Fire Regimes and Resultant Forest Structure in the Native Ano Nuevo Monterey Pine (Pinus radiata) Forest, California

SCOTT L. STEPHENS[1]

Division of Ecosystem Science, Department of Environmental Science, Policy, and Management, University of California, Berkeley 94720-3110

DOUGLAS D. PIIRTO

Natural Resources Management Department, California Polytechnic State University, San Luis Obispo 93407

AND

DOMENICO F. CARAMAGNO

Division of Ecosystem Science, Department of Environmental Science, Policy, and Management, University of California, Berkeley 94720-3110

[1] Corresponding author: *Division of Ecosystem Science, Department of Environmental Science, Policy, and Management, University of California, 151 Hilgard Hall, Berkeley, California, 94720-3114, Telephone (510) 642-7304; FAX (510) 643-5438; email:* stephens@nature.berkeley.edu

ABSTRACT. - Native Monterey pine (*Pinus radiata*) forests occur in five populations on the western coast of North America. High severity fire has been reported to be the main disturbance agent that initiates seedling establishment. To investigate the impacts of fire in this ecosystem, age structure and fire history data were collected from the native Ano Nuevo Monterey pine forest. Stump cross-sections were removed from ten randomly placed openings and each was dated to determine tree age and fire history. Average mean fire return intervals were 11.2 – 20.1 years. Fifty-one percent of the Monterey pine trees in all openings regenerated within five years of three moderate severity fires. This was below the predicted value of 75% that was based on the literature and life history characteristic of Monterey pine. A fire in 1948 produced the largest Monterey pine regeneration episode and this fire was verified by written records. Monterey pine forests are multi-aged and have a great amount of spatial heterogeneity, attributes common in moderate severity fire regimes. Monterey pine has characteristics of both fire evaders and fire resistors and may be more appropriately classified in an intermediate category. As we predicted, regeneration of Monterey pine was significantly higher than coast live oak (*Quercus agrifolia*) following moderate severity fires.

INTRODUCTION

Native Monterey pine (*Pinus radiata* D.Don) forests occur in five disjunct populations on the western coast of North America. Three are located in central-coastal California (Ano Nuevo, Monterey, Cambria) and two on islands off the Baja California peninsula (Guadalupe and Cedros). Recent work has proposed that Monterey pine maintained a meta-population strategy throughout it history in the California region (Millar, 1999). Trees may have occurred in distinct coastal populations that were subject to repeated events of colonization, coalescence, and local extirpation in responses to fluctuating climates (Millar, 1999).

Research on Monterey pine has focused on its ecological and timber properties in areas outside North America (Shelbourne *et al.*, 1979; Burdon *et al.*, 1997; Burdon *et al.*, 2001; Reyes and Casal, 2001) and the trees' response to diseases and insects (Old *et al.*, 1986; Storer and Wood, 1998; Gordon *et al.*, 1998). No information exists on native Monterey pine stand age structure and the impact of fire on this ecosystem (White, 1999).

Monterey pine is a closed-cone species and is intermediate in shade tolerance (Baker, 1949; McDonald and Laacke, 1990). Mature trees produce a canopy stored seed bank and cones can remain attached to the tree for many years (Vogl *et al.*, 1988). Cones can open and close in response to changing humidity and temperature but this releases little of the stored seed bank (McDonald and Laacke, 1990).

High severity fire has been reported to be the main disturbance agent that initiates seedling establishment (Fenton, 1951; Vogl *et al.*, 1988; McDonald and Laacke, 1990; White, 1999) even though there is no research that has documented the role of fire in native Monterey pine ecosystems. Fire severity is commonly defined by the effects of fire on the dominant organisms of a particular ecosystem (Agee, 1998). Fire regimes in Californian Monterey pine

forests may contain a mixture of low, moderate, and high severity fires. Low severity fires consume ground and surface fuels but cause little overstory mortality in most forests. Moderate severity fires cause some overstory tree mortality but substantial numbers of trees in the larger size-classes survive these events (Agee, 1998). High severity fires commonly kill the majority of the trees in an area and this allows for episodic regeneration if viable propagules survive and germinate (Turner *et al.*, 1994; Turner *et al.*, 1997; Agee, 1998).

Monterey pine has been classified as a fire evader primarily because of its canopy stored seed bank (Fonda *et al.*, 1998; Fonda, 2001). Characteristics of fire evaders include relatively thin bark, thin needle clusters that poorly protect meristems and aerial portions of the plant from thermal injuries, and closed-cones (Fonda *et al.*, 1998; Fonda, 2001).

There are no published studies that have estimated fire return intervals in native Monterey pine forests (Greenlee and Langenheim, 1990; White, 1999; Fonda, 2001). Furthermore, there are no studies that have investigated the effects of past fires on forest structure. One study has measured seedling density after a New Zealand Monterey pine plantation was burned by wildfire (Fenton, 1951). Three years after the 1946 wildfire, Fenton (1951) reported an average of 897,000 Monterey pine seedlings ha^{-1}. The area burned was a dense, 14-18 year old Monterey pine plantation and seedling densities from this study are probably not applicable to native forests.

The objective of this study is to investigate the fire history of the Ano Nuevo Monterey pine forest and to determine how past fires have affected forest structure. This is the first study in California or Mexico to investigate this topic in pine dominated forests with closed-cones (including Monterey pine, bishop pine (*Pinus muricata* D. Don), and knobcone pine (*Pinus*

attenuata Lemm.)). A second objective is to determine if individual species responses are significantly different following moderate or high severity fires in this forest community.

METHODS

STUDY SITE

Age structure and fire history information was collected from Monterey pine forests at Swanton Pacific Ranch, located at 37°04′26.91″E, 122°14′40.35″W, approximately 13 km north of Santa Cruz, California. Swanton Pacific Ranch encompasses 1280 ha and is contained in the Little Creek and Scott Creek watersheds. Swanton Pacific Ranch includes portions of the native Ano Nuevo Monterey pine forest. Trees in the study area include Monterey pine, Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), coast live oak (*Quercus agrifolia* Nee), and tanoak (*Lithocarpus densiflorus* Rehder.). No tree harvesting occurred in these forests until a study was initiated in 2001 to investigate the resistance of Monterey pine to pitch canker disease (*Fusarium moniliforme* var. *subglutinans*).

Understory species common in this area include coast live oak, bracken fern (*Pteridium aquilinum* L. (Kuhn)), poison-oak (*Toxicodendron diversilobum* E. Greene), coyote bush (*Baccharis pilularis* DC.), blue blossom (*Ceanothus thyrsiflorus* Eschsch.), California coffeeberry (*Rhamnus californica* Eschsch.), California blackberry (*Rubus ursinus* Cham. & Schldl.), coast sagebrush (*Artemisia californica* Less.), and several grasses (Poaceae) (McDonald and Laacke, 1990).

During the prehistoric period the Central California Ohlone Indians lived in the present area of Swanton Pacific Ranch. In 1843, the Mexican Governor of California granted this area to Ramon Rodriguez and Francisco Alviso and the land was used primarily for farming and dairy

cattle. These early land uses were concentrated in the grasslands and valleys of the area. From 1906-1923, the majority of the redwood (*Sequoia sempervirens* (D. Don) Endl.) and Douglas-fir forests were harvested to produce lumber to rebuild San Francisco after the 1906 earthquake; farming also continued during this period. In the 1940's the production of beef cattle intensified. Currently the ranch is California Polytechnic State University's field teaching and research property.

The climate at Swanton Pacific is Mediterranean and it receives 79 cm of precipitation in an average year (Swanton records from 1956-1996). The soils of Monterey pine forest at Swanton Pacific are in the Ben Lomond-Catelli-Sur complex. These soils are well drained and were formed in residuum derived from sandstone or quartz diorite. Soil depths are approximately 100 - 180 cm. Slopes within the experimental area varied from 8-30 %, aspects were mostly northern, and the average elevation of the study area is approximately 390 meters (Table 1).

AGE STRUCTURE AND FIRE HISTORY

Monterey pine forest delineation at Swanton Pacific Ranch was originally produced using a vegetation survey map. This map was converted into Geographic Information System (GIS) data and improved using the interpretation of black and white digital orthophotos. The interface between the Monterey pine forests and the grasslands and shrublands was clearly visible in the orthophotos. The delineating line between the Monterey pine forests and the other forest types (redwood and Douglas-fir) was determined using a combination of orthophotos and field surveys.

Once the Monterey pine forest area was delineated, a one-meter grid was superimposed on this area using ARC GIS. Each grid cell had unique x and y coordinates and the center of ten

openings were randomly selected from the grid with the following constraints: 1) maximum slope was limited to 30% to allow ground-based machinery to harvest the trees in the openings, and 2) each opening must have a 30 m buffer from an adjacent opening or the edge of the Monterey pine forest. If either of these constraints were violated, the selected grid point was rejected and a new grid location was randomly selected. Openings sizes were 0.05, 0.1, or 0.2 ha and were randomly assigned to the ten grid points. Trees in the openings were removed in 2001 using chainsaw felling and tractor yarding. The Monterey pine forests were separated into three areas (northern, middle, and southern clusters) (Fig. 1) to allow analyzes to determine if there was heterogeneity in age structure or fire history in the sampled areas.

After the harvesting was completed, the tops of all stumps larger than 10 cm in diameter were removed using a chainsaw. Each stump cross-section was sanded and polished to a high sheen (400 grit) so that tree rings and fire scars could be distinguished. Stump height, diameter and species were recorded. To describe the forests in this study, we calculated average basal area per ha, average number of trees per ha, average percent basal area by species, and average percent stocking by species using the stump information collected from the ten openings.

Fire scars were identified on each stump cross-section by the characteristic disruption and healing patterns of radial tree-ring growth (McBride, 1983; Dieterich and Swetnam, 1984). The year of each fire and age of each tree was determined by crossdating using standard dendrochronological techniques (Stokes and Smiley, 1977; Swetnam *et al.*, 1985). The position within the ring in which a fire scar occurred was noted as EE (early earlywood), ME (middle earlywood), LE (late earlywood), LW (latewood), D (dormant), or U (undetermined) (Caprio and Swetnam, 1995) to serve as an estimate of the season of fire occurrence (Ahlstrand, 1980; Dieterich and Swetnam, 1984).

Composite fire chronologies were developed for the northern, middle, and southern clusters independently, and this included all fires recorded in each site. Developing fire statistics using all fire was done because fire scars were relatively rare in this forest type. For each cluster, we determined the mean, minimum and maximum fire return interval (FRI) over the period of record (Grissino-Mayer, 2001).

We estimate fire severity by assessing the amount of regeneration that follows past fires, believing it to be an indicator of how fires affected the overstory tree canopy (the dominant organisms (Agee, 1998)). A high severity fire is defined here as one that initiates a minimum of 75% of the trees in all clusters (north, middle, south) within five years of the event. A moderate severity fire is defined as one that initiates between 10-75 % of the trees in all clusters within five years of the event. Five years was chosen because stumps were not sampled at the ground surface and there was variability in stump heights. Furthermore, Monterey pine is intermediate in shade tolerance (Baker, 1949) and would grow at different rates depending on its local environment (differences in overstory canopy cover after fire could effect seedling growth).

Since Monterey pine is a closed cone species (McDonald and Laacke, 1990) and it has been reported to be a fire evader (Fonda, 2001), it is hypothesized that over 75% of the Monterey pine trees in this forest will be attributed to high severity fires.

INDIVIDUAL SPECIES RESPONSES TO HIGH AND MODERATE SEVERITY FIRES

Monterey pine is the most shade intolerant species in this forest, in contrast, coast live oak is shade tolerant and has increased in abundance in the absence of disturbance (White, 1999). With these differing physiologies, we hypothesize that these two species will respond differently to moderate and high severity fires. It is anticipated that Monterey pine will

regenerate episodically after severe fire because of its relative shade intolerance and canopy stored seed bank. In contrast, coast live oak will not regenerate after such disturbances because it cannot protect its seed bank (acorns) from lethal temperatures during serve fires. Coast live oak should continue to recruit in the shaded understory once an overstory canopy has developed (White, 1999).

To assess statistical significance in recruitment for these two species, confidence limits for the number of trees recruited in the ten openings within five years of moderate or high severity fires were calculated using the normal approximation to the binomial variance (Condit *et al.*, 1995). Confidence limits were not calculated when there were less than ten trees of the same species in a cluster ($T < 10$). This cutoff was selected to remove data in which recruitment could have been impacted by an unusual event (e.g. individual tree fall or root pathogen mortality center) independent of fire.

For $T \geq 10$ we calculated exact confidence limits using binomial probabilities using S-Plus (Crawly, 2002). We calculated 95% confidence limits by species for every moderate and high severity fire by searching for a population mean R for which the binomial probability of observing R or less would be < 0.025; this was the upper confidence limit (Condit *et al.*, 1995). The lower confidence limit was determined analogously.

RESULTS

Ten openings with random locations were harvested from the Monterey pine forests at Swanton Pacific Ranch. Opening characteristics are summarized in Table 1. A total of 226 stump cross-sections were collected from the openings. The pith date and fire history was

obtained from 224 stump cross-sections, this information could not be obtained from two samples because of excessive rotten wood.

Average tree density and basal area in the openings was 193 trees ha^{-1} (SE 41.97) and 59.5 m^2 ha^{-1} (SE 7.94), respectively. Average stump height was 28.4 cm (range 19-43 cm). Monterey pine dominated the forests in the study area, contributing to 60% of average plot stocking (trees ha^{-1}) and 75% of average plot basal area (Table 2).

Crossdating was successful on all the conifer stump cross-sections (Monterey pine and Douglas-fir). Drought years in 1959-1961, and 1976-1977 assisted in crossdating. Crossdating of the angiosperm samples (coast live oak and tanoak) was not possible because of complacent rings and extensive rays that spread through annual ring boundaries. Several wood stains were used to try to enhance the annual rings but they were not successful. The best method of sample preparation was producing a very high polish on the stump cross-sections and this allowed us to count rings using a 20-power microscope.

Twenty-five stumps (13 Monterey pine, 9 coast live oak, 3 Douglas-fir) contained a total of 30 fire scars in this study. Fires were recorded from 1893-1976 and the mean fire return interval for the northern, middle and southern clusters was 11.4, 11.2, and 20.1 years, respectively (Table 3). Intra-annual ring position of the scars was determined for 63% of the fire scars. Fire scars were mostly located at the ring boundary that would be associated with dormant season fires (53%), fire scars in the late earlywood of the annual growth ring comprised 36% of all fire scars. Three moderate severity fires occurred from the late 1800's to 2001 (1936, 1948 and 1957) (Table 4). No high severity fires were recorded.

Monterey pine and coast live oak responded differently after moderate severity fires. Fifty-one percent of Monterey pine trees in all openings germinated within 5 years of three

moderate severity fires (1936, 1948, 1957), whereas only 16% of coast live oak was regenerated in the similar time period (Table 5). The percentage of Monterey pine regenerated after the moderate severity fires was significantly different from coast live oak in the northern, middle, and southern clusters (Table 5). Recruitment statistics were not calculated for Douglas-fir and tanoak because they were rare ($T < 10$).

DISCUSSION

Complete stump cross-sections were necessary to distinguish between adjacent annual rings and rays on coast live oak and tanoak samples. Although the hardwood samples were not crossdated, we believe the use of full cross-sections with excellent sample preparation reduced the chances for error. Most fire scars (72%) in this study were buried inside the tree stem and not recognizable from external tree characteristics (Stephens, 2001). Collection of fire scars samples from trees that only had visible injuries would have resulted in an incomplete fire record for this site.

Average mean fire return intervals varied from 11.2 – 20.1 years (Table 3) and low severity fires were relatively common, especially from 1940 to 1970 (Figs. 2-4). No high severity fires were recorded in the sample area. Changes in land management at Swanton Pacific Ranch in the early 1940's probably contributed to the higher number of low severity fires. Beginning the 1940's, the production of beef cattle became a priority of the Ranch and herbicides and burning were used to clear brush fields and maintain forage production. Since the Monterey pine forests at Swanton are adjacent to grasslands and shrublands (Fig. 1), many of the rangeland fires probably spread into the forest. Intentional burning to enhance forage production

ended in the 1960's and this is coincident with a reduction of fire-use in rangeland management throughout California (Biswell, 1989).

Most Monterey pines in this study are 40-60 years old and this corresponds to the occurrence of three moderate severity fires. All ten openings sampled in this study had trees that survived the moderate severity fires, none of the openings only contained trees from a single cohort (Table 4; Figs. 2-4). Monterey pine and coast live oak continued to recruit in most openings after all fires. Fifty-one percent of the Monterey pine trees in all openings regenerated within five years of three moderate severity fires. This is below the predicted value of 75% that was based on the literature (Vogl *et al.*, 1988; McDonald and Laacke, 1990) and life history characteristic (Fonda *et al.*, 1998; Fonda, 2001) of this species.

The 1948 fire produced the largest Monterey pine regeneration episodes in both the northern and middle clusters (Table 4; Figs. 2-3). This fire was the Pine Mountain Fire and it was ignited on August 31, 1948 (Santa Cruz Sentinel News, September 5, 1948). This wildfire burned 6,400 ha of forests, shrublands, and grasslands over a period of seven days. It was the largest wildfire in Santa Cruz County in 12 years and was spread by strong northwest winds and low humidities. Aggressive fire suppression was unsuccessful in controlling this fire until it moved out of the forests and into less hazardous grasslands and shrublands.

The 1948 Monterey pine regeneration episode is absent in the southern cluster (Table 3; Fig. 4). The dendrochronolgy-based record depicts the 1948 fire as moderate severity and eyewitnesses documented this behavior "… many areas were destroyed but in other parts of the burned area, some bushes and trees escaped the flames" (Santa Cruz Sentinel News, September 6, 1948). The written and tree-ring record are in agreement on the 1948 fire.

Historical accounts record that two other large wildfires occurred in northern Santa Cruz

County in the twentieth century (Santa Cruz Sentinel News, September 7, 1948). The first was in September, 1919, and it burned an area similar to that burned by the 1948 Pine Mountain Fire. The second was a 10,400 ha wildfire that burned in 1936. Both of these fires are recorded in this study. The 1919 fire was recorded in the northern cluster and the 1936 fire is recorded in the middle cluster (Figs. 2 and 3). The 1936 fire was classified as a moderate severity event in this work (Table 4).

Regeneration in the southern cluster occurred only after a 1957 moderate severity fire, a fire that was also recorded by fire scars in the northern and middle clusters without a corresponding episode of regeneration (Figs. 2-4). Conversely, the southern cluster did not record the 1936 or 1948 fires. The three high severity fires that burned in the study area had diverse behaviors and effects over a relatively small spatial scale (600 meters separate the northern and southern clusters). The Monterey pine forests sampled in this study are multi-aged (O'Hara, 1998) and have a great amount of spatial heterogeneity, attributes common in moderate severity fire regimes (Agee, 1998).

The fire regime type that best characterizes the Monterey pine forests sampled in this study over the last 125 years is moderate severity. Other forest types that have moderate severity fire regimes include red fir (*Abies magnifica* A. Murr.) in the southern Cascades mountains, Oregon (Chappell and Agee, 1996), and interior Douglas-fir in the Pacific Northwest (Morrison and Swanson, 1990).

Monterey pine produces thick bark (McDonald and Laacke, 1990) and this is a characteristic of fire resistors (Fonda *et al.*, 1998; Fonda, 2001). Thick bark enables trees to survive surface and ground fires because it insulates the cambium layer from lethal temperatures during combustion. Monterey pine has characteristics of both fire evaders (canopy stored seed-

back, episodic regeneration) and fire resistors (ability to survive repeated low severity fires) and may be more appropriately classified in an intermediate category. Monterey pine could be classified as a fire tolerater because it can succeed when exposed to diverse fire severities.

As we predicted, regeneration of Monterey pine was significantly higher than coast live oak following moderate severity fires (Table 5). The autecology of Monterey pine allows it to take advantage of the environment created by moderate severity fires. Coast live oak can survive 100% crown scorch by producing epicormic sprouts from dormant buds (Plumb, 1980; Plumb and McDonald, 1981) but it cannot shield its propagules from lethal temperatures.

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LITERATURE CITED

Agee, J. K. 1998. The landscape ecology of western forest fire regimes. *Northwest Sci.,* 72:24-34.

Ahlstrand, G. M. 1980. Fire history of a mixed conifer forest in Guadalupe Mountains National Park, p. 4-7. *In*: Proc. fire history workshop. Stokes, M. A., and J. H. Dieterich (eds.). *US For. Serv. Gen. Tech. Rep. RM-81*.

Baker, F. S. 1949. A revised tolerance table. *J. For*., 47:179-181.

Biswell, H. H. 1989. Prescribed burning in California wildland vegetation management. UC Press, Berkeley, California. 255 p.

Burdon, R. D., A. Firth, C. B. Low, and M. A. Miller. 1997. Native provenances of *Pinus radiata* in New Zealand: performances and potential. *New Zealand For*., 41:32-36.

Burdon, R. D., R. A. Britton, and G. B. Walford. 2001. Wood stiffness and bending strength in relation to density of four native provenances of *Pinus radiata*. *New Zealand J. For. Sci*., 31:130-146.

Caprio, A. C., and Swetnam, T. W. 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California, p. 8-14. *In*: Proc. of symposium on fire in wilderness and park management. Brown, J. K., R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, (eds.). *US For. Serv. Gen. Tech. Rep. INT-GTR-320.*

Chappell, C. B., and J. K. Agee. 1996. Fire severity and tree seedling establishment in Abies magnifica forests, southern Cascades, Oregon. *Ecol. Appl*., 6:628-640.

Condit, R., S.P. Hubbell, and R.B. Foster. 1995. Mortality rates of 205 neotropical tree and shrub species and the impact of a severe drought. *Ecol. Monogr*., 65: 419-439.

Crawly, M. J. 2002. Statistical computing, an introduction to data analysis using S-Plus. John Wiley and Sons. West Sussex, England. 761 p.

Dieterich, J. H., and Swetnam, T. W. 1984. Dendrochronology of a fire-scarred ponderosa pine. *For. Sci*., 30:238-247.

Fenton, G. R. 1951. Regeneration of *Pinus radiata*. *Forest research notes. New Zealand Forest Service Forest Research Institute* 1:1-14.

Fonda, R. W. 2001. Burning characteristics of needles from eight pine species. *For. Sci*., 47:390-396.

Fonda, R. W., L. A. Belanger, and L. L Burley. 1998. Burning characteristics of western conifer needles. *Northwest Sci*., 72:1-9.

Gordon, T. R., K. R. Wikler, S. L. Clark, D. Okamoto, A. J. Storer, and P. Bonello. 1998. Resistance to pitch canker disease, caused by *Fusarium subglutinans* f. sp. *pini*, in Monterey pine (*Pinus radiata*). *Plant Path*., 47:706-711.

Greenlee, J. M., and J. H. Langenhein. 1990. Historic fire regimes and their relation to vegetation patterns in the Monterey Bay Area of California. *Am. Midl. Nat*., 124:239-253.

Grissino-Mayer, H. D. 2001. FHX2 - Software for analyzing temporal and spatial patterns in fire regimes from tree rings. *Tree-ring Research*., 57:115-124.

McBride, J.R. 1983. Analysis of tree rings and fire scars to establish fire history. *Tree-ring Bull*., 43:51-67.

McDonald, P. M, and R. J. Laacke. 1990. *Pinus radiata*, p. 433-441. *In*: Silvics of North America, vol. 1. conifers. Burns, R. M., and B. H. Honkala, (tech. coord.). *US For. Ser. Agricultural Handbook 654.*

Millar, C. I. 1999. Evolution and biogeography of *Pinus radiata*, with a proposed revision of its quaternary history. *New Zealand J. For. Sci*., 29:335-365.

Morrison, P. H., and F. J. Swanson. 1990. Fire history and pattern in a Cascade landscape. *US For. Ser. Gen. Tech. Rep. PNW-GTR-254.* 77 p.

O'Hara, K. L. 1998. Silviculture for structural diversity: a new look at multiaged systems. *J. For*., 96:4-10.

Old, K. M., W. J. Libby, J. H. Russell, and K. G. Eldridge. 1986. Genetic variability in susceptibility to *Pinus radiata* to western gall rust. *Silvae Genetica* 35:145-149.

Plumb, T. R. 1980. Response of oaks to fire. *In*: Proc. of the symposium on the ecology, management, and utilization of California oaks. *US For. Serv. Gen. Tech. Rep. PSW-GTR-44.*

Plumb, T. R., and P. M. McDonald. 1981. Oak management in California. *US For. Serv. Gen. Tech. Rep. PSW-GTR-54.*

Reyes, O., and M. Casal. 2001. The influence of seed age on germination response to the effects of fire in *Pinus pinaster, Pinus radiata,* and *Eucalyptus globulus*. *Annals of Forest Science* 58: 439-447.

Shelbourne, C. J., R. D. Burdon, M. H. Bannister, and I. J. Thulin. 1979. Choosing the best provenances of radiata pine, *Pinus radiata*, for different sites in New Zealand. *New Zealand J. For.*, 24:288-300.

Stephens, S. L. 2001. Fire history of adjacent Jeffrey pine and upper montane forests in the Eastern Sierra Nevada. *Inter. J. of Wildland Fire* 10:161-176.

Stokes, M. A., and T. L. Smiley. 1977. An introduction to tree-ring dating. University of Chicago Press. Chicago, IL.

Storer, A. J., and D. L. Wood. 1998. Association between a native spittlebug (Homoptera: Cercopidae) on Monterey pine and an introduced tree pathogen which causes pitch canker disease. *Canadian Entom*., 130:783-792.

Swetnam, T. W., M. A. Thompson, and E. K. Sutherland. 1985. Spruce budworm handbook, using dendrochronology to measure radial growth of defoliated trees. *US For. Serv. Agriculture Handbook 639.*

Turner, M. G., W. W. Hargrove, R. H. Gardner, and W. H. Romme. 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. *J. Veg. Sci*., 5:731-742.

Turner, M. G., W. H. Romme, R. H. Gardner, and W. W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecol. Monogr*., 67:411-433.

Vogl, R. J., W. P. Armstrong, K. L. White, and K. L. Cole. 1988. The closed-cone pines and cypress, p. 295-358. *In*: Terrestrial Vegetation of California, Barbour, M. G., and J. Majors (eds). Wiley and Sons, New York.

White, K. L. 1999. Revisiting native *Pinus radiata* forests after twenty-five years. *Madrono* 46:80-87.

TABLE 1.-Forest opening characteristics in Monterey pine forests at Swanton Pacific Ranch, California

	Northern cluster				Middle cluster		Southern cluster			
Opening	L-8-1	L-4-1	B-4-1	L-4-2	L-2-1	B-2-1	L-8-2	B-4-2	B-2-2	L-2-2
Size (ha)	0.05	0.1	0.1	0.1	0.2	0.2	0.05	0.1	0.2	0.2
Elevation (m)	380	425	355	360	365	365	470	415	410	390
Slope (%)	29	24	25	11	25	24	24	8	12	15
Aspect	N	NE	N	N	E	N-NE	N	NW	N	N

1 TABLE 2.-Average basal area and tree density by species in the ten openings created at

2 Swanton Pacific Ranch, California. Number in parentheses are SE

Species	Monterey pine	Coast live oak	Douglas-fir	Tanoak
Basal area (m^2 ha^{-1})	44.8 (6.47)	9.48 (2.63)	4.93 (2.09)	0.25 (0.02)
Tree density (trees ha^{-1})	116.50 (30.27)	62.5 (16.38)	13.00 (4.48)	0.40 (0.04)

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TABLE 3.-Fire history statistics from Monterey pine forests at Swanton Pacific Ranch, California

	Northern cluster	Middle cluster	Southern cluster
Mean fire return interval (y)	11.4	11.2	20.1
Minimum fire return interval (y)	4.0	4.0	6.0
Maximum fire return interval (y)	29.0	40.0	44.0
Intra-ring fire scar position (%)	50% dormant 25% latewood 25% late earlywood	86% dormant 14% late earlywood	25% dormant 75% late earlywood
Area (ha)	6.0	5.5	16.0

TABLE 4.-Percent and total number of trees regenerated within five years after three moderate severity fires in Monterey pine forests at Swanton Pacific Ranch, California

Year	Northern cluster			Middle cluster			Southern cluster		
	Fire year	Older	Younger	Fire year	Older	Younger	Fire year	Older	Younger
1936	no	n.a	n.a	18% (9 Pira, 5 Quag)	27% (2 Pira, 16 Quag, 4 Psme)	55% (30 Pira, 10 Quag, 2 Lide)	no	n.a	n.a
1948	44% (33 Pira, 5 Quag, 4 Psme	25% (13 Pira, 10 Quag, 1 Psme)	31% (19 Pira, 10 Quag, 1 Psme)	20% (13 Pira, 2 Quag)	59% (18 Pira, 23 Quag, 4 Psme)	21% (10 Pira, 6 Quag, 2 Lide)	no	n.a	n.a
1957	8% (6 Pira, 1 Quag, 1 Psme)	83% (53 Pira, 21 Quag, 5 Psme)	9% (6 Pira, 3 Quag)	no	n.a	n.a	28% (12 Pira, 1 Psme)	29% (6 Pira, 6 Quag, 2 Psme)	43 % (14 Pira, 6 Quag)

Pira = Monterey pine, Quag = coast live oak, Psme = Douglas-fir, Lide = tanoak, n.a. not applicable

TABLE 5.-Total percent of trees regenerated from three moderate severity fires in ten openings in Monterey pine forests at Swanton Pacific Ranch, California. Mean values in a column followed by the same letter are not significantly different at $P < 0.05$

Years	Northern cluster	Middle cluster	Southern cluster	Average
Trees regenerated (%)	52	38	28	39
Monterey pine	60 a	54 a	38 a	51
Coast live oak	24 b	23 b	0 b	16
Douglas-fir	83	0	33	44

FIG. 1.-Location of the ten openings used to determine age structure and fire history in Monterey pine forests at Swanton Pacific Ranch, California

FIG. 2.-Tree age and composite fire history of the northern cluster in Monterey pine forests at Swanton Pacific Ranch, California. Each horizontal line is a tree and the pith date and fire scars are identified. Opening label given in upper left of each segment

FIG. 3.-Tree age and composite fire history of the middle cluster in Monterey pine forests at Swanton Pacific Ranch, California. Each horizontal line is a tree and the pith date and fire scars are identified. Opening label given in upper left of each segment

FIG. 4.-Tree age and composite fire history of the southern cluster in Monterey pine forests at Swanton Pacific Ranch, California. Each horizontal line is a tree and the pith date and fire scars are identified. Opening label given in upper left of each segment

FIG. 1

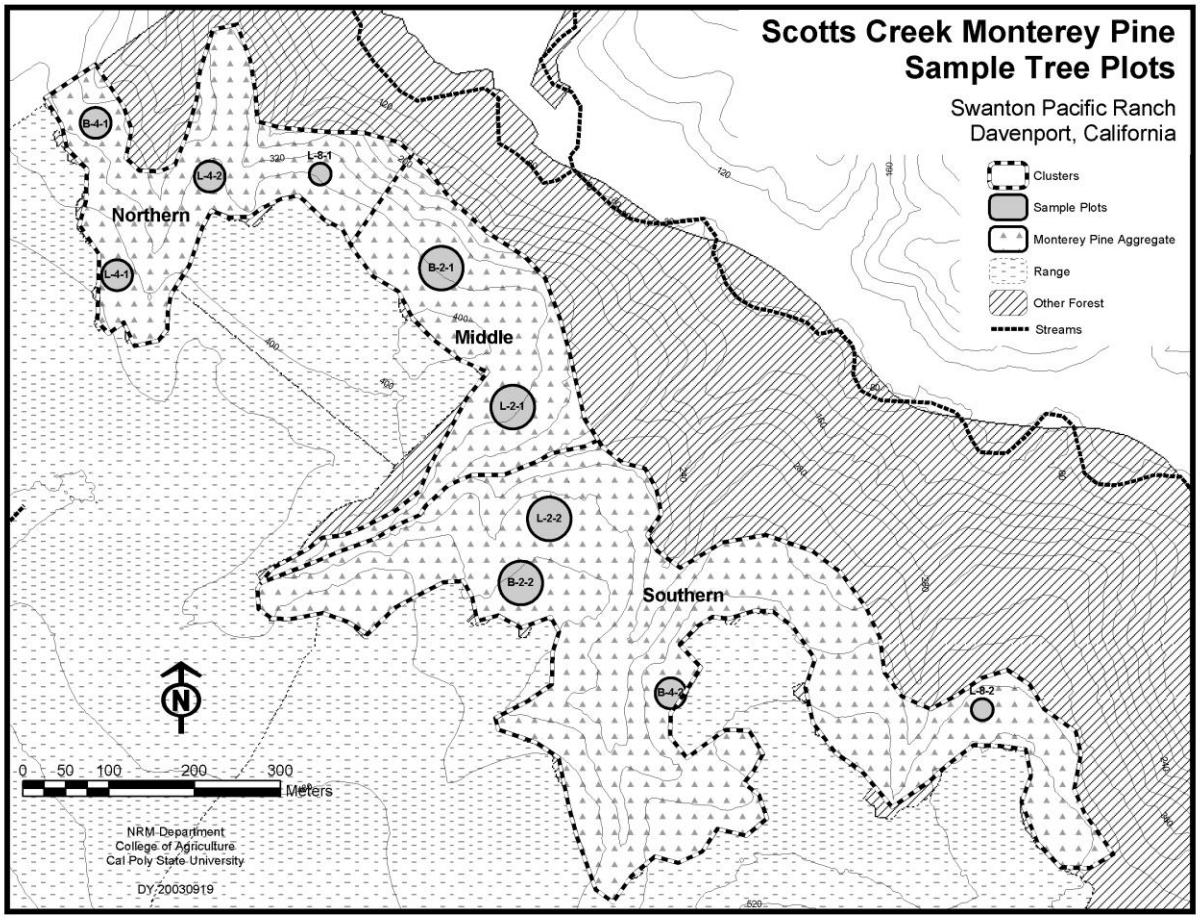

Scotts Creek Monterey Pine
Sample Tree Plots
Swanton Pacific Ranch
Davenport, California
Clusters
Sample Plots
Monterey Pine Aggregate
Range
Other Forest
Streams
Northern
Middle
Southern
B-4-1
L-4-2
L-8-1
L-4-1
B-2-1
L-2-1
L-2-2
B-2-2
B-4-2
L-8-2
N
0 50 100 200 300
Meters
NRM Department
College of Agriculture
Cal Poly State University
DY 20030919

FIG. 2

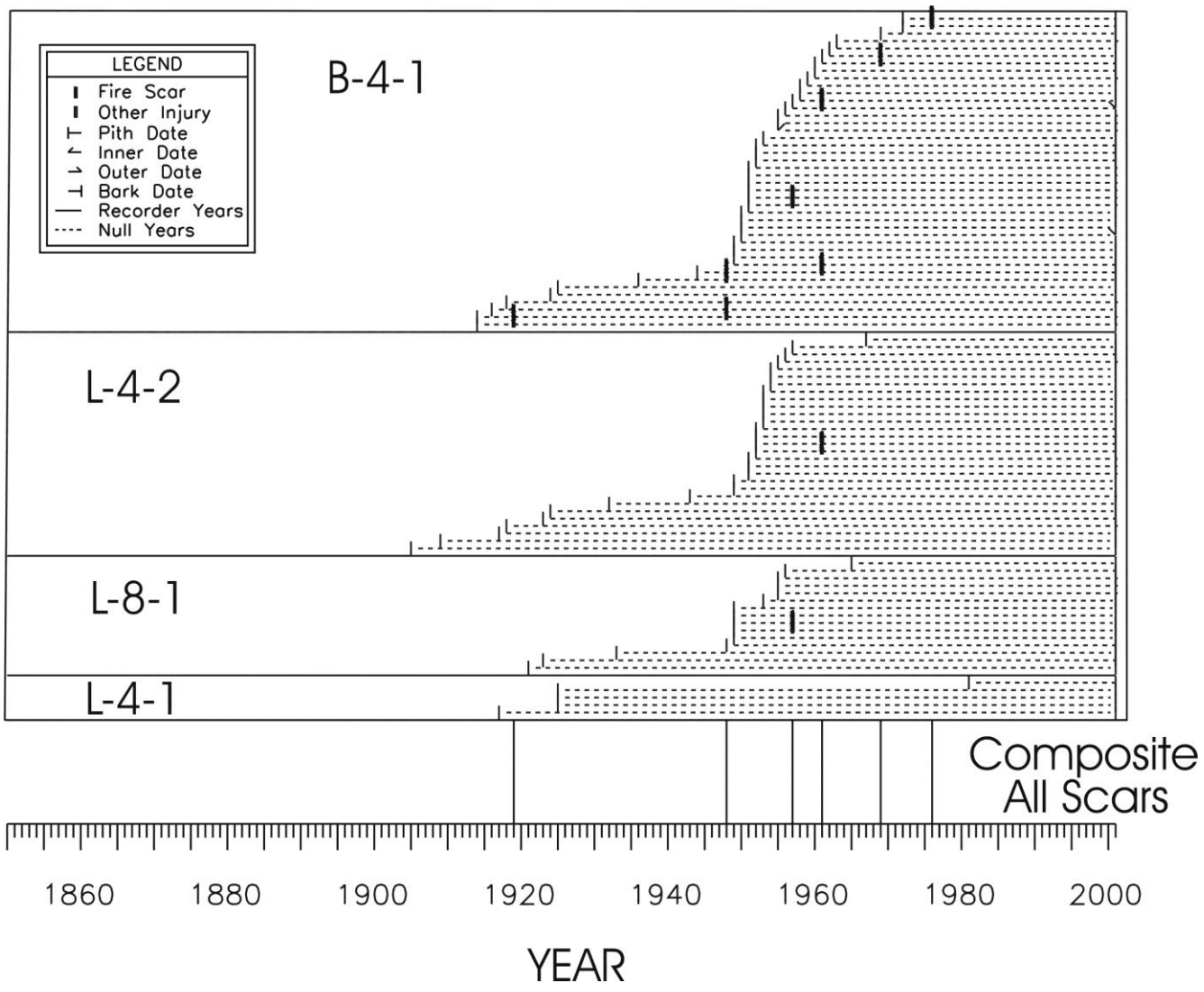

LEGEND
Fire Scar
Other Injury
Pith Date
Inner Date
Outer Date
Bark Date
Recorder Years
Null Years
B-4-1
L-4-2
L-8-1
L-4-1
Composite
All Scars
1860
1880
1900
1920
1940
1960
1980
2000
YEAR

FIG. 3

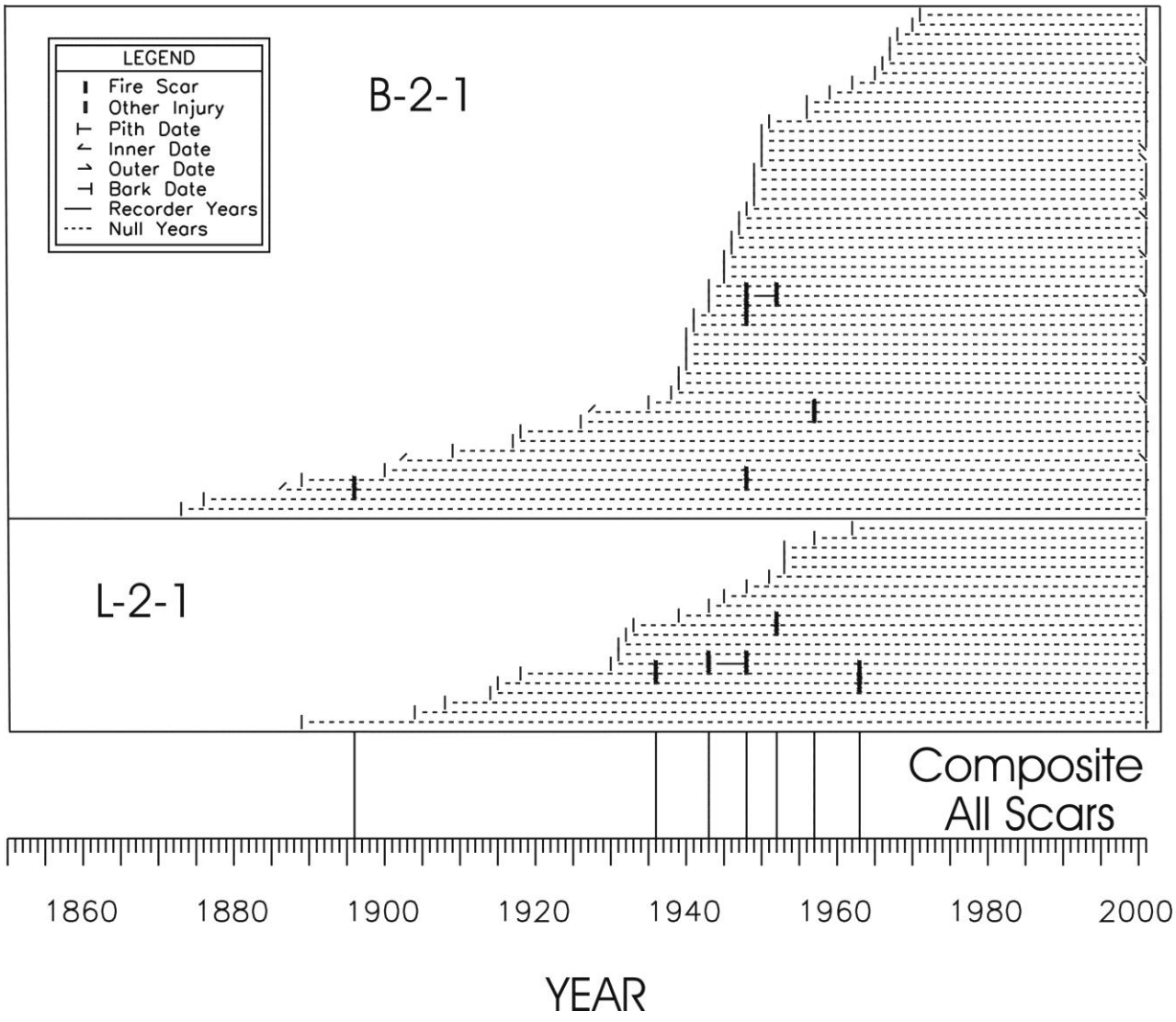
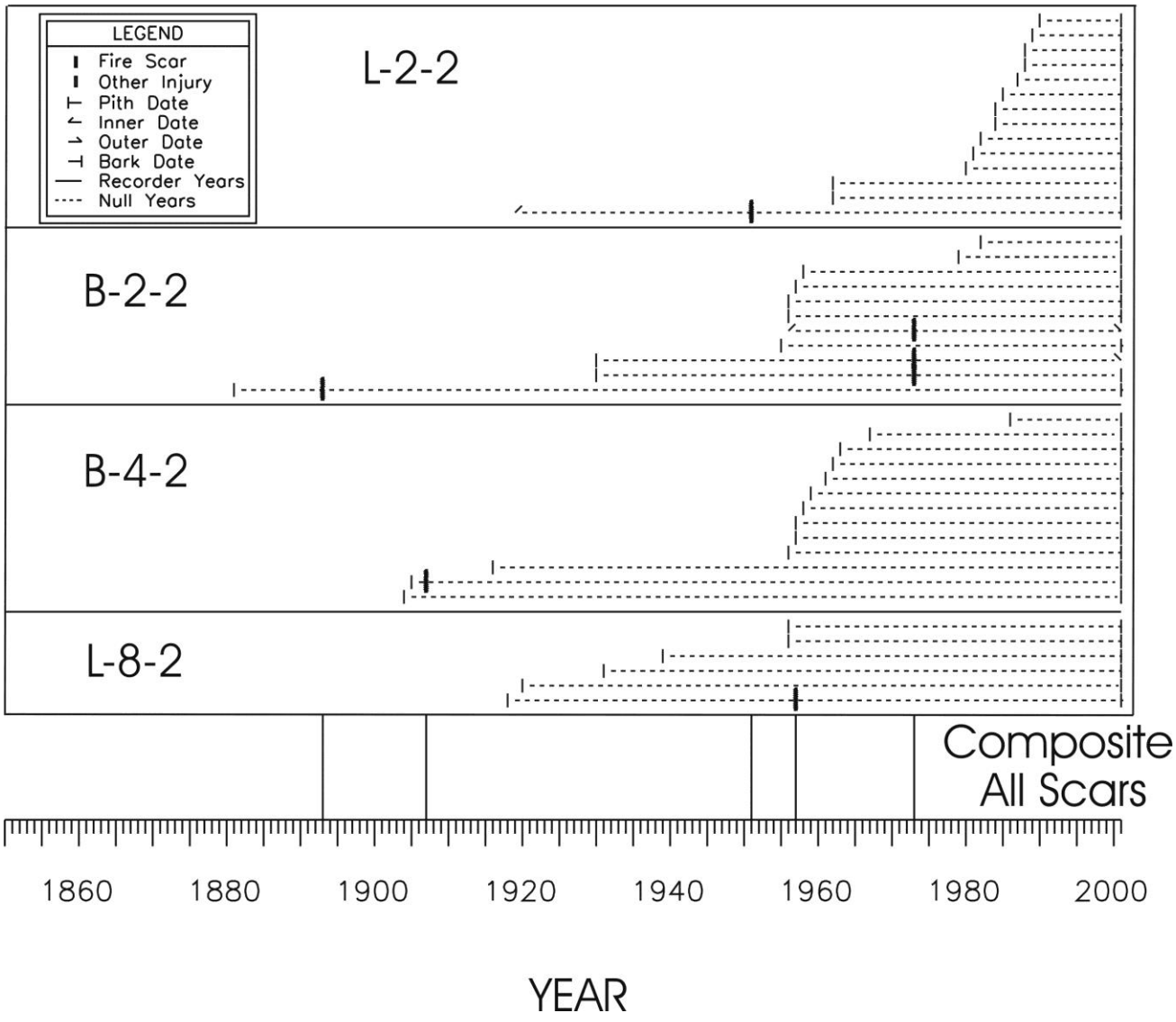

LEGEND
Fire Scar
Other Injury
Pith Date
Inner Date
Outer Date
Bark Date
Recorder Years
Null Years
B-2-1
L-2-1
Composite
All Scars
1860
1880
1900
1920
1940
1960
1980
2000
YEAR

FIG. 4


LEGEND
Fire Scar
Other Injury
Pith Date
Inner Date
Outer Date
Bark Date
Recorder Years
Null Years
L-2-2
B-2-2
B-4-2
L-8-2
Composite
All Scars
1860
1880
1900
1920
1940
1960
1980
2000
YEAR