettlement stands, but its density in contemporary forests exceeds the combined density of red fir and western white pine. The mass establishment of lodgepole pine after logging the red fir-western white pine forests indicates that it is a successful pioneer species. The post-logging expansion of lodgepole pine into red fir forests may be temporary. Seedlings and saplings of red fir and western white pine are abundant in the understory of these stands suggesting that they may replace lodgepole pine as stands develop.

Lodgepole pine regeneration was also prolific after logging in presettlement lodgepole pine forests. In fact, contemporary lodgepole pine forests are the densest forests in the Carson Range. On these sites, however, lodgepole pine appears to be self-replacing and not successional. Lodgepole pine saplings and seedlings are abundant in the forest understory and continuous regeneration of lodgepole appears to be a characteristic feature of Sierra Nevada lodgepole pine forests (Parker 1986).

Despite uncertainty associated with possible disappearance of material, reference conditions identified from stumps are similar to reference conditions reconstructed from remnant old-growth stands in other parts of the Lake Tahoe Basin (Manley et al. 2000). Average presettlement tree density in old-growth Jeffrey pine (n=7) and mixed conifer (n=11) stands ranged from 63-67 trees ha^{-1}, similar to the value (68 trees ha^{-1}) reconstructed from stumps. Mean basal area from stumps and old-growth trees was also similar (25.3 m^2 ha^{-1} vs. 27 m^2 ha^{-1}). The tree density estimate from old-growth red fir stands (n=14) is lower (mean =107 trees ha^{-1}) than for stumps (mean=161 trees ha^{-1}), but the basal area estimates are similar (53 m^2 ha^{-1} vs. 55.8 m^2 ha^{-1}). There are no data for old-growth lodgepole pine stands for the Lake Tahoe Basin for comparison with stump reconstructions. The similarity in the estimates of density and basal area from stumps and old growth forest suggest that the reference estimates from stumps are sufficiently reliable for use as a guide for forest restoration planning in the Lake Tahoe Basin.

Application to Desired Conditions

In the Lake Tahoe Basin, the goal of institutional and citizen stakeholders is to return contemporary forests to a presettlement structure (Christopherson et al. 1996). The measurements of preserved cut stumps provide a range of quantitative estimates of presettlement forest conditions that can be used to meet forest restoration goals. Resource managers, however, need to use this reference information prudently in the process of developing plans. The reference conditions were established for limited parts of the landscape, where stump preservation was excellent. Reference conditions for other sites on the landscape, or other areas in the Lake Tahoe Basin, may deviate from those for sites with well preserved cut stumps. Resource managers can accommodate for some of these limitations by incorporating other ecological knowledge into restoration plans. For example, the Jeffrey pine-white fir forest reference is from the Carson Range, which is more xeric than sites on the west shore of Lake Tahoe (Barbour et al. 2002). In mixed Jeffrey pine-white fir forests, white fir is more abundant on mesic than xeric sites (Barbour 1988, Vankat 1982). Thus, resource managers could adjust the reference to include more white fir on more mesic parts of the landscape. For restoration planning, a reference should be viewed as a foundation for designing restoration treatments that will be complemented by multiple types of other ecological information, rather than as a rigid target that defines the acceptable outcome (Allen et al. 2002, Landres et al. 1999).

Contemporary forests on the east shore of Lake Tahoe vary in different ways from the presettlement reference forest, and plans to achieve desired conditions need to vary accordingly. Contemporary Jeffrey pine-white fir forests deviate more from the presettlement reference conditions than other forest types and restoration of these forests should receive highest priority. In Jeffrey pine-white fir forests, the reference conditions suggest that restoration objectives should emphasize: (1) density and basal area reduction primarily of smaller diameter trees (<40 cm dbh), (2) reintroduction of frequent fire as a key regulating disturbance process, and (3) increasing structural heterogeneity by shifting clumped tree distributions to a more random pattern.

Reference conditions for presettlement red fir-western white pine forests indicate that restoration objectives for contemporary forests should emphasize: (1) a shift in species composition by a density and basal area reduction of pioneer lodgepole pine, and (2) increasing structural heterogeneity by shifting tree distributions to a more random pattern. Reference conditions for presettlement lodgepole pine indicate that restoration objectives for contemporary forests should emphasize: (1) a density and basal area reduction of small diameter trees (<30 cm dbh), and (2) increasing structural heterogeneity by shifting tree distributions to a more random pattern. Given the relatively low fire frequency in higher elevation red fir-western white pine and lodgepole pine forests, re-introduction of fire as a regulating process may be viewed as a long-term forest restoration goal. Given that the physical legacy of the presettlement forests on lands affected by early-day logging (cut stumps) is still present in many landscapes (Fule et al. 1997), the method of estimating reference conditions from well preserved stumps may also be applicable for use on other early cut-over lands in other forest ecosystems in the western United States.

References

Agee, J. and D.R. Johnson. 1988. **Ecosystem management for parks and wilderness.** University of Washington Press, Seattle.

Agee, J.K. 1993. **Fire ecology of Pacific Northwest forests.** Island Press, Washington D.C., USA.

Allen, C.D., M. Savage, D. Falk, K.F. Suckling, T.W. Swetnam, T. Schulke, P.B. Stacey, P. Morgan, M. Hoffman, and J.T. Klingel. 2002. **Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective.** Ecological Applications 12:1418-1433.

Baisan, C.H., and T.W. Swetnam. 1990. **Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, USA.** Canadian Journal of Forest Research 20:1559-1569.

Barbour, M.G., E. Kelley, P. Maloney, D. Rizzo, E. Royce, and J. Fites-Kaufman. 2002. **Present and past old-growth forests of the Lake Tahoe Basin, Sierra Nevada, USA.** Journal of Vegetation Science 13:461-472.

Barbour, M.G. 1988. **California upland forests and woodland,** Pages 131-164 In M.G. Barbour and W.D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, Cambridge, UK.

Bekker, M.F., and A.H. Taylor. 2001. **Gradient analysis of fire regimes in montane forests of the southern Cascade Range, Thousand Lakes Wilderness, California, USA.** Plant Ecology 155:15-28.

Caprio, A.C. and T.W. Swetnam. 1995. **Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada.** In: Brown, J.K., Mutch, R.W., Spoon, C.W., Wakimoto, R.H. (Tech. Coord.) Proceedings: Symposium on fire in Wilderness and Park Management; 1993, March 30-April 1; Missoula, MT. USDA Forest Service General Technical Report GTR-320.

Caprio, A.C. in press. **Reconstructing fire history of lodgepole pine on Chagoopa Plateau, Sequoia National Park California.** M.G. Narog, technical coordinator. Proceedings of the 2002 fire conference: Managing fire and fuels in the remaining wildlands and open spaces of the southwestern United States. U.S. Forest Service General Technical Report PSW-GTR-189.

Christopherson, J., S.R. Lewis, and M. Havercamp. 1996. **Lake Tahoe's Forest Health Consensus Group.** Journal of Forestry 94:10-12.

Covington, W.W. and M.M. Moore. 1992. **Post settlement changes in natural disturbance regimes: implications for restoration of old-growth ponderosa pine ecosystems.** pp 9-13. In Old-growth forests in the southwest and Rocky Mountain region. Proceedings of the symposium, 9-13 March, Portal, Arizona. USDA Forest Service General Technical Report RM-213.

Covington, W.W., P.Z. Fule, M.M. Moore, S.C. Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, and M.R. Wagner. 1997. **Restoration of ecosystem health in southwestern ponderosa pine forests.** Journal of Forestry 92: 39-47.

Dolph, K.L. 1989. **Non-linear equations for predicting diameter inside bark at breast height for young-growth red fir in California and southern Oregon.** USDA Forest Service Pacific Southwest Station Research Note PSW-409.

Duncan, R.P. 1991. **Competition and the coexistence of species in a mixed podocarp stand.** Journal of Ecology 79:1073-1084.

Fule, P.Z., W.W. Covington, and M.M. Moore. 1997. **Determining reference conditions for ecosystem management of southwestern ponderosa pine forests.** Ecological Applications 7:895-908.

Grumbine, R.E. 1994. **What is ecosystem management?** Conservation Biology 8:27-38.

Harmon, M.E., K. Cromack, and B.G. Smith. 1987. **Coarse woody debris in mixed conifer forests, Sequoia National Park, California.** Canadian Journal of Forest Research 17:1265-1272.

Hill, M. 1975. **Geology of the Sierra Nevada.** University of California Press, Berkeley, California, USA.

Kaufmann, M. R. et al. 1994. **An ecological basis for ecosystem management.** USDA Forest Service General Technical Report RM-246.

Kenkel, N.C., M.L. Hendrie, and I.E. Bella. 1997. **A long-term study of *Pinus banksiana* population dynamics.** Journal of Vegetation Science 8:241-254.

Kimmey, J.W. 1955. **Rate of deterioration of fire-killed timber in California.** USDA Circular 962.

Landres, P.B., P. Morgan, and F.J. Swanson. 1999. **Overview of the use of natural variability concepts in managing ecological systems.** Ecological Applications 9:1179-1188.

Larsen, D.R., and D.W. Hann. 1985. **Equations for predicting diameter and squared diameter inside bark at breast height for six major conifers of southwest Oregon.** Forest Service Research Laboratory Research Note 77. Oregon State University, Corvallis, Oregon, USA.

Leiberg, J.B. 1902. **Forest conditions in the northern Sierra Nevada, California.** U.S. Geological Survey Professional Paper No. 8. Series H. Forestry, No. 5. U.S. Government Printing Office, Washington D.C., USA.

Lindström, S. 2000. **A contextual overview of human land use and environmental conditions.** pp. 23-127 In Dennis D. Murphy, and C.M. Knopp, editors. Lake Tahoe watershed assessment: Volume I. U.S. Forest Service General Technical Report PSW-175.

Manley, P.N., J.A. Fites-Kaufman, M.G. Barbour, M.D. Schlesinger, and D.M. Rizzo. 2000. **Biological integrity.** pp. 403-597 In Dennis D. Murphy, and C.M. Knopp, editors. Lake Tahoe watershed assessment: Volume I. U.S. Forest Service General Technical Report PSW-175.

McKelvey, K.S. and J.D. Johnston. 1992. **Historical perspectives of forests of the Sierra Nevada and the Transverse Ranges of southern California: forest conditions at the turn of the century.** pp. 225-246. In Verner, J., McKelvey, K.S, Noon, B.R., Gutierrez, R.J., Gould, G.I., Beck, T.W. [Tech. Coord.], The California Spotted Owl: a Technical Assessment of its Current Condition, USDA Forest Service General Technical Report PSW-GTR-133.

Moore, M.M., W.W. Covington, and P.Z. Fule. 1999. **Reference conditions and ecological restoration: a southwestern ponderosa pine perspective.** Ecological Applications 9:1266-1277.

Morgan, P.G., G.H. Aplet, J.B. Haufler, H.C. Humphries, M.M. Moore, and W.D. Wilson. 1994. **Historical range of variability: a useful tool for evaluating ecological change.** Journal of Sustainable Forestry 2: 87-111.

Overbay, J.C. 1992. **Ecosystem management.** In Proceedings of the national workshop: Taking and ecological approach to management. USDA Forest Service, Watershed and Air Management: 3-15.

Parker, A.J. 1986. **Persistence of lodgepole pine forests in the central Sierra Nevada.** Ecology 67:1560-1567.

Pitcher, D.C. 1987. **Fire history and age structure in red fir forests of Sequoia National Park, California.** Canadian Journal of Forest Research 17:582-587.

Ripley, B.D. 1977. **Modeling spatial patterns.** Journal of the Royal Statistical Society Series B 39:172-212.

Rogers, J.H. 1974. **Soil survey Tahoe Basin Area: California and Nevada.** U.S. Department of Agriculture, Soil Conservation Service.

SNEP 1996. **Fire and fuels.** pp. 61-71 In: Sierra Nevada ecosystem project: final report to congress. Volume. I. Assessment strategies and management summaries. Wildland Resources Center Report number 36, University of California Davis, Davis, California, USA.

Stokes, M.A., and T.L. Smiley. 1968. **An introduction to tree-ring dating.** University of Chicago Press, Chicago, Illinois USA.

Strong, D.H. 1984. **Tahoe: An environmental history.** University of Nebraska Press, Lincoln, Nebraska, USA.

Swanson, F.J. J.A. Jones, D.O.O. Wallin and J.H. Cissel. 1994. **Natural variability and implications for ecosystem management,** pp. 80-94. In Jensen, M.E. and P.S. Bourgeron [eds.] Vol. II: Ecosystem management: Principles and Applications USDA Forest Service General Technical Report PNW-GTR-318. Pacific Northwest Research Station, Portland, Oregon.

Swetnam, T.W., C.D. Allen, and J.L. Betancourt 1999. **Applied historical ecology: using the past to manage the future.** Ecological Applications 9:1189-1206.

Taylor, A.H. 2000. **Fire regimes and forest changes in mid and upper montane forests in the southern Cascades, Lassen Volcanic National Park, California, USA.** Journal of Biogeography 27:87-104.

Vankat, J.L and J. Major. 1978. **Vegetation changes in Sequoia National Park, California.** Journal of Biogeography 5:377-402.

Vankat, J.L. 1982. **A gradient perspective on the vegetation of Sequoia National Park, California.** Madroño 29:200-214.

Veblen, T.T., K.S. Hadley, M.S. Reid, and A.J. Rebertus. 1991. **Methods of detecting past spruce beetle outbreaks in Rocky Mountain subalpine forests.** Canadian Journal of Forest Research 21:242-254.

Walters, D.K., and D.W. Hann. 1986. **Predicting merchantable volume in cubic feet to a variable top and in scribner board feet to a 6-inch top for six major conifers of southwest Oregon.** Forest Research Laboratory Research Bulletin 52. Oregon State University, Corvallis, Oregon, USA.

White, P.S., and J. Walker 1997. **Approximating nature's variation: selecting and using reference information in restoration ecology.** Restoration Ecology 5:338-349.