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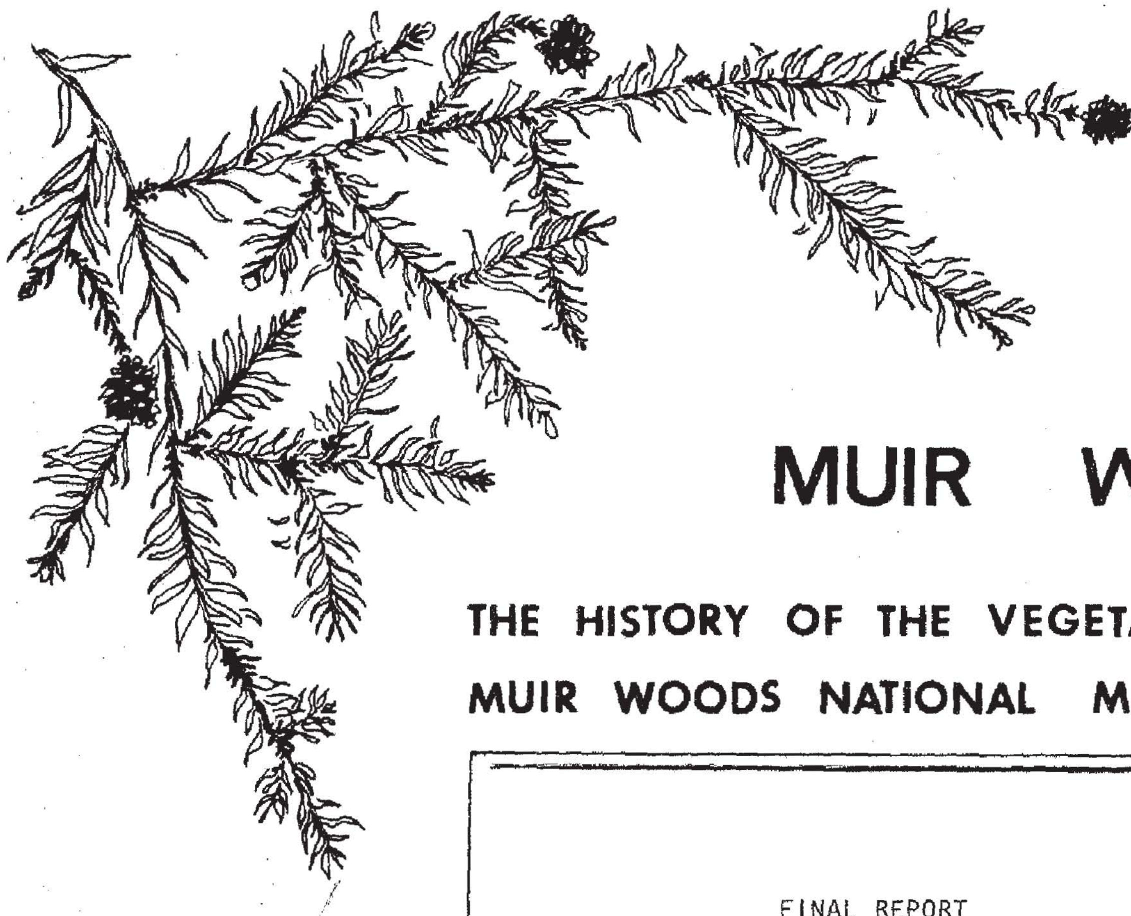

MUIR WOODS

THE HISTORY OF THE VEGETATION OF MUIR WOODS NATIONAL MONUMENT

FINAL REPORT

Phase III: Oct. 1, 1977 - Sept. 30, 1978

University of California
Berkeley, California 94720

Western Region
National Park Service
Dept. of the Interior
San Francisco, Ca. 94102

MUIR WOODS NATIONAL MONUMENT

President Theodore Roosevelt signed a proclamation in 1908 that established Muir Woods National Monument. Muir Woods is located within a small canyon near the Pacific Coast, 27.4 kilometers (17 miles) north of San Francisco. Named for the famed naturalist John Muir, the monument provides for the perpetuation of the specimen forest of coast redwoods found here. It is one of the few scattered groves that survive in primeval condition within the narrow zone of redwood occurrence along the Pacific Coast. Because of its unspoiled character and proximity to a large metropolitan area, Muir Woods is visited annually by thousands of people.

VEGETATION RESEARCH PROJECT

The National Park Service in 1976 initiated a three-year research project on the ecology of the coast redwood forest of Muir Woods National Monument and the impacts of human uses upon this forest. This investigation, conducted under contract by the University of California, Berkeley, is directed toward establishing the information base required to adequately perpetuate , interpret, and manage for recreational use the significant features of Muir Woods. Final reports will be reproduced in a series of Technical Reports, and subsequently this material will be published as Project Contributions in scientific journals.

Cover Drawing by Peggy Fiedler

Vegetation History of Muir Woods National Monument

National Park Service
Contract No. CX 8000-6-0035

FINAL REPORT

Phase III: Oct. 1, 1977 - Sept. 30, 1978

Joe McBride and Diana Jacobs

Department of Forestry and Conservation
University of California
Berkeley

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INTRODUCTION

Objectives

The objective of the study of the vegetation history at Muir Woods National Monument was to achieve an understanding of modern man's influence on the redwood forest. Two major characteristics of the vegetation were investigated to provide a framework for assessing modern man's influence and for predicting successional change. These were: (1) the composition and distribution of vegetation types; and (2) the age structure of tree-dominated types. Direct impacts on the vegetation were determined through studies of fire frequency, fire hazard, soil compaction, tree and fern planting, riprapping of stream channels, logging, removal of fallen trees, and inadvertent introduction of exotic species. It is hoped that the knowledge gained from this study will serve as a foundation for a vegetation management plan for Muir Woods. The report includes suggestions on how the results of this research may be applied for such a plan.

Previous Studies

This study was initiated with a thorough search of the literature of redwood ecology and the impact of man's use of the redwood forest as a site for recreational activities. This literature search has been reported in the form of an annotated bibliography (Jacobs and McBride, 1977) and a review (McBride and Jacobs, 1977).

STUDY AREA

Muir Woods is located seventeen miles north of San Francisco in a canyon along Redwood Creek (Fig. 1). At this location, Redwood Creek has a general northwest-southeast alignment. The adjacent slopes are predominantly northeast- or southwest-facing, the southwest-facing slope being considerably more incised by small ravines (Fig. 3). Elevation ranges from approximately 120 to 1,320 feet.

The geology of the area is dominated by sedimentary rocks of the Franciscan formation. Sandstone, chert and shales are the principal rock types in the Monument. A small area of Franciscan volcanic and metavolcanic rocks occurs at higher elevations along the eastern boundary of the Monument. Recent alluvial deposits of silt, sand and gravel occupy the floor of the canyon.

Six soil complexes, distinguished on the basis of soil type and slope, occur in the Monument: Centissima-Barnabe (30 to 50% slopes), Centissima-Barnabe (50 to 75% slopes), Cronkhite-Barnabe (15 to 30% slopes), Blucher-Cole (2 to 5% slopes), Deadwood-Killarc, and Sansal (Fig. 3). Descriptions of the complexes have been abstracted from a preliminary manuscript on Marin County soils by the United States Soil Conservation Service and appear in Table 1.

The vegetation of the Monument is a mosaic of redwood, Douglas-fir, hardwood, brush and grass dominated types. Redwood occurs primarily in uneven-aged stands with trees ranging up to 800 years old. Some redwood stands exhibit a more even-aged pattern which correlates with fires around 1845 and 1800. Only small areas within the redwood forest show evidence of logging. More detailed analyses of the vegetation follow later in this report.

The climate of Muir Woods National Monument is Mediterranean, with mild winters and dry summers. Summer fogs are a frequent occurrence. During the winter months the weather is dominated by a winter cyclone system that brings rain. Occasional intrusions of dry, cool polar air masses also occur. Climatic data recorded at the Monument show an average January temperature of 51°F and an average October temperature of 61°F. Average annual precipitation is 42 inches.

The land use of Muir Woods has varied during the past 200 years. The Coast Miwok Indians had permanent villages at Mill Valley and Bolinas Bay in the 18th century. Although no Indian occupation sites have been discovered within Muir Woods National Monument, plants which the Indians used for food, basketry, and medicine are common within its borders. Large tanoaks such as those found along the Dipsea Trail were prized for their acorns. California bay, madrone, elderberry and mugwort were also used. The anadromous fish of Redwood Creek and the various game animals of southern Marin County, especially the deer, were doubtlessly harvested within the eventual borders of the Monument.

Spanish settlement of the San Francisco Bay area began in 1776 with the establishment of a mission and presidio at San Francisco. Most of the Indians from southern Marin County moved to that mission by the year 1812. In 1817 a mission was established at the present site of San Rafael. Aboriginal cultural and land use patterns were replaced by those of the Hispanic culture at that time. Muir Woods was part of a land grant awarded to Antonio Richardson in 1838. Ranching was the principal land use during the early settlement period. Some livestock may have ventured into the margins of the forest on the Monument from the extensive grasslands to the south. Logging also took place on the land grant, but only a few trees within the Monument were cut. Hunting was probably the major use of the land within the Monument during the 19th century.

The construction of a wagon road in 1895 and a railroad spur line in 1907 opened the area to large numbers of recreationists. William Kent purchased the land in 1906 to protect the area from the extensive logging which eliminated old-growth redwood from the San Francisco Bay Area. During this period a small area of redwoods along Redwood Creek was logged to provide building materials for tourist facilities.

Kent donated the land to the federal government and President Theodore Roosevelt established Muir Woods as a National Monument in 1908. Hunting use and any further logging ended with the creation of the park. Subsequent to 1909 auto touring, camping, picnicking, and hiking have been permitted at various times. Land management activities have included tree and fern planting, trail construction, riprapping of portions of Redwood Creek, the removal of trees fallen across trails, and fire control.

STUDIES AND OBSERVATIONS

A number of studies and observations were conducted to gain an understanding of the ecology of the vegetation at Muir Woods and the impact of recreational use of the area on the redwood forest. Descriptions of the methods used and summaries of results are presented in the following sections. The application of the results to vegetation management at Muir Woods is presented as a conclusion to the report.

Vegetation Type Identification and Mapping

Objective

The objective of identifying vegetation types and preparing a map of their distribution was to provide a classification system and data base to facilitate subsequent studies and observations conducted for this report. The classification system and the map may also be used by the National Park Service to plan and direct future management activities at the Monument.

Previous Work

The vegetation of Muir Woods has been mapped by Wieslander (1914), French

(1935), and Cornelius and Kaye (1973). The maps of Wieslander and French distinguished few vegetation types. The map by Cornelius and Kaye classifies the vegetation into eight types. These maps were inadequate for the present study because of their scale, the minimum size of mapped unit, and the failure to distinguish age classes in the redwood and Douglas-fir types.

Method

Vegetation types were identified from a general field reconnaissance and from detailed examination of true-color and color-infrared aerial photographs. The field reconnaissance covered all trails, ridges, and drainages in the Monument. Field notes on species dominance and general age class were made during the reconnaissance. Aerial photographs taken during the summer of 1977 at a scale of 1:2000 (true-color) and 1:15,000 (color-infrared) were scanned to distinguish types identified from ground reconnaissance and to identify other types not observed during the reconnaissance. Species composition and apparent tree age based on density and crown diameter were used to recognize types on the aerial photographs. This procedure identified a total of fourteen vegetation types which were subsequently mapped.

Vegetation types were mapped on acetate overlays of the true-color aerial photographs. Minimum mapping area was .25 hectare. Types were distinguished by the following characteristics:

1. Life form
    a. Conifer
    b. Hardwood
    c. Shrub
    d. Grass
    e. Mixtures of the above

2. Tree Species (Conifer-dominated types)

   a. Redwood

   b. Douglas-fir

3. Age Class (Conifer-dominated types)

   a. More than 6 stems per 0.1 acre (Old-growth)

   b. Less than or equal to 6 stems per 0.1 acre (Young-growth)

4. Crown Cover (%)

   a. Pure type (Greater than 80% crown cover; e.g., Hardwoods)

   b. Mixed type (Two or more species each with greater than 20% but less than 80% crown cover; e.g., Redwood/Hardwoods)

5. Topographic position (Redwood-dominated types)

   a. Slope

   b. Alluvial terrace

The units delineated on each photograph were numbered and a random sample, representing twenty-five per cent of the area in each type, was selected for a ground check. Corrections of type classification were made as required by the ground check.

During the ground check the following information was taken on one or more 200 square meter plots located within the unit.

1. Tree species, diameter, crown cover, and age class of both overstory and understory.
2. Shrub species and cover (recorded on four 25 m^2 sub-plots for each 200 m^2 tree plot)
3. Herb species and cover (recorded on four 5 m^2 sub-plots for each 200 m^2 tree plot)
4. Topographic position

5. Ground slope
6. Aspect

A single 200 m^2 plot was located in a unit if the unit was homogeneous in appearance, based on species composition, structure, or age class of trees and shrubs, and less than five acres in an area. If the unit was composed of more than one homogeneous phase, a plot was located in each phase. Homogeneous units over five acres in area were sampled at an intensity of one plot per five acres. The information obtained from these plots was used to characterize the vegetation types as well as check the aerial photo interpretation.

The delineated vegetation types were compared to images on an orthophotograph to correct for variations due to scale changes and lens distortion. Corrected type boundaries were plotted on a topographic map at a scale of 1:4,800.

Results

The fourteen vegetation types classified and mapped in this study are as follows:

1. Redwood: Alluvial
2. Redwood: Slope, Old-Growth
3. Redwood: Slope, Young-Growth
4. Redwood/Douglas-fir
5. Redwood/Hardwoods
6. Douglas-fir: Old-Growth
7. Douglas-fir: Young-Growth
8. Douglas-fir/Hardwoods
9. Douglas-Fir/Brush
10. Hardwoods

11. Brush

12. Grassland/Brush

13. Hardwood/Brush

14. Grassland

The distribution of these types is illustrated in Figure 4. Most of these broad vegetation types, easily recognized on aerial photographs, could be further subdivided on the basis of understory conditions. Variations in species composition (Table 2) and crown cover were used to identify phases in each type. Crown cover was deemed a significant factor because of the influence on forest regeneration. Naming of phases was based on a species contributing at least 30% of the total crown cover in the overstory or understory. The double slash mark (//) was used in the name to separate the dominant species in the overstory from the dominant species in the understory (e.g., Redwood//Tanoak). The phases identified are listed along with their structural characteristics in Table 3. These phases represent on-the-ground variations in the vegetation types which result from differences in micro-environment and stand history. As units of the vegetation, they are comparable to the aggregation types proposed by Bonnicksen and Stone (1978).

Many of the vegetation types are the same as or closely related to types identified by other authors. The general redwood forest community described by Cornelius (1969) and Howell (1970) and the redwood-sword fern alliance described by Becking (1968) encompass the various redwood types and their phases reported here. The subdivision of this general type according to topographic position, age class, and structural phase provides a more detailed classification which will be useful for predicting successional change and for planning management activities. The Douglas-fir forest type characterized by Howell (1970) and

Zinke (1977) incorporates the Douglas-fir dominated types and their phases identified at Muir Woods. The phases of the hardwood types are similar to variants in the mixed-evergreen forest (Sawyer et al, 1977; Howell, 1970) and the oak woodland (Griffin, 1977; Howell, 1970). The manzanita dominated chaparral in Northern California has been described by Cooper (1922) and Howell (1970) and is similar to the manzanita phase of the brush type at Muir Woods. The coastal prairie grassland described by Howell (1970) and Heady et al (1977) is reflected by the grassland type at the Monument.

Those vegetation types which combine life forms (e.g., Douglas-fir/Brush, Hardwood/Brush, Grassland/Brush) are early successional types which are not usually classified because of their transitory nature. They were identified and mapped in this study because their presence must be recognized in any management plan. Although they are temporary on a successional time scale, they will remain a feature of the landscape at the Monument for several decades.

Stand Age Structure

Objective

The objective of determining the age structure of the various phases of vegetation types was to provide an understanding of the origin of these phases and a basis for the prediction of successional change.

Previous Work

Clements (1905) was the first to use stand-age analysis to gain an understanding of the history of forest stands and to predict future successional change. His methods were utilized by Cornelius (1969) to date stands in the southern portion of the Monument. He estimated that portions of this area burned around 1850. Cornelius used stand age analysis to predict the successional replacement of certain bay dominated hardwood stands by redwood.

Method

Tree ring counts were used to establish age diameter regressions for the major species in the Monument. Tree age can be approximated from ring counts on increment cores removed from living trees. Problems associated with missing and false rings make exact age determinations difficult (Glock, 1937). Trees selected at random from representative diameter classes were cored on the sample plots used to check the quality of aerial photointerpretation. The rings on these cores were counted in the field whenever possible. With some hardwood cores, it was necessary to use a dissecting microscope to identify and count rings. The diameter of each tree cored was measured at breast height to establish a diameter-to-age correlation. All other trees over ten centimeters in diameter at breast height were also measured on each plot. Trees under ten centimeters in diameter were tallied as regeneration of either seed or sprout origin. Seedlings were recorded as individuals (the actual number counted) while sprouts were tallied as clumps of sprouts when five or more sprouts arose from the same base. Sprouts can often number more than 100 at the base of large redwood trees and each individual sprout usually does not provide a significant contribution to regeneration. Total shrub and herbaceous cover was also estimated on each plot.

Correlations were established according to general site (east-facing, west-facing slopes) and age class (Old-growth, Young-growth) for redwood and Douglas-fir. Preliminary segregation of samples by site for hardwood species did not show significant differences between sites so all samples were combined for each species. Linear regression (Prodan, 1968) was used to establish a correlation between tree diameter and age. Once a relation was established, curves fitted by the least squares method were used to estimate the ages of all trees on the sample plots.

Results

Ages of redwood trees over ten centimeters in diameter at breast height ranged from 30 to 650 years (17.5 cm - 143 cm dbh). Trees larger than 150 cm could not be cored and no doubt exceed 650 years in age. The distribution of ages in east-facing slope, young-growth redwood samples confirm the occurrence of the fire in the mid-nineteenth century as suggested by Cornelius (1969).

Scatter diagrams, regression lines, and correlation coefficients for each species, site, and stand age class are shown in Figures 5 to 8. Inspection of the curves show a considerable scatter of points along the regression lines for the Redwood: Slope, Old-growth type (Fig. 5). Trees approximately 50 cm in diameter can vary more than 100 years in age. Such variation suggests a very cautious application of the regression lines in estimating age.

Tree age distribution was approximated from diameters taken on the sample plots and from regeneration counts. Five broad age classes were used: 0-50 (seedlings and sprouts), 51-100, 101-150, 151-200, and over 200 years. The age distributions are shown in Table 4.

Stand Origin and Future Successional Change

Table 5 summarizes the origin and future successional changes anticipated over the next 200 years for each phase of the various vegetation types. The predicted succession is based on the assumption that no major fire will occur. Succession following a major fire would depend upon the degree to which plants are consumed by the fire as well as the availability of seeds and climatic patterns in the year following any fire. Furthermore, National Park Service management personnel may choose to replant burned areas or otherwise modify the pattern of regeneration following a major fire.

Fire Frequency

Objective

One of the less obvious influences of modern man upon the vegetation of Muir Woods is the prevention and suppression of wildfires. Fire exclusion from the area produces effects more subtly than some other human activities, however, the actual impact of this policy on the vegetation is one of the greatest. To better gauge this impact, it is essential to know the natural fire frequency before establishment of the park.

Previous Work

The continued presence of fire in the natural environment of Muir Woods is well-evidenced by the many charred trees throughout the park. The last large fires to burn there have been estimated to have occurred around 1800 on the flat (Sudborough, 1966) and 1850 on the slopes (Cornelius, 1969). The frequency of fires prior to this last fire has not previously been determined for the Muir Woods area, and only a few fire frequency studies have been done anywhere for the redwood forest type. Fritz (1932) estimated at least four fires per century burned over a period of 1,100 years in an area of Humboldt County. Greenlee et al (1975) found a mean interval between fires of 56 years for two stumps cut near Big Basin Redwoods State Park in Santa Cruz County. Both of these investigators looked at freshly-cut redwood stumps and counted fire scars and growth rings in between the scars.

Methods

Because there was no opportunity to examine freshly cut stumps in the Monument to determine fire frequency, another method was chosen.

It is known that logging took place in other areas of redwood forest in Marin County in the 19th century and areas with old-growth redwood stumps were located and visited. Although the stumps were over a century old, the wood was still sound on many of them.

Two sites in the vicinity of Muir Woods were found on which a survey of fire scars on old stumps could be made. The first site was at the head of Old Mill Creek, up the slopes of Mt. Tamalpais from the town of Mill Valley. The Old Mill Creek drainage is adjacent to, and lies to the east of, the Redwood Creek watershed containing most of Muir Woods. The second site was near the intersection of Ridgecrest Road and Bolinas-Fairfax Road, above Alpine Dam. This is north of Muir Woods and on the first ridge from the ocean. The Old Mill Creek site (site #1) receives about 34 inches of rainfall yearly, and the Alpine Dam site (site #2) receives about 50 inches. Muir Woods has a yearly precipitation of 42 inches (Rantz, 1971). Because the position of Muir Woods from the ocean is intermediate geographically as well as meteorologically, it was felt that a good estimate of the fire frequency for Muir Woods could be made by stump surveys on these two sites.

Every cut stump from the original logging in each of the study sites was examined. Only stumps which were not rotted or burned and had at least five consecutive fire scars visible were used in determining fire intervals. Fire scars on the stumps were recognized by several features. After fire kills the cambial tissue of a tree, a healing process usually ensues in which growth rings larger than normal are laid out in exaggerated curves. Complete healing-over may occur, but the fire is recorded as a dark-staining line followed by a dramatic change in ring width. If healing is not complete, the old fire scar is evidenced by longitudinal lines on the faces of the burned "goosepen" stumps, as well as the staining and growth ring changes.

The basic procedure used was to make a horizontal cut with a hand saw across the areas of vertical fire scars, then another cut at a slight angle. The piece was removed, exposing the growth rings and fire scars. The surface then was cleaned with a sharp knife, wire brush and hand broom. Sandpaper and files were not useful because the wood was usually too damp. Hand lenses and flashlights facilitated ring counting between scars.

The mean interval between fires (fire frequency) was calculated for each stump investigated. All the stump means were then averaged again to give an average interval for the entire site. In this way, scars from the same fire but on different stumps would not weight the mean to give a misleading figure.

Only 42 stumps from the hundreds examined on both sites were found in good enough condition to allow dating. These stumps were considered to be random samples, representative of the entire population at each site, because no apparent differences in slope, aspect, elevation, or other topographic features were found between the locations of the suitable stumps and the locations of stumps which were rotted away or badly burned after logging.

Results

The results of the stump survey are shown in Table 6. The average interval between fires was 21.7 years for the first site at Old Mill Creek and 27.3 years for the second site at Alpine Dam. The difference between these averages is statistically significant at the 0.01 level. The difference in rainfall and position relative to the Pacific Ocean, which influences summer fog occurrence, may account for the difference in fire intervals. Based on location and yearly precipitation it is concluded that the average natural interval between wildfires prior to the last large fire around 1850 was slightly longer than that for the Old Mill Creek site.

The above reported estimates are subject to a number of possible errors. The major factor which may cause an error in fire frequency estimation is the fact that every fire does not scar every tree. Fire intensity, extent of the fire, fuel build-ups near the tree, presence of old scars, and many other variables influence whether a fire scar will be left on any particular tree. The fire intervals determined for these two areas may be low estimates of the true values. One more likely cause of underestimating the actual fire frequency is that evidence of lighter and possibly more frequent fires was burned off the scarred faces of the trees, leaving only the deeper scars caused by more intense but less frequent fires. In fact, successive intervals as short as four or five years on some stumps were found. The natural fire frequency at Muir Woods prior to the last fire in the nineteenth century was probably around one every 20 years.

Fire Hazard

Objective

Wildfires burned regularly in Muir Woods before it became a National Monument. Fire prevention and suppression since has altered the environment and the vegetation undoubtedly looked much different at the turn of the century than it does today. This change in the vegetation has a direct effect on the potential danger of fire damage to present and future park values. A build-up of ground and ladder fuels has occurred since the last fire in the early nineteenth century. Because of this increase in fuel and because of the increased visitor use of the park, it is important that the different vegetation types of Muir Woods be classified according to relative fire hazard. This will be useful in developing management programs and priorities for the different vegetation types in the park.

Previous Work

Three different systems of assessing fire hazard were adapted and incorporated into a system developed specifically for Muir Woods. The Fire Hazard Severity Classification System for California's Wildlands (Helm et al, 1973) provided a basic model upon which to work, but was found too general in scope to be used alone. The National Fire-danger Rating System (Deeming et al, 1974) developed by the United States Forest Service was helpful in its designation of the most important determinants of fire behavior. Many of these determinants dealt with fire weather factors or other variables not appropriate for measurement in this study. The Crowning Potential and Rate of Spread Indexes developed by Fahnestock (1970) suggested fire behavior determinants that could be easily quantified to give two ways of appraising forest fire fuels, and thus were incorporated into the present fire hazard rating system.

Methods

The system developed for Muir Woods is based upon the field determination of nine variables suggested by the three above systems (Table 7). The variables were measured at the same time other vegetation parameters were measured for the sample units of each vegetation type. The nine variables chosen for consideration are those determinants of fire behavior which are sufficient to give an indication of the fire hazard for this area. At the same time, they are easily evaluated in the field. Each variable can take on only a very few values in most cases, allowing the field observing and recording to be both rapid and precise.

The measured variables are combined into five major categories of fire hazard, each with a possible ranking of 1 to 5 (1 = lowest). The five categories are: Surface fuel condition, Ladder fuel condition, Downed woody fuel, Slope-wind, and Ignition Risk. Table 8 shows these categories and the derivations of the rankings to be used in classifying the vegetation sample units according to fire hazard.

Surface fuel condition (Table 8A) indicates the potential for a fire to burn and spread on the ground. This category combines a component of litter condition with fuel bed depth (Variable C). Litter condition is derived by subtracting the rating for living herbaceous ground cover (Variable B) from the rating for Fine-surface fuel (Variable A).

Ladder fuel condition (Table 8B) indicates the potential for a fire to burn and spread above the ground, including crowning potential. Ladder density (Variable E) and Ladder height (Variable D) were combined for this category. Ladder density was weighted more heavily than height in deriving rankings. The density of the ladder complex affects the potential heat of a fire and probably influences crowning potential more than ladder fuel height because flames and heat rise anyway.

Downed woody fuel (Table 8C) was estimated according to the method of Brown (1974) for the forest vegetation types. The amount of dead woody fuel on the ground which is measured can indicate the potential heat energy which might be released by a fire. Brown's planar-intersect method is only applicable to fallen twigs, branches and logs. Standing dead brush and dead grass are usually estimated by destructive sampling and weighing. Because the grass and brush areas in the park are small, ground fuel amounts for these types were estimated from values given in the literature (Helm et al, 1973).

The Slope-wind category (Table 8D) represents a major determinant of fire spread. Slope and wind (Variables G and H) act on fire behavior in a similar fashion. Thus these variables were weighted equally in determining rankings for this category.

Ignition Risk (Table 8E) gives an indication of the relative potential for a fire starting due to man. The likelihood of a firebrand being cast on the ground by human visitors is indicated by relative accessibility and proximity to trails (Variable I). The likelihood that a firebrand might catch ground fuels on fire is indicated by the litter condition (Variable A minus Variable B). The relative risk of wildfires being started by lightning is not known for Muir Woods and was not considered in relative hazard ratings for ignition.

Results

A spectrum was chosen as the best representation of relative fire hazard for the vegetation types rather than a single index, for two reasons. Combining the five categories into a single index of manageable size would require the loss of too much of the information presented by the measurements of the nine field variables. In addition, there is a problem in determining the relative contribution of each of the variables to fire hazard.

The Fire Hazard Spectra for the vegetation types of Muir Woods are presented in Figure 9. The number of samples taken in each vegetation type varied with the relative areas covered so the rankings are presented on the basis of relative frequencies, rather than absolute. The rankings in each category were not averaged for the final presentation of results because this would give an incomplete picture of the actual range of fire hazard conditions for the different vegetation types.

For example, for Type 9 (Douglas-fir/Brush) Fig. 9 shows 50 percent of the areas have a low (1) score in Ignition risk, and 50 percent have a relatively high (4) score. This presents more information for management purposes than an average of all scores would.

The Surface Fuel Condition category shows a low to medium fire hazard rating condition for most vegetation types in the park. It is important to remember that the present conditions are probably more hazardous than they were at the establishment of the Monument, and without prescribed fires or other types of fuel manipulation, this hazard is certain to further increase in the future. The brush vegetation type and some units of the young redwood and Douglas-fir/hardwood types do show a high hazard in this category at the present.

The Ladder Fuel Condition category results show a hazardous condition exists in many areas of the park with respect to above-ground burning and spread potential, especially crowning potential. Like surface fuels, the ladder fuels have increased steadily since the last fire and will similarly continue to increase into the future without any fuels management programs. The vegetation types which are mixtures of dominant species show especially potentially dangerous situations, e.g., the vegetation types with hardwoods and mixed hardwoods/conifers. The types containing redwood and old-growth Douglas-fir show an interesting bimodality for this category, with some units being fairly hazardous and others being less so within the type.

The Downed Woody Fuel category shows a high variability throughout most types. This variability can probably be attributed to the presence or absence of fallen logs in the sample units. Wood decomposition is much slower than the yearly addition of woody fuel to the ground fuel layer and significant increases are expected as natural tree mortality and windfall occur.

The Slope-wind category will show more or less unchanging rankings over time, as the rankings are due to the prevailing winds from the Pacific Ocean and topography.

The Ignition Risk category may show increases or decreases in hazard in the future. Trail locations and usage may be changed, altering visitor accessibility. More areas may be fenced to protect herbaceous species, thus decreasint the flammability of the litter fuels, and decreasing the risk of a fire igniting on the ground.

Soil Compaction

Objective

The objective of this study was to measure the effect of soil compaction on the radial growth of redwood. Radial growth was used as an index to evaluate the influence of soil compaction associated with trail construction and use on general tree vigor. Heavy visitor use of alluvial areas along Redwood Creek began in 1908.

Previous Work

Meinecke (1929), Zinke (1962), Sturgeon (1964) and Krenzelock (1974) have investigated the impact of soil compaction on the redwood forest. Evidence from these studies is inconclusive as to the effect of soil compaction on the growth and vigor of mature redwoods. Meinecke found a reduction in the size and health of feeder roots of trees growing in compacted soil. Zinke suggests a reduction in tree vigor should be associated with soil compaction, but offers no data to support this view. Krenzelock demonstrates a significant impact of trampling and soil compaction on the distribution and abundance of herbaceous species in the alluvial flat redwood areas at Muir Woods. Although his work does not treat redwood tree vigor, it does demonstrate a correlation between soil compaction and poor vigor of herbaceous species. Sturgeon concludes that no definite statement regarding the effect of recreational use impact on redwood trees can be made. He points out that certain areas have received a tremendous amount of human use for thirty years or more and yet no apparent decline in vigor of the overstory is observed.

Methods

Thirty mature redwood trees (minimum DBH = 100 cm) growing in alluvial areas along Redwood Creek were selected for this study. Fifteen trees are located next to visitor trails or in otherwise heavily trampled soils, and were designated the "impacted" group. Fifteen trees are located away from visitor trails where no trampling is apparent, and were designated the "control" group.

Soil compaction levels were inferred from cone penetrometer readings taken at eight points around each tree. These points were on cardinal directions from the center of the tree and halfway between the tree's stem base and crown drip line. The eight readings at each tree were averaged and indicate the force (in pounds) required to penetrate the soil surface below each tree. Penetrometer readings confirmed "impacted" versus "control" group designations.

Two increment cores were taken from each tree at breast height. The cores were taken at points below the deepest portion of each tree's canopy in order to minimize the possiblity of missing rings which are common in redwood (Fritz and Averill, 1929). The two cores were taken at least 90° apart.

Radial growth was measured for two periods on each core: 1) 1871 to 1900, i.e., before any significant visitor use of Muir Woods; and 2) 1941 to 1970.

Most trees show reduced radial growth as they mature. The study hypothesis was that "impacted" trees would show a greater reduction in radial growth between the two periods than "control" trees. Therefore, radial growth differences between the two periods were determined and averaged for each tree. These radial growth differences were compared for the "impacted" group versus the "control" group using Student's T-test (Gosset, 1908).

Results

"Control" trees had an average force required to penetrate surface soil of 5.2 pounds while "impacted" trees required an average force of 35.2 pounds. Twelve trees in the "control" group had an average radial growth reduction between the two periods of 13.42 mm while three "control" trees increased radial growth between the two periods an average of 10.21 mm. Eleven trees in the "impacted" group decreased radial growth between 1871-1900 and 1941-1970 an average of 11.73 mm, while four "impacted" trees increased radial growth an average of 10.26 mm (Table 9).

The comparison of radial growth differences failed to show a significant difference between the two groups of trees. The results of this experiment did not provide any evidence that tourist trampling and subsequent soil compaction have caused reduced radial growth or lowered tree vigor.

Tree and Fern Planting

Objective

The objective of this study was to determine the impact of the planting of trees and ferns on the appearance of plants in certain forest areas at Muir Woods National Monument.

Previous Work

Several studies have demonstrated the influence of what is perceived to be an appearance of naturalness in vegetation on enjoyment in outdoor recreation. The aniticipation of naturalness by recreationists contributes to their satisfaction in wildland settings (Lee and Absher, 1978). Research conducted to identify those characteristics of forest vegetation which correlate with user selection of sites for camping has shown a high correlation between site selection and apparent naturalness (Klukas and Duncan, 1967; Cordell and James, 1972). Moir (1972), in a review of characteristics used by various agencies in selecting natural areas for preservation, found a common denominator to be the unmodified or primeval appearance of the vegetation.

The arrangement of plants on the ground surface, or the pattern, can contribute to the perception of naturalness by the observer. Contagious patterns are usually encountered in natural vegetation (Daubenmire, 1968). Random patterns occur less commonly; regular patterns are very seldom encountered, and never at all in forest types.

Method

Pattern can be determined with data collected from a large number of plots by examining the departure of observed values from a Poisson distribution which assumes that individuals are randomly distributed (Chapman, 1976). Pattern can also be detected by examination of maps of individual plant locations. The latter method was chosen because of limited information on the locations of planted areas. Several references to planting occur in the Historical Chronology of Muir Woods and Vicinity (Hildreth, 1966) but the locations of these plantings are not precisely given. Since not enough plots could be identified as having been planted, a single stand of planted Douglas-fir was studied. A 100 ft. by 100 ft. plot was mapped in this stand and a similar-sized plot was mapped in a natural stand for comparison. Visual comparison of the resultant maps was used to detect pattern. Apparent naturalness of the two stands was ranked by a group of five forest ecology students who visited the stands in August, 1978.

Results

Maps of trees in the planted and naturally established stands reveal different patterns (Fig. 10). The pattern of the planted stand shows evidence of a 10 ft. by 10 ft. spacing. There is an absence of any clustering of the larger trees (trees which were planted). The pattern fails to be exactly regular due to variation in spacing during planting and subsequent mortality. The pattern of the natural stand is a random one characterized by isolated as well as clumpled trees. This pattern is to be expected in a species like Douglas-fir which regenerates from wind-dispersed seeds following a fire.

All five forest ecology students ranked the appearance of the planted stand as artificial and the other stand as natural when the stands were visited. The larger trees in the planted stand clearly appear in rows which primarily contributes to the unnatural appearance. In addition, the absence of any other tree species and sparse undergrowth were identified as characteristics which contributed to the unnatural appearance of the planted stand.

A search of the alluvial flat along Redwood Creek failed to clearly identify areas referred to by Hildreth (1966) where sword fern and redwood were planted. The pattern used in the planting of these species apparently simulated natural patterns as opposed to the regular pattern observed in the Douglas-fir plantation.

Riprapping of Stream Channel

Objective

Riprapping of portions of Redwood Creek was initiated in 1933 to replace brush revetments installed in 1925 (Hildreth, 1966). Thirty-one per cent of the total length of stream bank (considering both sides) has been riprapped (Fig. 10). This has controlled stream bank erosion and protected stream-side trees from being undercut in the Monument. The objective of this investigation was to determine if changes in soil particle size distribution has occurred along the riprapped portions of Redwood Creek.

Previous Work

Flooding of creeks and rivers through alluvial flats in redwood forests results in the deposition of stream-carried materials upon the alluvial flats. The significance of these deposits to redwood regeneration has been discussed by Becking (1968, 1971) and Stone and Vasey (1968). Silt deposits free of organic matter provide suitable seed beds for redwood seedling establishment. Heavy clay, large-sized sand or gravel deposits are not well suited for redwood regeneration. Riprapping of larger stream channels in Northern California has prevented the deposition of large diameter sand and gravel, and may have a tendency to increase the relative amount of clay in alluvial deposits. Long term deposition of clay would be detrimental to redwood regeneration.

Methods

Two soil pits were dug at each of three locations along Redwood Creek

(Figure 10). These locations were selected because they represent areas of maximum deposition of stream-carried sediments on the basis of stream configuration. Soil samples were collected at depths of 0-1, 3-4, 6-7 and 12-13 inches. The depths were presumed to span depositions prior to and since riprapping. Observations in the alluvial flat redwood forest along San Leandro Creek in Alameda County, California indicate an average deposition of five inches of material since 1930.

The hydrometer method (Day, 1965) was used to determine the percentage of different size fractions in each sample. Particle size distribution in the soil profiles was compared to see if trend toward smaller diameter particles was evident in the upper portion of the profile.

Results

No increase in clay (particles less than 2 mu) subsequent to riprapping was noted in the sample profiles (Figure 11). Six floods have been reported along Redwood Creek in the Monument since the initial riprapping was completed (Hildreth, 1966). Deposition of material during these floods was noted for the February 6, 1942 flood (two feet of gravel deposited in trail near the redwood cross-section) and the January 14, 1956 flood (600 tons of debris in parking lots). These descriptions together with the results of the soil profile analysis indicate that riprapping has not altered the composition of alluvial deposits along Redwood Creek.

Removal of Fallen Trees

Objective

Under natural conditions trees which fall in a forest remain on the ground surface and decay. Subsequent to falling, the branches and foliage on the ground or above it can modify local microenvironments of small tree seedlings. Crown openings resulting when trees fall may encourage regeneration in areas not covered by debris. The objective of this investigation was to analyze the influence of the removal of fallen trees upon tree regeneration in the Redwood: Alluvial type.

Previous Work

Fallen logs provide suitable seedbeds in some forest types. Hemlock (*Tsuga heterophylla*) commonly becomes established on logs and is capable of sending its roots around the log to reach mineral soil (Fowell, 1965). Similar redwood seedlings have been observed on logs at Muir Woods and in other parts of the redwood region (Daubenmire and Daubenmire, 1975). No studies of the impact of fallen branches and foliage have been reported.

Methods

Locations where twenty trees had fallen in the last 20 years across trails on the alluvial flat along Redwood Creek were examined for the following characteristics:

1. Type of maintenance
2. Sprouting behavior
3. Impact of fallen stem and/or canopy on forest regeneration
4. Contribution to fire fuels

Thirteen of these trees were bay, three tanoak, one big leaf maple, two redwood, and one Douglas-fir.

Results

The results of the survey are summarized in Table 10. Fallen bay trees, because of their sprouting behavior, have a significant impact upon forest regeneration. The vigorous growth of sprouts along the fallen trunk creates a deep shade which may be detrimental to tree seedlings. They also contribute to the ladder fuel complex. A more complete removal of fallen bay trees from redwood-dominated areas is merited. Current maintenance activities applied to other hardwoods and conifer species seem adequate in terms of forest regeneration, but may not be sufficient to control temporary accumulations of ground and ladder fuels. The openings in the forest canopy as a result of trees toppling allows significant amounts of light to reach the forest floor to promote seedling establishment and vigorous sprout growth.

Exotic Species

Objective

The purpose of this study was to determine the frequency of exotic species in the Monument and to evaluate the significance of their presence to the appearance of naturalness of the vegetation and to the distribution and vigor of native species.

Previous Work

The potential for encroachment of exotic species into native plant communities of California is best illustrated with the example of the take-over of the native perennial bunch grass type by European annuals (Hendry, 1931; Burcham, 1956; Robbins, 1940). Frankel (1970) studied floristic composition along roadsides within the redwood forest type. He found relatively few introduced species, but those which were important included: Myosotis sylvatica, Hedera canariensis, H. Helix, Vinca major and Cytisus scoparius. No work has been reported on the encroachment into the redwood forest type by exotics.

Methods

Relative frequency of exotic species was calculated from tree, shrub and herb plots measured to characterize vegetation types. Additional observations of exotics in tree- and shrub-dominted types were recorded throughout the period of field work. No observations were recorded for the grass-domated areas because of nearly complete transition of the grassland type to exotics.

Results

Five exotic herbaceous species were found, which were widespread but uncommon. This can be seen in the low percentages of frequency of occurrence (Table 11). Three of the exotics were found within the redwood vegetation types, but because of such low occurrence, the native redwood herbaceous flora should not be threatened by exotic invasion.

Many more exotic species than the five listed in Table 11 have been observed. However, these appeared to be concentrated on the periphery of the Monument (grassland-forest interface), and in areas of heavy visitor use (parking lot). A supplementary list of exotic species was compiled by the Muir Woods staff in 1974 (Table 11). Three species on this list (Acacia farnesiana (L.) Willd., Cytisus scoparius (L.) Link, and C. monspessulanus L.) are potential invaders of grassland and brush-dominated types. They have taken over local areas of native vegetation near Mill Valley and on Mt. Tamalpais. Their presence in the Monument should be periodically monitored.

APPLICATION OF RESULTS TO DEVELOPMENT OF A VEGETATION MANAGEMENT PLAN

The development of any vegetation management plan requires an initial formulation of an objective of management. In 1974 (U. S. NPS) the National Park Service stated the following objective for the management of Muir Woods:

> "Because of the unique age and size of the coastal redwoods, their location near a large metropolitan center, and the primeval character of the forest in which they survive, the perpetuation of the coastal redwood and supporting ecosystems is the prime objective of natural resource management planning in Muir Woods. The regeneration of the coastal redwood is prerequisite to the identity of Muir Woods National Monument, for the enjoyment of present and future generations of visitors."

In 1977 (U. S. NPS) the following statement of a management objective was made:

> "Three strategies have been developed for the management of natural resources within the zones defined by the land classification system. These strategies are preservation management, protection management, and enhancement management.
>
> Preservation Management
> This strategy applies to natural areas that can accommodate only minimal use and/or areas that support significant ecosystems and habitats. These lands will be managed to allow natural processes to continue uninterrupted (including the normal changes associated with ecological succession), or to facilitate a return to natural conditions.
>
> Included in this management category is the outstanding natural feature subzone (Muir Woods and Audubon Canyon Ranch)."

Different vegetation management plans would need to be developed for each of these objectives. Preservation of process will not insure the preservation of large redwood trees at Muir Woods. The preservation of these trees will require a modification of natural processes at the Monument. Fire in particular presents a management dilemma in the absence of a clearly stated objective. It can destroy or badly scar the large trees in the Monument while preparing seed bed conditions to insure re-establishment of the forest. The question which the

Park Service must answer is whether or not the time interval between possible forest destruction by a natural fire and regrowth of trees of significant size (probably 300 years) would be acceptable at Muir Woods.

Leopold et al (1963) suggested the goal for management of the National Parks should be the maintenance of biotic associations as nearly as possible in the condition that prevailed when each area was first visited by white men. This goal seems very appropriate for Muir Woods.

Vegetation management planning to preserve a certain character of the landscape must start with knowledge of the distribution of vegetation types and their successional potentials. The vegetation map (Fig. 4) together with the information developed on the successional potential of each phase (Table 4) provide this information. Another valuable kind of information for the development of a vegetation management plan is knowledge of the fire hazard associated with various types. The fire hazard spectra presented in Fig. 9 provides this information for Muir Woods. Information on modern man's impact on vegetation is also needed both to understand the character of the vegetation and to manage future recreational use in a way which will minimize adverse aspects. This kind of information has been developed in this study.

General applications of the information generated by this study are given in the following sections. Each section suggests one or more guiding principles. Specific management prescriptions must be developed by Park Service managers or other professional vegetation management specialists.

Distribution and Maintenance of Vegetation Types

The distribution of vegetation types at Muir Woods provides an interesting mosaic for nature study and enjoyment of the redwood forest. This mosaic should be maintained. Maintenance of rapidly changing units in the mosaic such as hardwood-brush is important. These units provide important areas where the development of vegetation can be studiend, and important wildlife habitat. The vegetation map (Fig. 4) developed in this study can serve as a management map for planning the logistics of management activiies in different vegetation types.

Successional Change

Succession within the redwood-dominated types which will lead to a reduction in the dominance of redwood should be halted. Phases where this may be a problem can be identified in Table 4. Phase descriptions presented in Table 3 will provide managers with the information needed to identify local stand conditions.

The large majority of sites visited in the redwood forest exhibited sufficient numbers of redwood seedlings or sprouts to provide for continuation of redwood dominance. Low light intensity resulting from shading by hardwoods may be detrimental to the growth of this regeneration. In many areas a clearing of the hardwood understory would allow redwoods to form an understory and eventually grow into the overstory level of the crown canopy.

Succession should not be permitted to eliminate the diversity of the present vegetative mosaic. The types involving different plant life forms (e.g., Douglas-fir/Brush) are succeeding to types dominated by the life form of greater stature. Control burning or mechanical clearing could be used to halt succession in these types.

Fire Hazard

Fire control at Muir Woods over the past 70 years has resulted in an increased fire hazard due to increased fuel loads and the development of ladder fuels in most forest types. The information presented in Fig. 9 can be used to establish management needs concerning fuel modifications and time schedules for carrying these out. For example, the Brush vegetation type shows a high hazard for the categories of surface and ladder fuel conditions. Areas containing this type can be identified on the vegetation map along with surrounding units. A program of fuels modification can be planned on the basis of the hazards presented in the brush areas themselves and in the surrounding areas. Some units of the Douglas-fir/Hardwoods type also present high hazards that will require attention fairly soon. While the chance for humans starting a fire seems low, if a fire did reach these areas, the potential for a conflagration is very high. Hand-clearing of understory woody species and removal of downed fuel in the larger size classes is indicated. Most of the areas containing redwood do not in themselves present high fire hazards and immediate management actions should probably be taken in other types first, although with time, all areas are expected to increase significantly in fire hazard without some fuel modifications.

Soil Compaction

Soil compaction was not demonstrated to reduce radial growth of redwoods. No correlation between the proximity of trails to individual trees and the vigor of these trees as expressed in ring width could be established. Trail construction should not be limited by a fear of adversely influencing the trees. If trails are relocated in the future, it would be advisable as Krenzelok (1974) has suggested, to loosen the compacted soil in order to encourage a more rapid rate of establishment of herbaceous species.

Planting

Planting should be considered only as a technique to insure a more rapid recovery of locally devastated areas which may result from future floods, fires, or relocations of facilities. Any planting design should reflect the natural pattern of the species to be planted.

Riprapping

Riprapping should be renewed in several areas along Redwood Creek. Deterioration of revetments at certain locations is resulting in a loss of stream bank protection. No evidence was developed to show any significant change in the distribution of soil particle size resulting from riprapping of the stream channel.

Removal of Fallen Trees

Hardwood species, especially bay, which fall into redwood-dominated types on the alluvial flat should be removed. The sprouts they produce reduce the growing space for other species and contribute to ground and ladder fuels. They should not, however, be removed when they fall in the hardwood type along Redwood Creek. Their sprouting will perpetuate the type and help to maintain the vegetative mosaic of the Monument. Limbs and branches of fallen conifers should also be removed when trees fall on the alluvial flat because of the increase in fire hazard associated with this debris. Logs should be left unless their numbers are so high that they eliminate too much growing space on the alluvial flat.

Any extensive blow-down in the conifer forest types along the Dipsea trail should be promptly removed because of the increased fire hazard.

Exotics

Only local elimination of exotics may be called for at Muir Woods. Areas adjacent to the parking lot or along forest-grassland boundaries show significant densities of undesirable exotic species. Over a large percentage of the area, the few exotics which are encountered do not detract from the natural appearance of the native vegetation. An annual monitoring program of areas sensitive to invasion by broom and acacia should be initiated.

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TABLES AND FIGURES

Table 1. Soil Complexes of Muir Woods National Monument

CENTISSIMA-BARNABE COMPLEX
(30 to 50% and 50 to 75% slopes)

The Centissima-Barnabe complex occurs on sloping land above Redwood Creek and on some ridges. It is the most commonly encountered soil complex in the Monument, and supports all of the slope redwood stands. The areas mapped as this complex are about 55 per cent Centissima soil, 25 per cent Barnabe soil, 15 per cent Dipsea, and 10 per cent Henneke soil and rock outcrops.

The Centissima soil portion of this complex has a brown loam surface about 10 to 20 inches thick. It has a light brown, very gravelly clay loam subsoil 10 to 20 inches thick that lies on highly fractured sandstone or shale. The Centissima soil is well drained and its permeability is moderate. Effective rooting depth is 20 to 40 inches. Available water capacity is moderate. Surface runoff is rapid and erosion hazard is high.

CRONKHITE-BARNABE COMPLEX
(15 to 30% slopes)

This mapping unit is located along the Dipsea Trail where the redwood forest gives way to the grassland. It consists of about 50 per cent Cronkhite soil and 30 per cent Barnabe soil. Remaining areas contain Dipsea soil and rock outcrops.

The Cronkhite soil has a surface layer of brown and dark, grayish brown clay loam about 15 inches thick. The subsurface layer is dark, grayish brown clay loam about 11 inches thick. The subsoil has mixed colors of yellowish brown and strong, brown clay over yellowish brown clay loam. The subsoil is about 19 inches thick. The substratum is highly fractured sandstone and shale. In a few areas the surface layers of Cronkhite is clay loam. Cronkhite soil has moderately slow permeability and the available water capacity is moderate. Surface runoff is moderate to rapid and erosion hazard is high. The effective rooting depth is 40 inches or more. Reaction is slightly acid.

The Barnabe soil has a surface layer of grayish brown and dary grayish brown, very gravelly loam about 8 inches thick. This surface layer contains between 35 and 50 per cent gravel by volume. The subsoil is very dark grayish grown, gravelly loam about 8 inches thick. The subsoil contains 15 to 35 per cent gravel by volume. Barnabe soil has moderate permeability and the available water capacity is very low. Surface runoff is rapid and erosion hazard is high. The effective rooting depth is 10 to 20 inches. Reaction is medium acid to neutral.

BLUCHER-COLE COMPLEX

This complex occurs on the stream terrace along Redwood Creek, and has developed on alluvial deposits. The largest redwood and hardwood trees in the Monument occur on the Blucher-Cole Complex. The Blucher and Cole soils are so intricately mixed, or so small in size, that it is not practical to separate them for mapping purposes.

The Blucher soil has a surface layer of brown loam about 10 inches thick. The subsoil is unrelated material consisting of brown, fine sandy loam about 8 inches thick. This is underlain by two or more unrelated layers of gray silt loam over gray loam about 22 inches thick. Still lower is a buried horizon of dark gray silty clay about 25 inches thick. This is underlain by a similar buried layer of dark gray, light silty clay about 25 inches thick. This is underlain by a similar buried layer of dark gray, light silty clay to a depth of 65 inches.

Table 1. continued

Blucher-Cole Complex

Blucher soil has moderate permeability. The available water capacity is moderately high. Surface runoff is slow and erosion hazard is slight. The effective rooting depth is over 60 inches. Reaction is medium acid to moderately alkaline.

The Cole soil has a surface layer of gray and dark gray light clay loam and silty clay loam about 14 inches thick. The subsoil is dark gray silty clay about 28 inches thick. The substratum is grayish brown and dark gray silty clay. It ranges to a depth of over 60 inches.

Cole soil has slow permeability. Its available water capacity is high. Surface runoff is slow and erosion hazard is slight. The effective rooting depth is over 60 inches. Reaction is strongly acid to moderately alkaline.

DEADWOOD-KILLARC COMPLEX

The Deadwood-Killarc Complex occurs beneath brushfields at a few locations along the northern boundary of the Monument. The mapping unit is made up of more than 50 per cent Deadwood soil, the remaining area being composed of Killarc soil and rock outcrops.

The Deadwood soil is a shallow, well drained, gravelly loam with a very gravelly light clay loam subsoil underlain by fractured sandstone and shale. The thickness of the solum ranges from 10 to 20 inches and contains 20 to 30 per cent by volume gravel in the A-horizon and 45 to 60 per cent in the B-horizon.

The Killarc soil is grayish brown, slightly acid, very stony light loam and sandy clay loam about 9 inches thick. The upper part of the subsoil is light brownish gray and pale brown, extremely acid clay about 13 inches thick. Below this, the substratum is light gray, very strongly acid sandy clay loam. The soil is moderately well drained and subject to landslips. It is of slow permeability and had medium to rapid runoff on steaper slopes.

SANSAL SOIL

Salsal soil occurs in a small area at the western end of the Monument. It is a grassland soil which supports annual grasses and forbs. Sansal is morphologically similar to Cronkhite except in texture. The subsoil of the Sansal is loam rather than the clay and clay loam which characterizes Cronkhite soil. As a result, Sansal soils are well drained and have moderate surface runoff.

TABLE 2. Plant Species Recorded in the Vegetation Types at Muir Woods

	Vegetation Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TREE SPECIES														
Acer macrophyllum Pursh. Bigleaf maple										X				
Aesculus californica (Spach.) Nutt. California buckeye										X				
Alnus rubra Bong. Red alder										X				
Arbutus menziesii Pursh. Madrone			X									X	X	
Castanopsis chrysophylla (Dougl.) A.DC. Chinquapin								X		X				
Lithocarpus densiflorus (H.&A.) Rehd. Tanoak	X	X	X	X		X		X		X		X	X	
Pseudotsuga menziesii (Mirb.) Franco. Douglas fir		X		X		X	X	X	X	X		X		
Quercus agrifolia Nee Coast live oak						X		X		X		X		
Quercus chrysolepis Liemb. Maul oak										X				
Quercus wislizenii A.DC. Interior live oak							X				X			
Sequoia sempervirens (Lamb.) Endl. Redwood	X	X	X	X		X	X	X		X		X		
Torreya californica Torr. California nutmeg										X				
Umbellularia californica (H.&A.) Nutt. California bay	X	X	X			X	X	X		X			X	
SHRUB SPECIES														
Adenostoma fasciculatum H.&A. Chamise											X			
Arctostaphylos glandulosa Eastw. Eastwood manzanita								X			X			
Baccharis pilularis DC. Baccharis									X		X	X		
Berberis nervosa Pursh. Longleaf mahonia												X		

TABLE 2. (Cont.)

	Vegetation Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Corylus cornuta Marsh. var. *californica* (A.DC.) Sharp Hazelnut	X	X	X			X		X		X				
Gaultheria shallon Pursh. Salal		X												
Heteromeles arbutifolia (Ait.) Roem. Toyon			X			X		X						
Lonicera hispidula (Lindl.) T.&G. California honeysuckle								X	X	X	X			
Mimulus aurantiacus Curt. Sticky monkey flower								X						
Rhamnus californica Esch. Coffeeberry								X	X	X				
Rhododendron macrophyllum D.Don. Coast rhododendron										X				
Rhododendron occidentale (T.&G.) Gray Western azalea										X				
Rhus diversiloba T.&G. Poison oak	X	X	X			X	X	X		X				
Rosa gymnocarpa Nutt. ex Benth. Wood rose		X		X		X				X				
Rubus parviflorus Nutt. var. *velutina* (H.&A.) Greene Thimbleberry										X				
Rubus ursinus C.&S. California blackberry		X	X			X		X	X	X				
Symphoricarpos mollis Nutt. Creeping snowberry		X	X	X		X		X	X	X		X		
Symphoricarpos rivularis Suksdorf Snowberry						X				X				
Vaccinium ovatum Pursh. Huckleberry		X	X			X	X	X						
HERB SPECIES														
Achillea millifolium L. Yarrow												X		
Actaea rubra (Ait.) ssp. arguta (Nutt.) Hult. Baneberry						X								
Adenocaulon bicolor Hook. Trailmarker plant	X	X	X	X		X								

TABLE 2. (Cont.)

	Vegetation Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Carex sp. L. Sedge			X							X		X		
Circium vulgare (Savi)Ten. Bull thistle						X			X			X		
Clintonia andrewsiana Torr. Clintonia		X		X	X	X								
Convolvulus occidentalis Gray Bindweed												X		
Corallorhiza striata Lindl. Coral root						X								
Diosporum smithii (Hook.) Piper Fairy bells		X	X	X	X	X		X	X	X				
Fragaria californica C.&S. California strawberry										X		X		
Gallium aparine L. Bedstraw	X	X	X	X		X		X	X	X				
Gallium nuttallii Gray Bedstraw						X								
Gastridium ventricosum (Gouan) Schinz & Thell. Nitgrass														X
Goodyera oblongifolia Raf. Rattlesnake plantain						X								
Iris douglasiana Herb. Douglas iris		X		X		X		X		X				
Lupinus bicolor Lindl. Lupine														X
Madia gracilis (Smith) Keck Tarweed										X				
Marah fabaceus (Nand.) Dunn Wild cucumber		X						X		X				
Myosotis sylvatica (Ehrh.) Hoffm. Forget-me-not										X				
Osmorhiza chilensis H.&A. Sweet cicely	X		X			X								
Oxalis oregana Nutt. Redwood sorrel	X	X	X	X	X	X				X				
Plantago lanceolata L. Plantain												X		X
Polygala californica Nutt. Milkwort					X									

TABLE 2. (Cont.)

	Vegetation Types													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rumex acetocella L. Sheep sorrel												X		
Satureja douglasii (Benth.) Briq. Yerba buena							X	X	X					
Smilacina racemosa (L.) Desf. var. amplexicaulis (Nutt.) Wats. False solomon's seal														
Stachys bullata Benth. Hedge nettle	X													
Stachys rigida Nutt. Hedge nettle		X	X		X	X	X	X	X	X				
Stellaria media (L.) Cyr. Chickweed		X												
Trientalis latifolia Hook. Starflower		X		X	X	X		X		X				
Trillium ovatum Pursh. Trillium	X	X	X		X	X				X				
Vicia americana Muhl. ssp. oregana (Nutt.) Abrams. Vetch						X			X	X				
Viola sempervirens Greene Redwood violet	X	X		X		X				X				
Wyethia angustifolia Nutt. Mule-ears														X
Xerophyllum tenax (Pursh.) Nutt. Beargrass								X						
GRASS SPECIES														
Aira caryophyllea L. Silver hairgrass												X		
Avena barbata Brot. Slender oat														X
Avena fatua L. Wild oat														X
Bromus carinatus H.&A. California brome						X				X		X		

TABLE 2. (Cont.)

	Vegetation Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bromus rigidus Roth. Ripgut brome												X		
Elymus glaucus Buckl. Blue wild ryw												X		X
Festuca megalura Nutt. Foxtail fescue														X
Hierochloe occidentalis Buckl. California sweetgrass	X	X		X		X				X				
Poa pratensis L. Kentucky bluegrass			X									X		X
Sitanion jubatum J.G. Smith Big squirreltail														X
Stipa pulchra Hitchc. Purple needlegrass												X		X
FERN SPECIES														
Dryopteris arguta (Kaulf.) Watt Shield fern		X	X	X		X				X				
Pityrogramma triangularis (Kaulf.) Maxon Goldenback fern										X				
Polysticum munitum (Kaulf.) Presl. Sword fern	X	X	X	X				X		X				
Pteridium aquilinum (l.) Kuhn Bracken fern	X	X	X	X		X		X	X	X	X	X		X
Woodwardia fimbriata Sm. in Rees. Chain fern		X												

Table 3. Characteristics of Vegetation Types at Muir Woods

			CROWN COVER (%)				
VEGETATION TYPE	PHASE	SPECIES	Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
1. Redwood:Alluvial	a. Redwood	SESE*	87	8		411	383
		LIDE		3	11		
		PSME		1	<1		
		DMCA			<1		
		POMU			16		
		COCO			3		
		RHCA			1		
2. Redwood:Slope, Old growth	a. Redwood	SESE	95	3	10	453	575
		PSME	2			4	50
		UMCA		8		3	100
		LIDE		4	10		
		RHDI			9		
		RHCA			5		
		POMU			1		
		GASH			<1		
	b. Redwood//Redwood	SESE	100	30	9	183	550
		LIDE			30		
		UMCA			10		
		RHCA			1		
	c. Redwood// Redwood-Bay	SESE	100	16	2	224	400
		UMCA		24		1	100
		POMU			10		
	d. Redwood//Bay	SESE	78	2		238	300
		UMCA		32		5	75
		LIDE		9	7	<1	25
		COCO			7		
		POMU					
		VAOV			14		
		RUUR			<1		

* symbol based on first two letters of plant genus and species

Table 3. Characteristics of Vegetation Types at Muir Woods, cont'd.

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
2. Redwood:Slope, Old growth cont'd.	e. Redwood//Tanoak	SESE	80	5		137	450
		LIDE	5	56	31	13	325
		ARME	5				
		VAOV			3		
		COCO			2		
		RHDI			<1		
		POMU			<1		
	f. Redwood// Bay-Tanoak	SESE	61			207	350
		UMCA	3	10			
		LIDE	6	20	30		
		VAOV			12		
		COCO			8		
3. Redwood:Slope, Young growth	a. Redwood	SESE	85	15	22	160	1508
		ARME		4		3	50
		UMCA		3		1	25
		VAOV			9		
		LIDE	<1	<1	<1		
		COCO			<1		
		POMU			3		
		RHDI			<1		
	b. Redwood// Redwood-Bay	SESE	75	30		57	950
		UMCA		30		7	550
		VAOV			15		
		LIDE	14				
		POMU			<1		
	c. Redwood//Tanoak-Redwood-Bay	SESE	95	15		233	700
		LIDE		20	6	7	150
		UMCA		15		2	150
		POMU			10		
		COCO			4		
		RHCA			3		
		RUPA			5		
		RHDI			<1		
		HEAR			<1		
		SYRI			<1		

Table 3. Characteristics of Vegetation Types at Muir Woods

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
4. Redwood-Douglas-fir	a. Redwood-Douglas-fir//Tanoak-Bay-Redwood	SESE	40	12	8	103	400
		PSME	32			52	100
		LIDE	8	16	20	3	100
		UMCA		12			
		VAOV			13		
		POMU			14		
	b. Redwood-Douglas-fir//Tanoak	SESE	73		2	113	175
		PSME	25			35	100
		LIDE	3	30	32	7	750
		VAOV			10		
		POMU			4		
5. Redwood-Hardwood	a. Redwood-Tanoak//Tanoak	SESE	30	1		146	175
		LIDE	20	64	34	26	225
		ARME		4		3	25
		VAOV			42		
		COCO			4		
		POMU			2		
	b. Redwood//Bay	SESE	50		4	284	300
		UMCA		42	2	7	450
		LIDE		15	16	1	100
		PSME		3			
		POMU			13		
		RHCA			2		
6. Douglas-fir: Old growth	a. Douglas-fir//Bay	PSME	55	3		87	333
		UMCA		47	1	13	633
		QUAG		13		3	83
		ARME		3		<1	17
		LIDE			2		
		POMU			3		
		RHCA			4		
		RHDI			5		
		RUUR			<1		
		HEAR			3		
		SYMO			<1		
		BAPI			<1		

Table 3. Characteristics of Vegetation Types at Muir Woods

			CROWN COVER (%)				
VEGETATION TYPE	PHASE	SPECIES	Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
6. Douglas-fir: Old growth, cont's	b. Douglas-fir// Tanoak	PSME	80			91	250
		LIDE		30	10	3	150
		VAOV			5		
		POMU			10		
	c. Douglas-fir// Madrone	PSME	90				
		ARME		40			
		SESE		24		70	400
		LIDE		16	20	1	100
		VAOV			20		
		POMU			1		
	d. Douglas-fir// Bay-Tanoak	PSME	88			104	150
		UMCA		22		4	250
		LIDE		25	57	5	200
		SESE	2	1	4	16	75
		VAOV			9		
		POMU			6		
	e. Douglas-fir// Bay-Redwood	PSME	70			161	200
		UMCA		56	4	8	250
		SESE		21		7	100
		LIDE			20		
		VAOV			16		
		POMU			15		
		COCO			>1		
		RUUR			>1		
		RHDI			>1		
		SYMO					
7. Douglas-fir: Young growth	a. Douglas-fir// Bay-Douglas-fir	PSME	60	20		38	700
		UMCA		20		11	1000
		VAOV			10		
		QUWI			10		
		RHDI			1		

Table 3. Characteristics of Vegetation Types at Muir Woods

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
8. Douglas-fir/ Hardwood	a. Douglas-fir -Bay//none	PSME	75			55	500
		UCMA	10		45	4	450
		HEAR			6	<1	25
		QUWI			4		
		RHDI			1		
		RHCA			2		
		COCO			1		
		RUUR			<1		
		POMU			3		
	b. Douglas-fir// Coast live oak	PSME	40	8		29	150
		QUAG		64		25	800
		UMCA		8			
		RUUR			21		
		RHDI			21		
		RHCA			14		
		COCO			35		
		PTAQ			5		
		RUUR			7		
		SYMO			<1		
		LOHI			<1		
	c. Douglas-fir Chinquapin// Redwood- Chinquapin	PSME	30			55	50
		SESE		60		45	650
		CACH		40		4	450
		VAOV			95		
9. Douglas-fir/Brush	a. Douglas-fir// Baccharis- Blackberry	PSME	35			12	150
		RUUR		28			
		BAPI		28			
		RHCA			5		
		LOHI			1		
	b. Douglas-fir- Redwood/ Huckleberry	SESE	15			10	100
		PSME	15			10	100
		VAOV			60		
		ARGL			25		

Table 3. Characteristics of Vegetation Types at Muir Woods

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
9. Douglas-fir/Brush cont'd.	b. Douglas-fir-Redwood/Huckleberry con'td.	LIDE			5		
		CACH			5		
		RHCA			<1		
		UMCA			<1		
10. Hardwood	a. Tanoak	LIDE	98		33	41	400
		VAOV			7		
		COCO			6		
		POMU			4		
	b. Tanoak-Bay	LIDE	50		27	41	225
		UMCA	40		28	9	200
		SESE	2			3	25
		QUAG	2			2	25
		RHCA			<1		
		POMU			7		
		RHDI			<1		
		RUUR			<1		
		ROCA			<1		
	c. Bay	UMCA	83	2.5	10	59	1800
		LIDE		2.5	3	<1	17
		QUAG		2.5		3	17
		SESE		2.5	1	4	50
		PSME			2		
		COCO			7		
		RMCA			<1		
		RHDI			<1		
		POMU			<1		
		HEAR			1		
	d. Bay-Big leaf maple	UMCA	60	4		72.72	100
		ACMA	40			13.67	50
		LIDE		12	8	0.56	50
		SESE		4		2.06	50
		POMU			56		
		COCO			16		
		VAOV			4		

Table 3. Characteristics of Vegetation Types at Muir Woods

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
10. Hardwood (cont'd.	e. Chinquapin	CACH	53		12	40.51	1300
		SESE	18			10.59	400
		VAOV			56		
		rhca			12		
	f. Alder	ALRU	95			33.7	400
		ACMA		6			
		UMCA		2			
		RUPA		6			
		COCO		1			
		RUUR			56		
	g. Coast live oak//Bay	QUAG	54			50.61	250
		UMCA	18	21		9.98	75
		PSME		6	2	0.85	50
		COCO			40		
		RHCA			7		
		RHDI			12		
		POMU			31		
		RUUR			2		
		LOHI			<1		
		SYRI			<1		
	h. Bay-Canyon live oak	UMCA	40	10		17.86	1450
		QUCH	35			20	300
		PSME	25			11.3	150
		HEAR		8		0.39	50
		TOCA		2			
		RHDI			8		
		POMU			72		
		RHCA			12		
	i. Buckeye-Bay	AECA	50			32.10	1750
		UMCA	30			21.16	1400
		HEAR	20			5.46	500

Table 3. Characteristics of Vegetation Types at Muir Woods

VEGETATION TYPE	PHASE	SPECIES	CROWN COVER (%) Over-story	Under-story	Shrub Layer	Basal Area (m^2/ha)	Density (#/ha)
11.Brush	a. Manzanita	ARSP			90		
		ADGL			5		
		QUWI			5		
12.Grassland/Brush	a. Grass-Baccharis	GRASS			43		
		BAPI			56		
		RHDI			1		
		BENE			>1		
13.Hardwood/Brush	a. Bay-Baccharis	PSME	10			10	100
		UMCA		12		10	150
		QUAG				5	50
		BAPI			70		
14.Grassland	a. Grassland	GRASS			100		

Table 4. Shrub cover, herb cover and tree age distribution of the phases of vegetation types at Muir Woods

Vegetation Type	Phase	Total Shrub Cover (%)	Total Herb Cover (%)	Species	Tree Age Distribution (No./ha.) Seedlings	Sprouts	50-100	100-150	150-200	200
1. Redwood: Alluvium	a. Redwood	25	17	SESE	83	300	-	50	33	217
				LIDE	333	175	33	17	-	-
				UMCA	-	33	-	-	-	-
				PSME	-	-	17	-	-	-
2. Redwood: Slope, Old Growth	a. Redwood	32	1	SESE	100	-	200	100	50	250
				PSME	-	-	25	-	-	-
				UMCA	100	50	50	-	-	-
				LIDE	1800	-	-	-	-	-
	b. Redwood//Redwood	39	1	SESE	-	300	250	50	150	100
				LIDE	3700	-	-	-	-	-
	c. Redwood//Redwood-Bay	12	2	SESE	600	-	50	100	50	200
				UMCA	500	200	100	-	-	-
				LIDE	100	-	-	-	-	-
	d. Redwood//Bay	61	6	SESE	-	-	100	25	75	150
				UMCA	100	50	75	-	-	-
				LIDE	900	-	50	-	-	-
	e. Redwood//Tanoak	33	2	SESE	425	50	125	25	150	125
				LIDE	645	700	75	25	-	-
				TOCA	100	-	-	-	-	-
	f. Redwood//Bay-Tanoak	11	11	SESE	150	50	75	-	50	200
				LIDE	275	1800	25	-	-	-
3. Redwood: Slope, Young Growth	a. Redwood	18	2	SESE	333	233	933	417	50	33
				ARME			33	17		
				UMCA	75	117	17			
				LIDE	450					
	b. Redwood//Redwood Bay	7	8	SESE	1000	300	300	150		
				UMCA	1400	100				
				LIDE		200				
	c. Redwood//Tanoak-Redwood-Bay	39	6	SESE		100	250	50	400	
				LIDE	300		50			
				UMCA	1600	50	200			
4. Redwood/Douglas fir	a. Redwood-Douglas fir//Tanoak-Bay-Redwood	51	14	SESE		200	300		50	50
				PSME			50	50		
				LIDE			2150	200		
				UMCA	100	50				
	b. Redwood-Douglas fir//Tanoak	40	25	SESE	100			25	25	100
				PSME			100			
				LIDE	2875	500	150			

Table 4. (continued)

Vegetation Type	Phase	Total Shrub Cover (%)	Total Herb Cover (%)	Species	Tree Age Distribution (No./ha.) Seedlings	Sprouts	50-100	100-150	150-200	200
5. Redwood/Hardwood	a. Redwood-Tanoak//Tanoak	87	1	SESE	100	50		25	50	100
				LIDE	150	350	100	25		
				ARME					25	
	b. Redwood//Bay	22	0	SESE		200	50		100	150
				UMCA	400		50			
				LIDE	100	1400				
				QUWI	100					
6. Douglas fir: Old Growth	a. Douglas fir//Bay	13	20	PSME	83	-	100	33	-	-
				UMCA	550	133	100	-	-	-
				QUAG	150	-	-	-	-	-
				ARME	-	-	17	-	-	-
				LIDE	167	-	-	-	-	-
	b. Douglas fir//Tanoak	27	64	PSME	25	-	75	200	-	-
				LIDE	4725	150	-	-	-	-
				SESE	350	100	100	-	-	-
				UMCA	100	-	-	-	-	-
	c. Douglas fir//Madrone	60	4	PSME	400	-	-	50	50	-
				SESE	-	200	150	100	100	50
				ARME	100	5500	-	-	-	-
	d. Douglas fir// Bay-Tanoak	65	17	PSME	-	-	50	75	-	25
				UMCA	100	-	150	-	-	-
				LIDE	175	1800	175	-	-	-
				SESE	50	-	25	25	25	-
	e. Douglas fir//Bay-Redwood	54	14	PSME	-	-	-	150	50	-
				UMCA	350	100	-	-	-	-
				SESE	50	-	100	-	-	-
				LIDE	1300	200	-	-	-	-
7. Douglas fir: Young Growth	a. Douglas fir//Bay-Douglas fir	22	8	PSME	700	-	-	-	-	-
				UMCA	100	700	1000	-	-	-
				QUWI	-	200	-	-	-	-
8. Douglas fir/Hardwoods	a. Douglas fir-Bay//none	21	8	PSME	670	--	25	--	--	--
				UMCA	475	400	25	--	--	--
				QUWI	25	--	--	--	--	--
				LIDE	25	--	--	--	--	--
	b. Douglas fir//Coast Live Oak	69	4	PSME	450	--	--	--	--	--
				QUAG	1650	--	--	--	--	--
				UMCA	200	--	--	--	--	--
				LIDE	--	100	--	--	--	--
	c. Douglas fir-Chinquapin// Redwood-Chinquapin	71	2	PSME	--	--	--	50	--	--
				SESE	250	100	350	250	--	--
				CACH	--	100	450	--	--	--

Table 4. (continued)

Vegetation Type	Phase	Total Shrub Cover (%)	Total Herb Cover (%)	Species	Tree Age Distribution (No./ha.) Seedlings	Sprouts	50-100	100-150	150-200	200
9. Douglas fir/Brush	a. Douglas fir//Baccharis-Blackberry	62	18	PSME	150	--	--	--	--	--
	b. Douglas fir-Redwood//Huckleberry	100	--	PSME	100	--	--	--	--	--
				SESE	100	--	--	--	--	--
				LIDE	--	200	--	--	--	--
				UMCA	100	--	--	--	--	--
				QUAG	200	--	--	--	--	--
10. Hardwood	a. Tanoak	1	53	LIDE	1650	1200	125	150	75	--
	b. Tanoak-Bay	2	40	LIDE	150	3650	25	175	25	--
				UMCA	250	100	75	--	--	--
				SESE	75	--	--	--	--	--
				QUAG	--	--	25	--	--	--
	c. Bay	47	20	UMCA	100	233	1667	117	--	--
				LIDE	184	33	--	--	--	--
				QUAG	17	--	17	--	--	--
				SESE	517	--	17	--	--	--
				PSME	1167	--	--	--	--	--
	d. Bay-Bigleaf Maple	4	25	UMCA	--	200	300	--	--	--
				ACMA	--	--	150	--	--	--
				LIDE	450	--	--	--	--	--
				SESE	--	--	50	--	--	--
	e. Chinquapin	0	58	CACH	--	900	1100	200	--	--
				SESE	200	400	350	50	--	--
				UMCA	50	--	--	--	--	--
				PSME	50	--	--	--	--	--
	f. Alder	81	14	ALRU	600	--	--	--	--	--
				AMCA	300	--	--	--	--	--
				UMCA	100	--	--	--	--	--
	g. Coast Live Oak//Bay	86	23	QUAG	25	--	250	--	--	--
				UMCA	50	100	25	75	--	--
				PSME	100	--	--	--	--	--
	h. Bay-Canyon Live Oak	100	5	UMCA	100	400	1450	--	--	--
				QUCH	100	200	100	--	--	--
				PSME	250	--	--	--	--	--
				TOCA	300	--	--	--	--	--
	i. Buckeye-Bay	55	16	AECA	--	--	--	1750	--	--
				UMCA	--	500	--	1200	--	--
				PSME	400	--	--	--	--	--
11. Brush	a. Manzanita	97.5	1	QUWI	--	200	--	--	--	--
12. Grassland/Brush	a. Grass-Baccharis	57.25	82.5	QUAG	1400	--	--	--	--	--
				ARME	100	--	--	--	--	--
				LIDE	200	--	--	--	--	--
				PSME	400	--	--	--	--	--
				UMCA	100	--	--	--	--	--
13. Hardwood/Brush	a. Bay-Baccharis	(No plots were taken due to small area in park.)								
14. Grassland	a. Grass	--	--	--	--	--	--	--	--	--

Table 5. Origin and successional potential of phases of vegetation types at Muir Woods.

Vegetation Type	Phase	Origin	Successional Potential
1. Redwood: Alluvium	a. Redwood	Irregular establishment of redwood over a long time in response to sporadic fire, siltation, and tree toppling. Local circumstances (canopy openings, ground surface disturbance, seed dispersal) have allowed the establishment of tanoak, bay, redwood, and an occasional Douglas fir in the understory.	Continued dominance of redwood overstory with a sparse discontinuous understory of tanoak, bay, and redwood. If openings in the redwood canopy occur, a more significant understory of tanoak, bay, and redwood will develop.
2. Redwood: Slope, Old Growth	a. Redwood	Irregular establishment of redwood over a long period in response to sporadic fire and disturbance by toppled trees. Local circumstances (canopy openings, ground surface disturbance, seed dispersal) have allowed the establishment of a sparse understory of bay. Recent fire exclusion has allowed a dominance of tanoak in the shrub layer.	Continued dominance of redwood overstory with an understory of tanoak and bay. If openings occur in the redwood canopy a significant increase in tanoak will occur due to abundance of seedlings in the shrub layer.
	b. Redwood//Redwood	Irregular establishment of redwood over a long period in response to sporadic fire and tree toppling. Shrub layer of tanoak has resulted from recent fire exclusion.	Continued dominance of redwood overstory. Redwood understory will fill in overstory crown openings as they occur. Maintenance of a low light intensity will prevent establishment of a tanoak understory. Shrub layer of tanoak will decline.
	c. Redwood//Redwood-Bay	Irregular establishment of redwood over a long time in response to fire and disturbance. Redwood and bay in understory have arisen as sprouts since the last fire.	Continued dominance of redwood overstory. Bay and redwood understory will persist. Occasional bay seedling establishment will not contribute to bay understory due to heavy deer browsing.
	d. Redwood//Bay	Irregular establishment of redwood over a long time in response to fire and tree toppling on steep slopes. Bay understory developed following last major fire but also exhibits recruitment of sprouts from fallen trees. Tanoak in understory developed following last fire.	Continued dominance of redwood overstory. Understory of bay and tanoak will increase in stature and cover over time. Significant increase in tanoak-dominated shrub layer.
	e. Red//Tanoak	Irregular establishment of redwood over a long time in response to fire and disturbance by toppled trees. Tanoak understory has arisen as sprouts since the last fire.	Continued dominance of redwood overstory. Tanoak understory will be present, but may decrease due to eventual crown closure by redwood. California nutmeg will become a minor understory component in some areas.
	f. Redwood//Bay-Tanoak	Irregular establishment of redwood over a long time due to fire or disturbance by tree toppling. Sparse bay and tanoak understory has arisen as sprouts after fire. On ridgetop sites where redwood canopy height is less, bay and tanoak have been able to grow into the overstory since the last fire.	Continued dominance of redwood overstory. Tanoak and bay understory will probably decrease, except on ridgetop sites.
3. Redwood: Slope, Young Growth	a. Redwood	Previous stands consumed by crown fire circa 1845. Present stands are dense thickets of redwood sprouts from root crowns that survived the fire. Scattered madrone, bay, and tanoak are also sprouts.	Continued dominance by stagnated redwood overstory with sparse tanoak and bay understory. Total canopy cover and canopy depth will increase as stem density of redwood gradually decreases. Madrone will decline with reduction of available light.
	b. Redwood//Redwood-Bay	Previous stands consumed by crown fire circa 1845. Present stands are dense thickets of redwood and bay sprouts from root crowns that survived the fire. Redwood height growth has been more rapid than bay.	Continued dominance by stagnated redwood overstory, with understory of bay. Total canopy cover and canopy depth will increase as stem density of redwood gradually decreases.
	c. Redwood//Tanoak-Redwood-Bay	Previous stands partially consumed by crown fire over 200 years ago. Present redwoods are stool sprouts growing on remains of old stumps. Bay and tanoak understory from sprout origin also.	Continued dominance by redwood overstory, with understory of tanoak and bay.

Table 5. (cont.)

4. Redwood / Douglas Fir	a. Redwood-Douglas Fir// Tanoak-Bay-Redwood	Irregular establishment of redwood over a long time due to fire or disturbance by tree toppling. Large canopy openings allowed establishment of Douglas fir subsequent to last fire. Understory of tanoak, bay and redwood sprouts have also arisen since the last fire.	Redwood and Douglas fir will continue to share overstory dominance Tanoak will drop out of overstory, but will continue with bay and redwood in the understory.
	b. Redwood-Douglas Fir// Tanoak	Irregular establishment of redwood over a long period due to fire or disturbance by tree toppling. Large canopy openings allowed establishment and and growth of Douglas fir and tanoak subsequent to last fire.	Redwood and Douglas fir will conto share overstory dominance. Tanoak will drop out of overstory as redwood-douglas fir canopy closes, but will continue to dominate in the understory.
5. Redwood / Hardwood	a. Redwood-Tanoak// Tanoak	Irregular establishment of redwood over a long period due to fire and disturbance events. Low canopy cover of redwood allowed tanoak to become codominant with redwood in overstory subsequent to last fire.	Redwood will become sole overstory dominant as tanoaks in overstory undergo age-related mortality. Tanoak will continue to dominate the understory.
	b. Redwood//Bay	Irregular and patchy establishment of redwood over long time period due to fire and disturbance events. Bay-dominated understory sprouted from root crowns subsequent to last fire and survived under overstory openings.	Redwood will remain overstory dominant but with low total canopy cover. Bay will continue to dominate understory but will be unable to assume overstory stature due to its occurrence in stagnated thickets.
6. Douglas fir: Old Growth	a. Douglas fir//Bay	Last large fire created open sites favorable for establishment of Douglas fir seedlings which now form overstory. Understory bay resulted from sprouting after fire. An occasional Coast live oak and madrone were able to establish due to open canopy.	Douglas fir will be present in the overstory, but will be declining. Open canopy will allow bay to gain in importance from current position in understory. Individuals of hardwoods such as Coast live oak, tanoak and madrone may enter overstory or understory layers.
	b. Douglas fir//Tanoak	Douglas fir overstory a result of seedling establishment after last fire. Understory tanoak and redwood in some areas are of sprout origin from fire. Present canopy conditions have allowed establishment of tanoak and redwood seedlings in some areas.	Douglas fir will continue as dominant overstory except in areas containg redwood, which will enter overstory as a dominant. Tanoak understory will be present on all areas, though less so on areas with redwood
	c. Douglas fir//Madrone	Douglas fir overstory a result of seedling establishment after last large fire. Madrone, redwood and tanoak in understory are sprouts arisen after fire. Thick shrub layer of tanoak is also of sprout origin.	Continued dominance by Douglas fir in overstory with redwood filling in from below. Tanoak and madrone understory will decrease as redwood becomes part of overstory.
	d. Douglas fir//Bay-Tanoak	Douglas fir overstory a result of seedling establishment after last large fire and occasional survival of older trees. Bay, tanoak, and some redwood in understory are from sprouting after last fire, as are the many tanoak sprout clumps in shrub layer. Shrub layer also contains redwood, tanoak and bay seedlings and sprouted seedlings which were able to survive present canopy conditions.	Douglas fir decreases in importance in overstory, and redwood will fill in overstory in some areas. Tanoak and bay in present understory will increase in stature due to openings created by Douglas fi decline with age. Understory of bay, tanoak and redwood will be created by present seedlings and sprouts.
	e. Douglas fir//Bay-Redwood	Douglas fir overstory a result of a wave of seedlings becoming established following last large fire. Redwood and bay in understory are sprouts which arose following fire. Shrub layer contains redwood,bay and tanoak seedlings which have been able to survie due to openings in the canopy.	Douglas fir will still be present in overstory, with redwood growing into canopy. Understory will be bay with tanoak entering from below.
7. Douglas fir: Young Growth	a. Douglas fir//Bay-Douglas fir	Douglas fir overstory represents two waves of seedling establishment after two separately occurring recent fire, one in a bay stand, one in an adjacent manzanita-dominated brushfield. Bays which sprouted and small Douglas firs which seeded in after the fires form the understory. Sprout clumps of Interior live oak and bay present in the shrub layer are probably survivors of the fires.	Douglasfir stem density will decrease, but remaining trees will mature, closing overstory canopy. Bay will maintain in understory.

8. Douglas fir/Hardwoods	a. Douglas fir-Bay	Douglas fir overstory is a result of one or more past fires creating conditions favorable for seedling establishment. Bay found as codominant in overstory or present in understory and thick shrub layer is in form of sprouts which arose after fire.	Douglas fir will increase in overstory canopy, decreasing in stem density in some areas. Bay understory importance will vary with Douglas fir development. Understory may also include some tanoak and bay.
	b. Douglas fir//Coast live oak	Previous stands consumed by crown fire in 1840's. Douglas fir overstory grown up from seedlings established shortly after fire. Understory Coast live oak and bay are sprouts after fire.	Douglas fir will increase in overstory to dominate site totally. Coast live oak will drop out, leaving bay in the understory.
	c. Douglas fir-Chinquapin// Redwood-Chinquapin	Previous stands consumed by crown fire. Douglas fir overstory resulted from wave of post-fire seedling establishment. Understory chinquapin and redwood are dense clumps of sprouts.	As redwood slowly decreases in stem density, some individuals will enter overstory, joining Douglas fir. Chinquapin will eventually disappear leaving redwood sprouts in the understory.
9. Douglas fir/Brush	a. Douglas fir//Baccharis-Blackberry	Abandoned disturbance site-relict meadow edge areas invaded by baccharis, blackberry and Douglas fir.	Douglas fir will increase in overstory. Baccharis will disappear; blackberry will decease in shrub layer.
	b. Douglas fir-Redwood// Huckleberry	Stand a result of crown fire. Redwood component of overstory is of sprout origin. Douglas fir component has arisen from seedlings established after fire. Low density of present overstory allowed survival of thick shrub layer of huckleberry and manzanita post-fire sprouts.	Overstory of Douglas fir and redwood will increas in crown cover. Manzanita will decline as canopy closes, leaving huckleberry as shrub layer.
10. Hardwood	a. Tanoak	Tanoak in overstory, understory, and shrub layer is present as sprouts and seedlings arisen after periodic disturbances such as soil movement on steep slopes and fire.	Tanoak will continue to dominate site. Overstory positions vacated by trees dying from age-related causes will be filled from below.
	b. Tanoak-Bay	Tanoak and bay in overstory and understory are sprouts from periodic fires. Shrub layer contains sprouts of these two species also, with some individuals of seedling origin establishing under crown openings.	Tanoak and bay will continue as overstory dominants. Canopy openings will be filled from below from ample supply of understory trees.
	c. Bay	Previous stands partially consumed by crown fire. Present overstory is chiefly bay of sprout origin with scattered large Coast live oaks and bay individuals which survived fire. Mixed hardwood-conifer understory established after fire.	Bay will continue in overstory, but will share dominance with Douglas fir and redwood in some areas, especially ridgetops were conifer seedlings are present now. Understory will be chiefly of bay.
	d. Bay-Bigleaf maple	Irregular establishment over last century of overstory bay and bigleaf maple, and understory of tanoak, redwood and bay in response to disturbance events such as tree toppling, flooding, and fire.	Bigleaf maple will drop out of overstory and redwood will enter from below to share dominance with bay. Understory will be of bay and tanoak unless canopy openings are created which allow establishment of maple seedlings.
	e. Chinquapin	Previous stands consumed by crown fire over 100 years ago. Present overstory is composed of redwood and chinquapin post-fire sprouts. Openings in overstory created by increasing chinquapin mortality allow some seedling establishment of Douglas fir, bay and redwood.	Redwood will increas in stature and crown cover to totally dominate overstory. Chinquapin will drop out due to low light availability. Sparse understory of redwood and bay may be present.
	f. Alder	Present even-aged stand established on alluvial terrace created by flood in the 1930's.	Alders will begin to die out at 100 years of age. Present understory species (bay, bigleaf maple and redwood) will then assume dominant positions in the overstory.
	g. Coast live oak//Bay	Present stands are the result of gradual invasion by Coast live oak and some bay into former grasslands. Douglas fir and bay have subsequently become established in the understory.	Douglas fir will become established and grow to sufficient height to shade out most live oak and replace it as the dominant overstory species. Bay will remain in the understory. Some redwood establishment may occur.

Table 5. (cont.)

	h. Bay-Canyon live oak	Present hardwoods regenerated as sprouts following fire more than 100 years ago. Bay sprouts have stagnated as thickets of spindly trees. All Canyon live oak stems are sprouts from one root crown and have attained diameters appropriate for their ages. Douglas fir and California nutmeg have become established beneath bay and Canyon live oak.	Douglas fir and California nutmeg will gradually supersede bay and Canyon live oak in the overstory.
	i. Buckeye-Bay	Present even-aged hardwood stand regenerated as sprouts from root crowns subsequent to fire more than 100 years ago. Poor soil conditions on ridgetop have contributed to creation of a stagnated dense thicket of these hardwoods.	As stand gradually thins out with falling apart of spindly buckeye and toyon crowns, Douglas fir will will become established and eventually replace the hardwoods as the dominant overstory tree.
11. Brush	a. Manzanita	Present brushfield arose as sprouts after fire.	With long-term absence of fire, manzanita will senesce and interior live oak may temporarily dominate. Douglas fir may be expected to eventually invade as brush dies out opening shrub canopy.
12. Grassland/Brush	a. Grass-Baccharis	Grassland areas near the forest edge which have had fire excluded from them have been invaded by baccharis. Some establishment of tree seedlings such as madrone, bay, Douglas fir, and Coast live oak has also occurred, although all but the live oak have been severely browsed by deer.	Continued invasion by baccharis with decrease in grass will occur until tree seedlings grow above browse line of deer. Eventual tree canopy of Douglas fir and hardwood mix will cause shading out of brush.
13. Hardwood/Brush	a. Bay-Baccharis	Brush areas resulting from grassland invasion in absence of fire invaded further by tree seedlings. Bay and some Coast live oak and Douglas fir have grown up through the brush.	Baccharis will be shaded out by tree canopy. Overstory will be dominated by Douglas fir and bay; live oak may also disappear due to low light levels.
14. Grassland	a. Grass	Grassland maintained by periodic fires and possibly grazing.	In absence of fire baccharis will gradually invade, with subsequent establishment of Douglas fir and Coast live oak as tree cover.

TABLE 6. Interval Between Wildfires in the Redwood Forest Type Near Muir Woods National Monument.

Study Site	Approximate Precipitation	Number of Stumps Sampled	Average Interval Between Fires
1. Old Mill Creek	34 in.	22	21.7 years
2. Alpine Dam	50 in.	20	27.3 years

TABLE 7. Variables and Corresponding Potential Values Used to Determine Fire Hazard

A. Fine-surface fuel density and arrangement

0 = bare ground
1 = open to loose
2 = thatched or compact
3 = fluffy (grass)

B. Living herbaceous ground cover

0 = none
1 = cover > 0-33%
2 = cover 33-66%
3 = cover 66-100%

C. Fuel bed depth

1 = 0-3 inches
2 = 3-6 inches
3 = 6-9 inches
4 = > 9 inches

D. Height of ladders fuels complex (relative to canopy height)

1 = 0-33%
2 = 33-66%
3 = 66-100%

E. Density of ladder fuels complex (ratio of fuel to space)

1 = < 1:2
2 = 1:2 - 2:2
3 = > 2:1

F. Downed woody fuel (tons/acre)

Estimates for downed woody fuel in forest types are from the planar-intersect method of Brown (1974). Estimates for ground fuel amounts in grass and shrub types are from the figures from Helm et al (1973).

G. Slope

1 = < 30%
2 = 30-50%
3 = > 50%

H. Prevailing wind condition (daytime)

1 = calm
2 = moderately breezy
3 = very windy

I. Probability of ignition by man

1 = remote
2 = occassional visitation
3 = highly accessible

TABLE 8. Muir Woods Fire Hazard Categories and the Derivation of Rankings (1 = Low, 5 = High).

A. Surface Fuel Condition

Litter Condition	Fuel Bed Depth			
	1	2	3	4
0	1	1	1	2
1	1	2	3	3
2	2	4	5	5
3	4	4	5	5

B. Ladder Fuel Condition

Density of Ladder Fuels	Height of Ladder Fuels		
	1	2	3
1	1	1	2
2	3	4	4
3	4	5	5

C. Downed Woody Fuel

tons/acre	rank
0-2	1
2-5	2
5-10	3
10-25	4
25	5

D. Slope-Wind

Slope	Wind		
	1	2	3
1	1	2	3
2	2	3	4
3	3	4	5

E. Ignition Risk

Ignition By Man	Litter Condition*			
	0	1	2	3
1	1	2	3	4
2	1	3	4	5
3	1	4	5	5

* Litter Condition = Fine surface fuel minus living herbaceous ground cover.

TABLE 9. Radial Growth From 1871 to 1900 and 1941 to 1970 of Redwood Trees on Compacted and Non-Compacted Soils.

	Impacted Trees (Compacted Soils)				Control Trees (Non-Compacted Soils)			
	Average Force Required To Penetrate Soil (lbs.)	Average Radial Growth (mm)			Average Force Required To Penetrate Soil (lbs.)	Average Radial Growth (mm)		
Tree Number		1871-1900	1941-1970	Difference		1871-1900	1941-1970	Difference
Decreasers								
1	31	55.68	55.15	- 0.53	5	42.38	37.58	- 4.80
2	30	75.63	40.81	-34.82	2	30.97	18.14	-12.83
3	46	49.22	40.20	- 9.02	6	53.70	52.31	- 1.39
4	25	43.60	39.88	- 3.72	3	27.08	21.40	- 5.68
5	30	69.76	54.95	-14.81	6.5	66.91	43.01	-23.90
6	25	38.86	19.08	-19.78	6	53.95	48.43	- 5.52
7	45	49.84	37.51	-12.33	6	58.61	56.80	- 1.81
8	45	18.83	17.70	- 1.13	6	37.55	26.09	-11.46
9	39	55.18	43.25	-11.93	9	30.44	19.88	-10.56
10	24	33.72	20.20	-13.52	4	30.75	24.64	- 6.11
11	22	41.23	33.76	- 7.47	9	67.75	22.12	-44.63
12	--	--	--	--	3	63.17	30.80	-32.37
Average	32.9	48.32	36.59	-11.73	5.5	46.94	33.43	-13.42
Increasers								
1	33	42.99	45.04	+10.81	2.5	47.60	47.66	+ 0.06
2	39	25.96	51.89	+25.93	6	22.79	37.87	+15.08
3	45	36.55	39.34	+ 2.79	7	20.58	36.06	+15.48
4	24	21.32	22.80	+ 1.51	-	--	--	--
Average	35.25	31.71	39.77	+10.26	5.2	30.32	40.53	+10.21

Table 10. Summary of maintenance, sprouting, impact on forest regeneration, and contribution to fuels of fallen trees.

Species	Type of Maintenance	Sprouting Behavior	Impact on Regeneration	Contribution to Fuels
Bay	sections across trails and creek removed (occasional removal of entire downed crown)	abundant sprouting along downed trunk	elimination of growing space; shading out conifer regeneration where down trunk is sprouting; tanoak, bay and shrub species become established beneath crown opening	very high local increase in down fuel biomass and ladder fuels
Tanoak	sections across trails and creek removed	limited sprouting from root collar	no significant reduction in growing space; tanoak, redwood, big leaf maple and shrub species become established or grow as sprouts beneath crown opening	very high local increase in down fuel biomass; ladder fuels only temporarily increased
Big leaf maple	sections across trail and creek removed (occasional removal of entire downed crown)	limited sprouting at base and along trunk for a short period after falling. Sprouts along trunk are seldom successful in long run	no significant reduction in growing space; adjacent redwoods sending sprouts into opening in crown; tanoak and shrubs become established beneath crown opening	little increase in down fuel biomass or ladder fuels
Redwood	sections across trails and creek removed	many vigorous basal sprouts	elimination of growing space by trunks of larger diameter trees is locally significant; opening in canopy significant for growth of redwood sprouts	downed fuel biomass very high; ladder fuels only temporarily increased
Douglas-fir	sections across trail removed	no sprouting occurs in Douglas-fir	minor elimination of growing space by trunk; crown opening stimulates establishment and growth of redwood and tanoak	downed fuel biomass high; ladder fuels only temporarily increased

Table 11. Percent frequency of occurrence of exotic species recorded on vegetation survey plots in forest types at Muir Woods.

Exotic Species	Forest Type	Percent Frequency of Occurrance
Circium vulgare (Savi.) Ten.	Douglas fir	4.69
Gallium aparine L.	Redwood	13.79
	Douglas fir	23.44
	Hardwood	19.64
Myosotis sylvatica (Ehrh.) Hoffm.	Hardwood	7.14
Poa pratense L.	Redwood	0.09
Stellaria media (L.) Cyr.	Redwood	0.09

Table 12. Exotic species observed at Muir Woods (USNPS, 1974)

Scientific Name	Common Name
Acacia farnesiana	sweet acacia
Anagallis arvensis	scarlet pimpernel
Brassica nigra	black mustard
Briza maxima	quaking grass
Bromus rigidus	ripgut grass
Cirsium vulgare	bull thistle
Conium maculatum	poison hemlock
Cytisus scoparius	Scotch broom
Cytisus monspessulanus	French broom
Erechtites prenenthoides	Australian burnweed
Erodium botrys	long-beaked filaree
Erodium cicutarium	red-stemmed filaree
Foeniculum vulgare	sweet fennel
Galium aparine	goose grass
Hordeum leporinum	farmer barley
Hypocheris radicata	hairy cats
Madia sativa	Chilean tarweed
Marrubium vulgare	common horehound
Mysotis sylvatica	wood forget-me-not
Plantago major	common plantain
Polypogon interruptus	beard grass
Polypogon monspeliensis	beard grass
Raphanus sativus	wild radish
Rubus procerus	Himalaya blackberry
Rumex acetosella	sheep sorrel
Solanum nodiflorum	small-flowered nigntshade
Sonchus oleraceus	common sow-thistle
Taraxacum officinale	common dandelion
Eucalyptus globulus	bluegum
Eucalyptus viminalis	manna gum

Figure 1. Location of Muir Woods National Monument

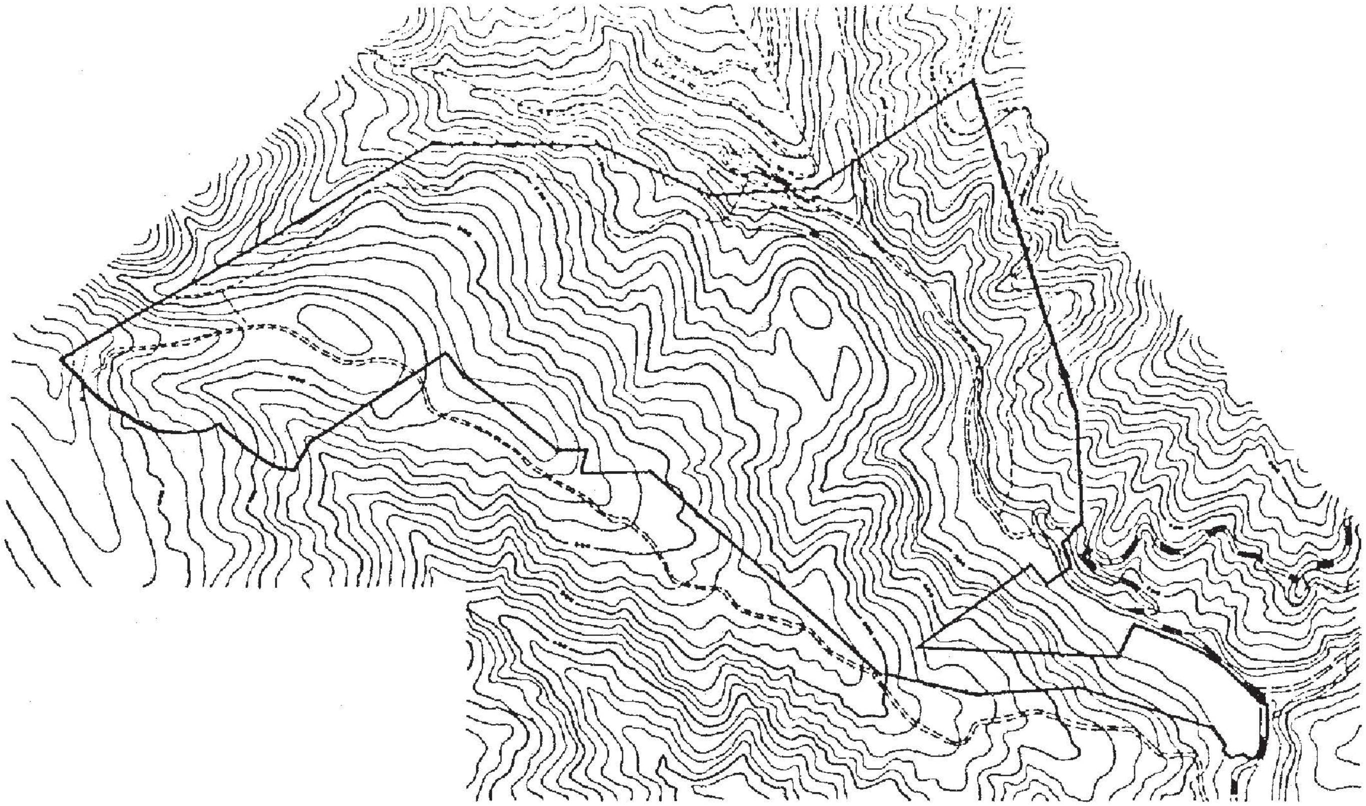


Figure 2. Topography of Muir Woods. Contour interval is 40 feet.

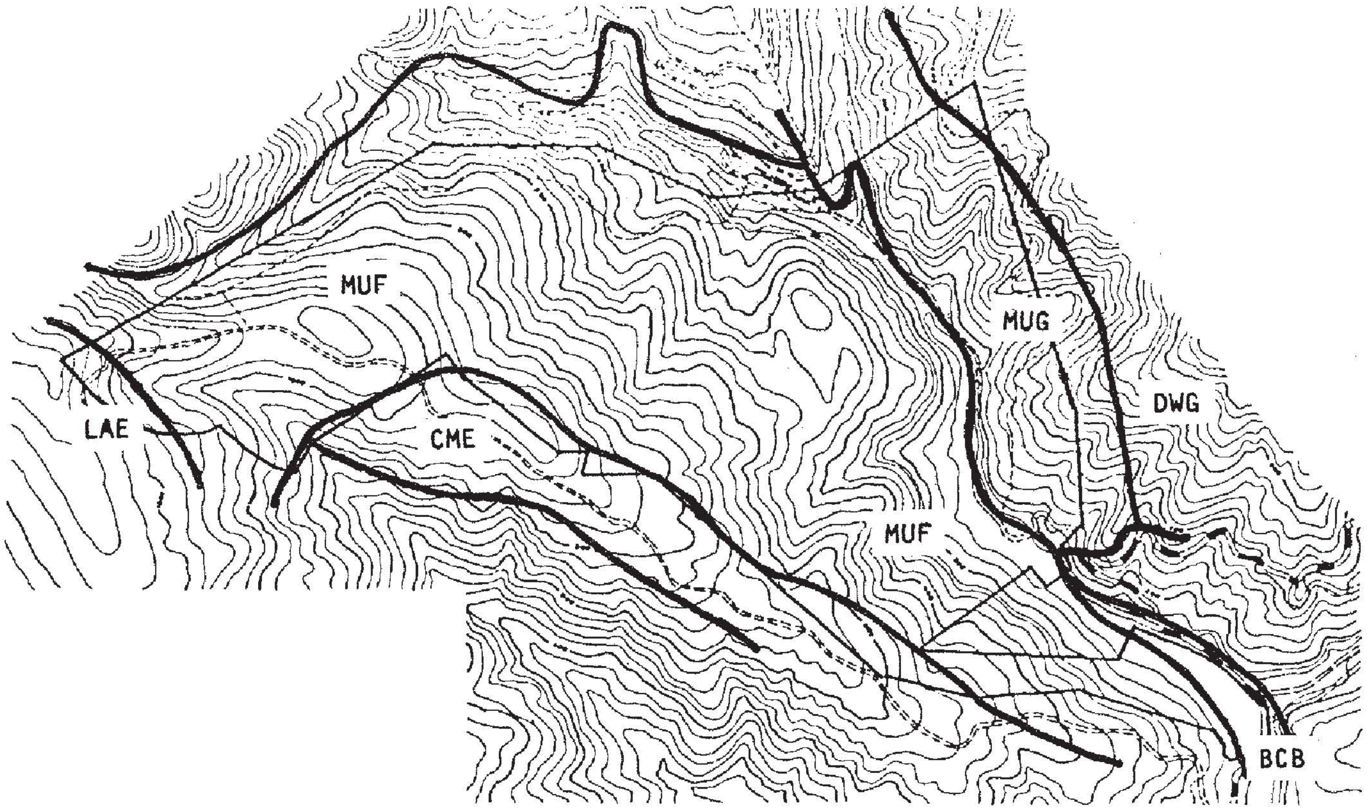


Figure 3. Soil Type Distribution at Muir Woods.

Key to Type Symbols:
- BCB - Blucher-Cole Complex (2-5% slopes)
- CME - Cronkhite-Barnebe Complex (15-30% slopes)
- DWG - Deadwood-Killarc Complex (50-75% slopes)
- LAE - Sansal Complex (15-30% slopes)
- MUF - Centissima-Barnabe Complex (30-50% slopes)
- MUG - Centissima-Barnabe Complex (50-75% slopes)

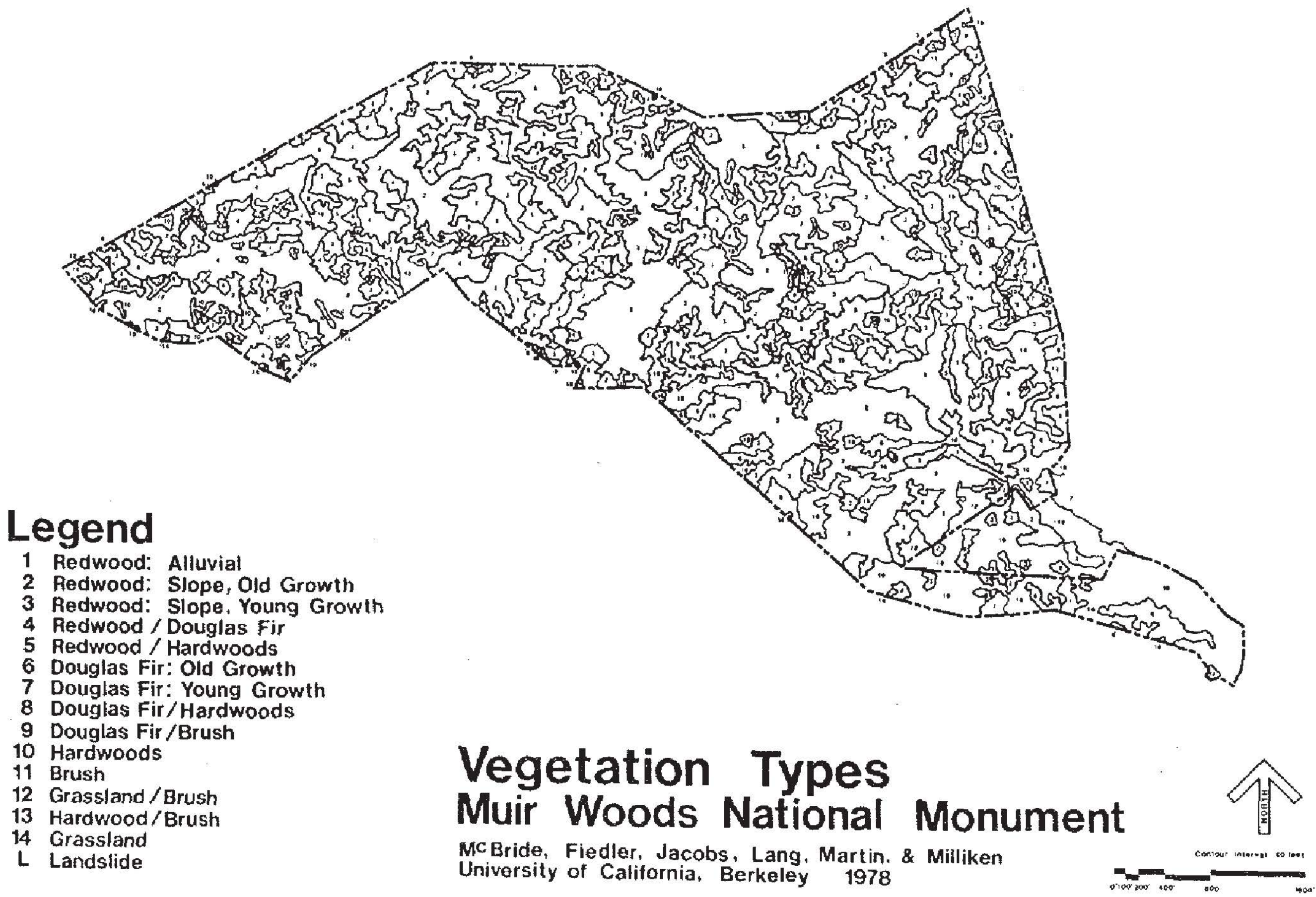
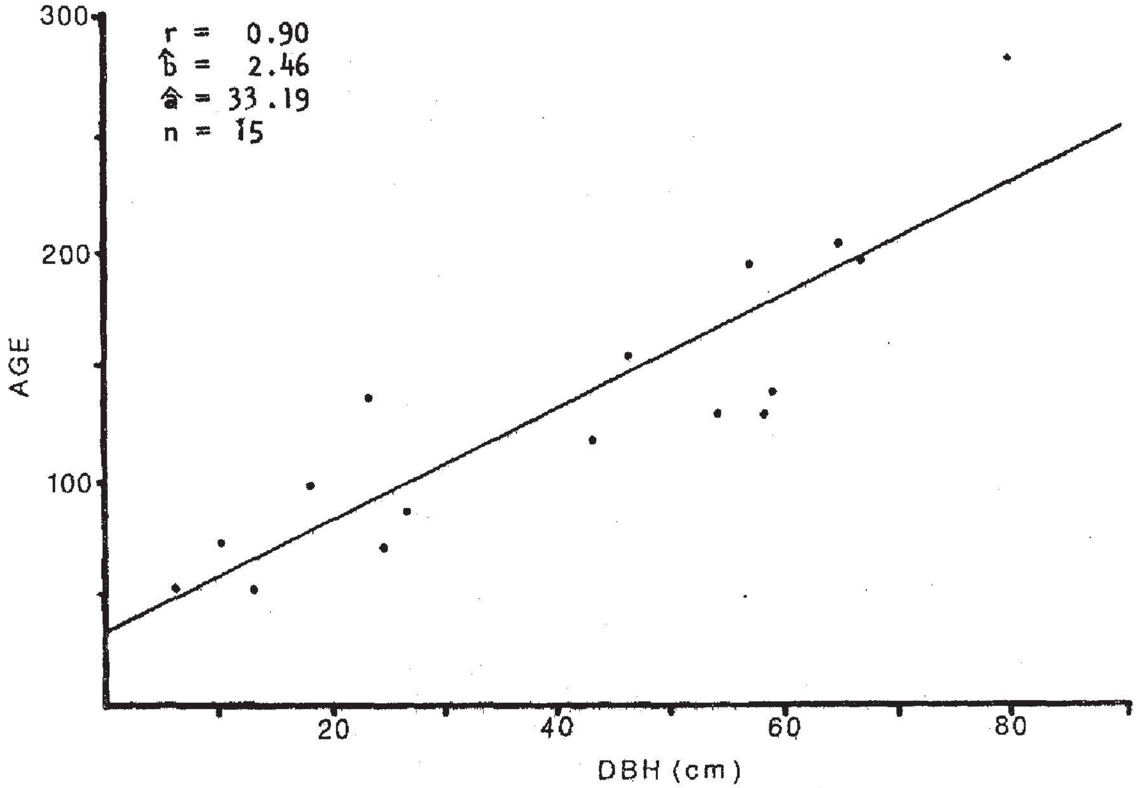


Figure 4. Vegetation Types at Muir Woods. (See field map inside back cover)

A. West-facing slope



B. East-facing slope

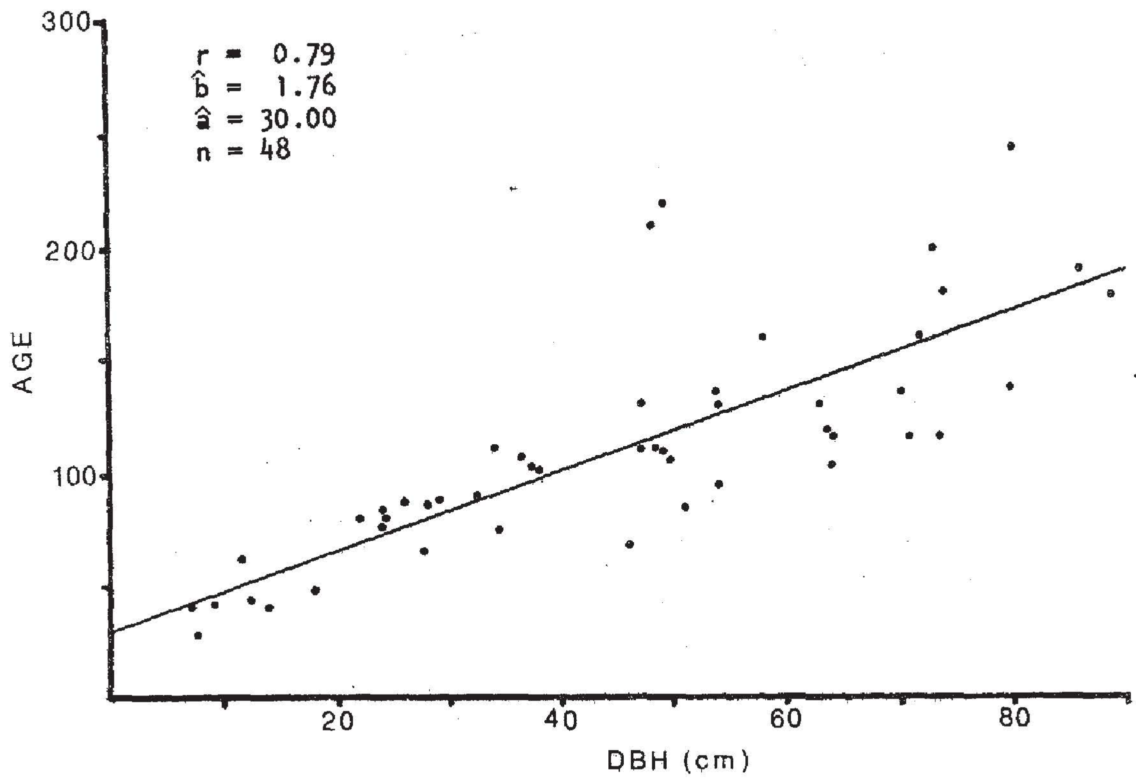


Fig. 5. Age-diameter relationship in Redwood: Slope, Old Growth (A. West-facing, B. East-facing).

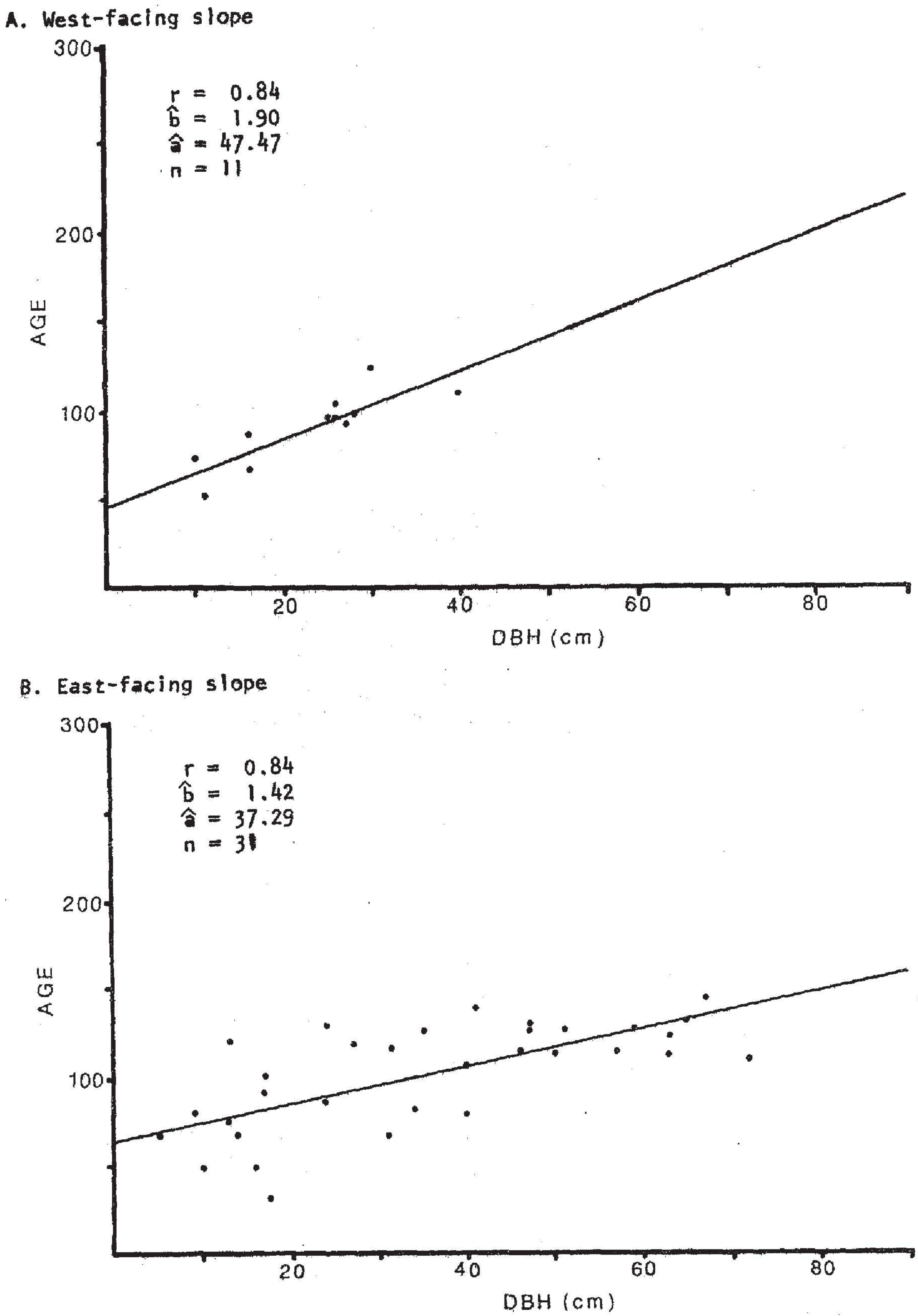
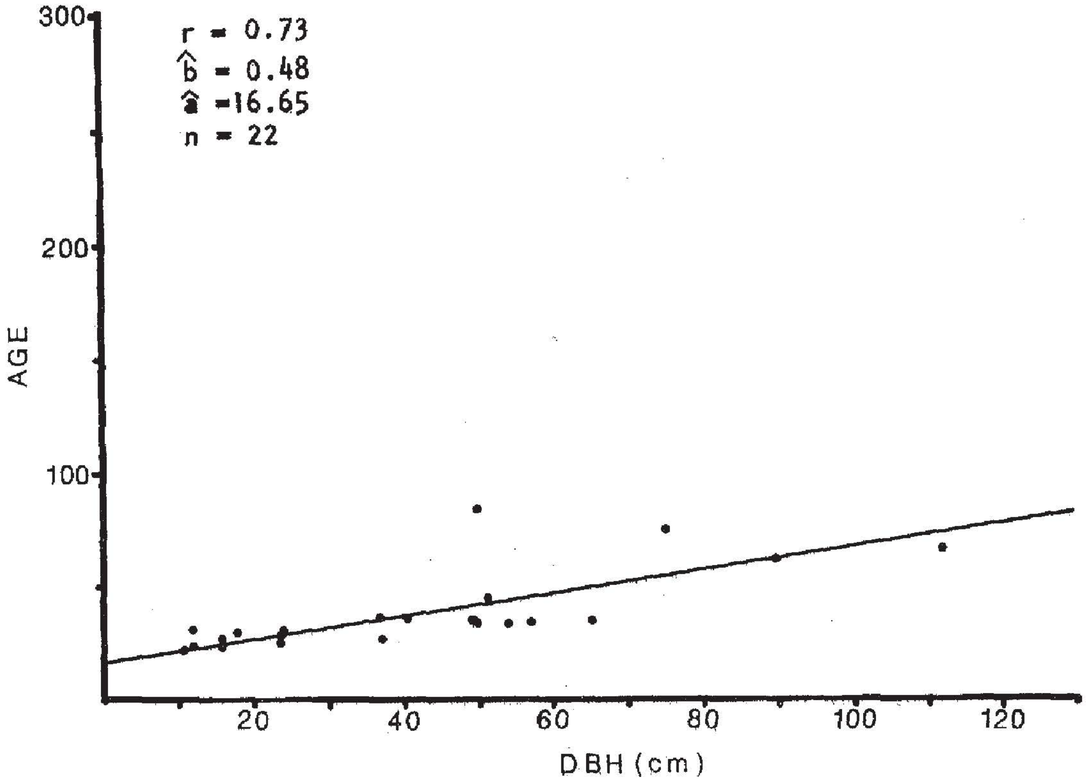


Fig. 6. Age-diameter relationship in Redwood: Slope, Young Growth
(A. West-facing, B. East-facing)

A. West-facing slope



B. East-facing slope

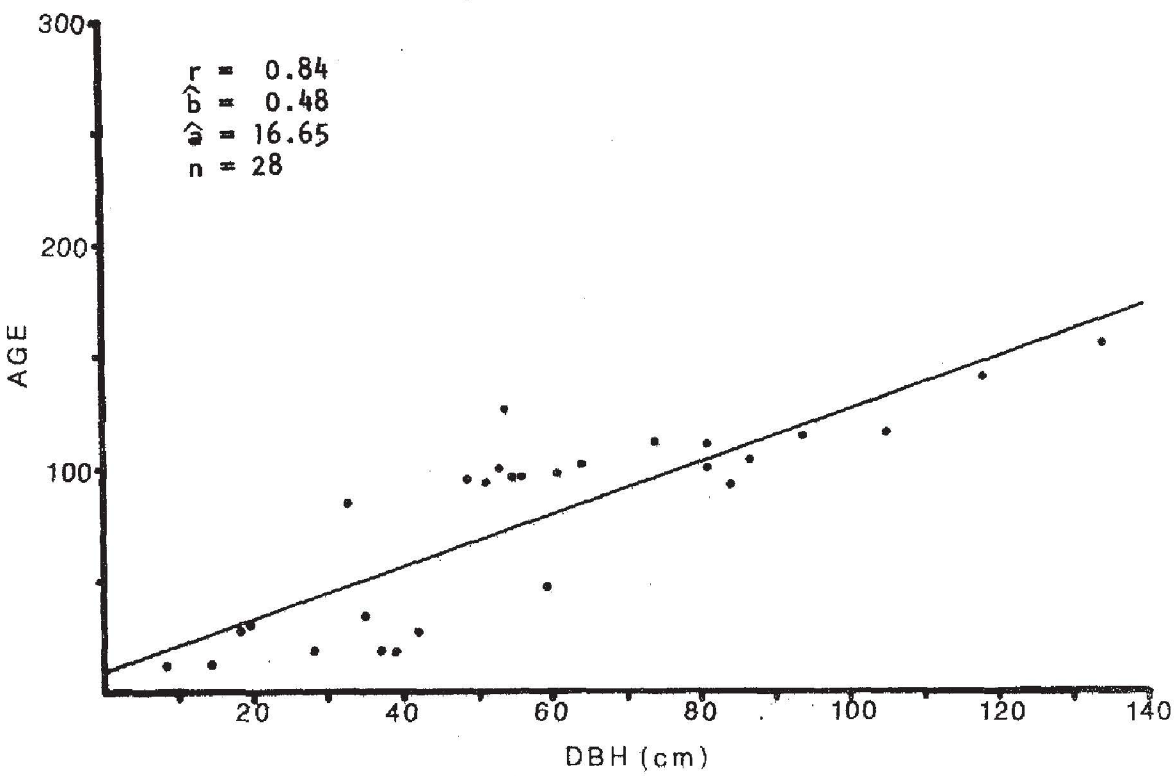
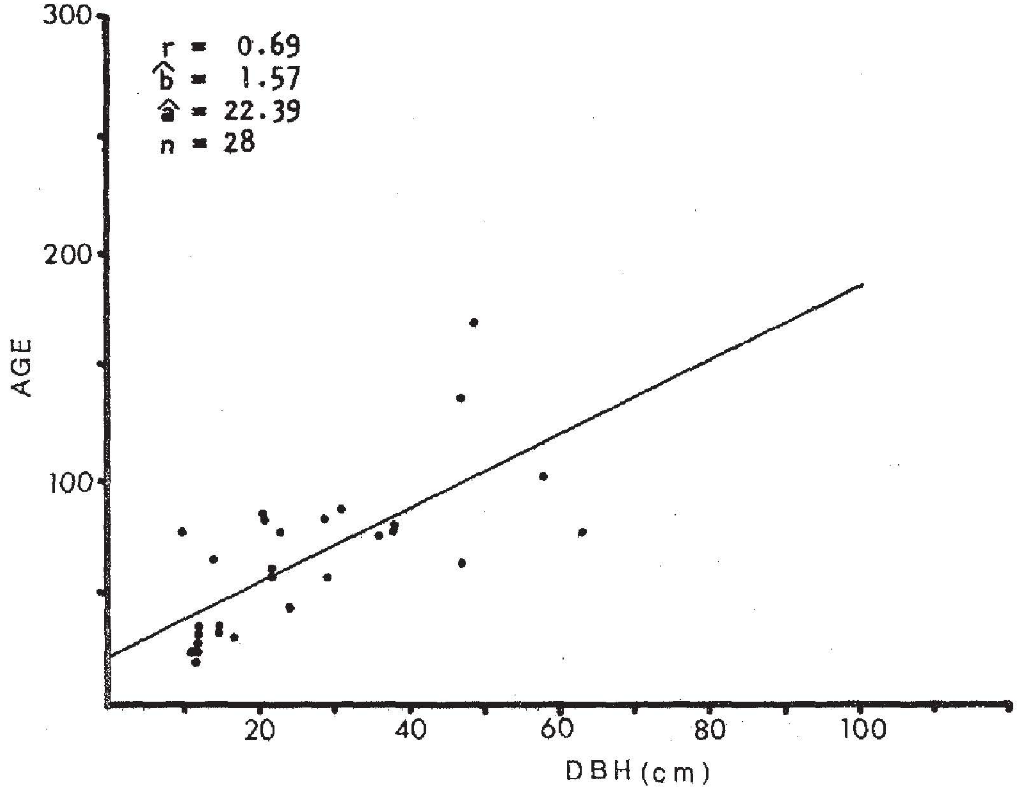


Fig. 7. Age - diameter relationship in Douglas fir (A. West-facing, B. East-facing).

A. Tanoak



B. California bay

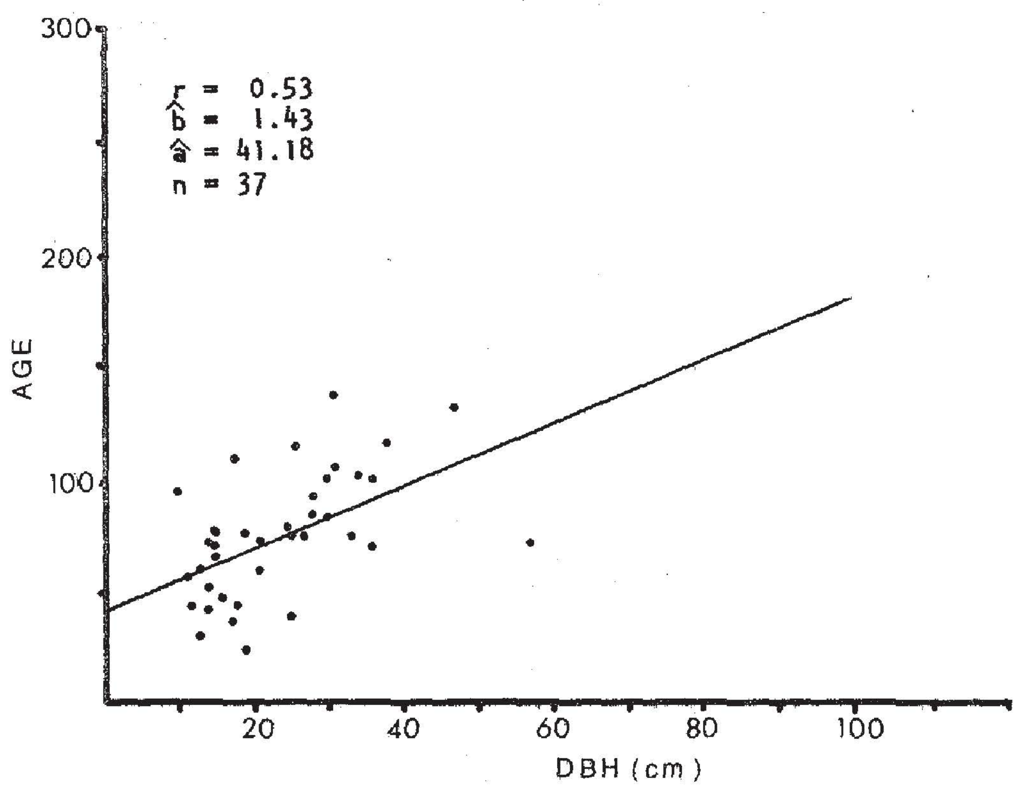


Fig. 8. Age - diameter relationship in hardwoods (A. Tanoak, B. California bay).

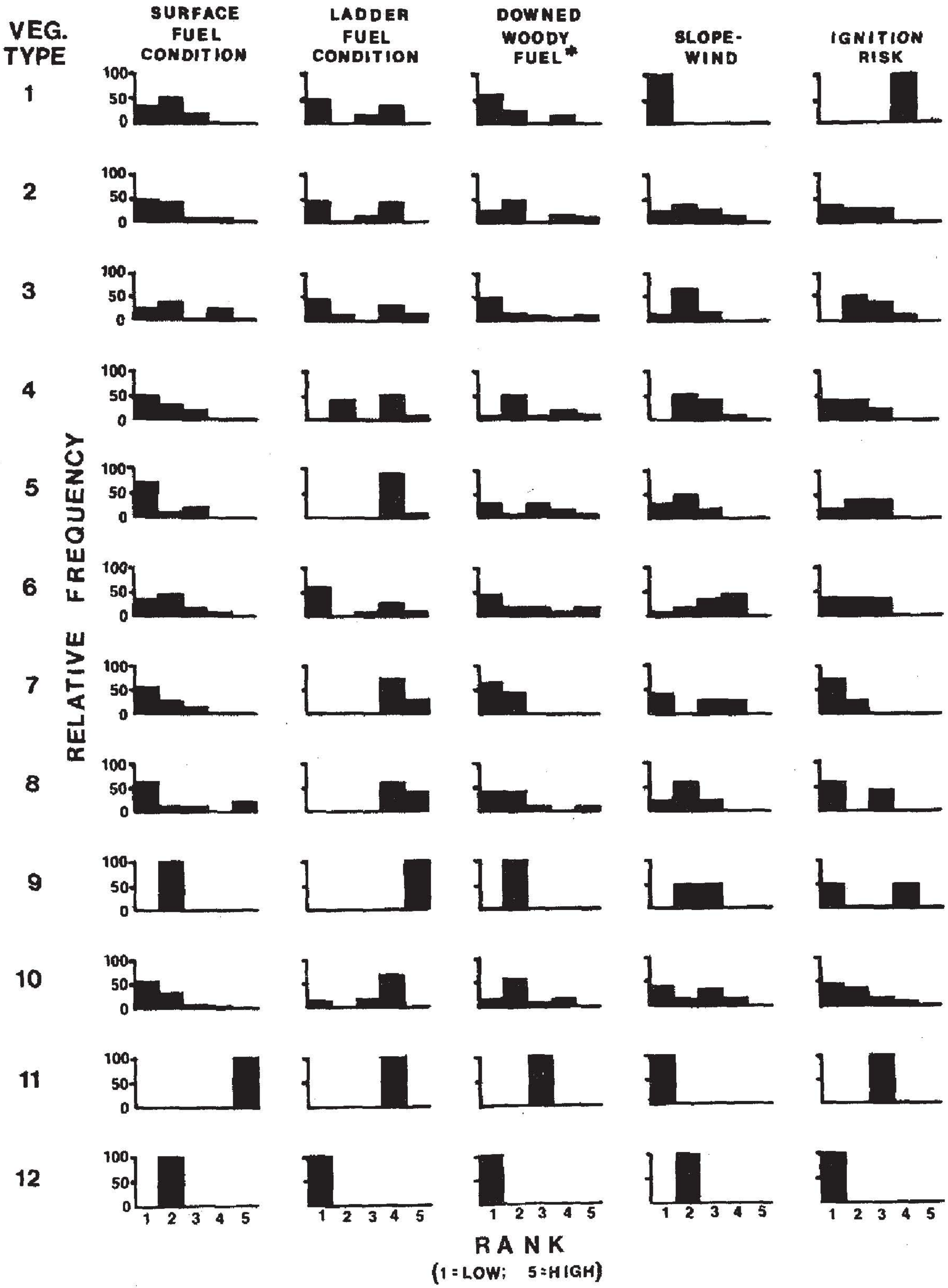


Figure 9. Fire Hazard Spectra of Vegetation Types at Muir Woods. (Veg. Types: 1-Redwood: Alluvial; 2-Redwood: Slope, Old Growth; 3-Redwood: Slope, Young Growth; 4-Redwood/Douglas fir; 5-Redwood/Hardwoods; 6-Douglas fir: Old Growth; 7-Douglas fir: Young Growth; 8-Douglas fir/Hardwoods; 9-Douglas fir/Brush; 10-Hardwoods; 11-Brush; 12-Grassland/Brush; 13-Hardwood/Brush; 14-Grassland.) * Values for grass and Brush areas based on Helm et al (1973)

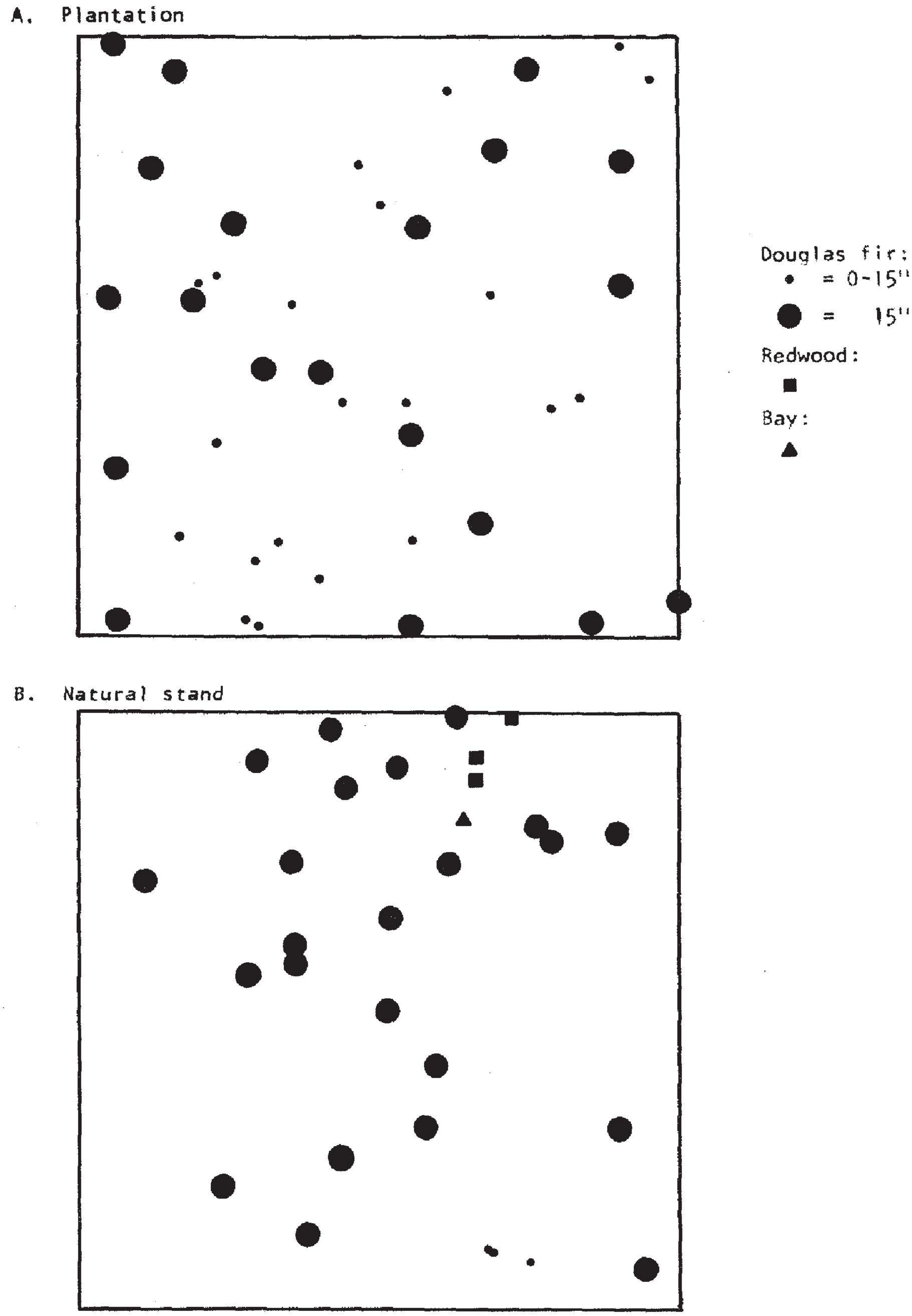


Fig. 10. Pattern of planted (A) and naturally occurring (B) Douglas fir.

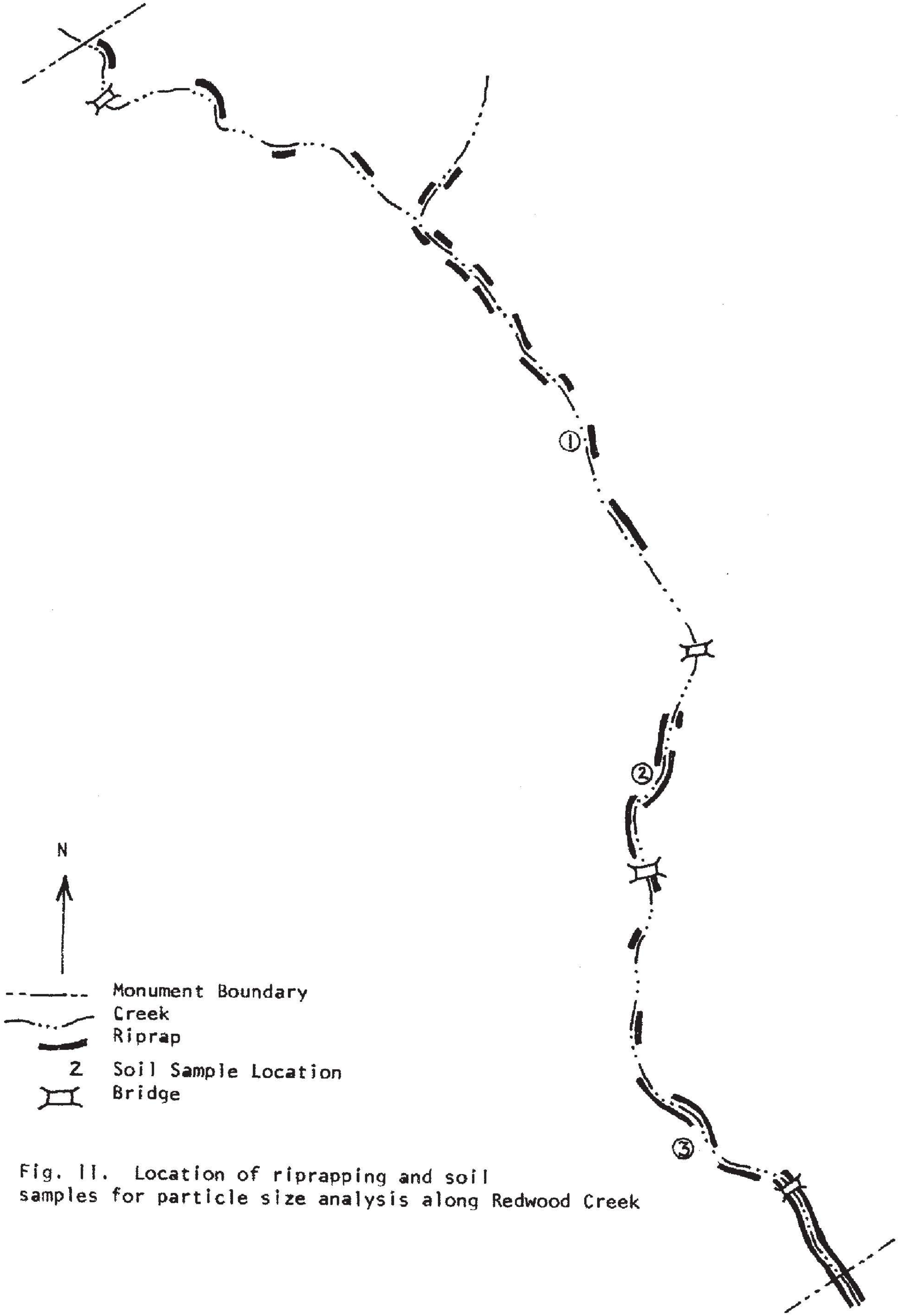


Fig. 11. Location of riprapping and soil samples for particle size analysis along Redwood Creek

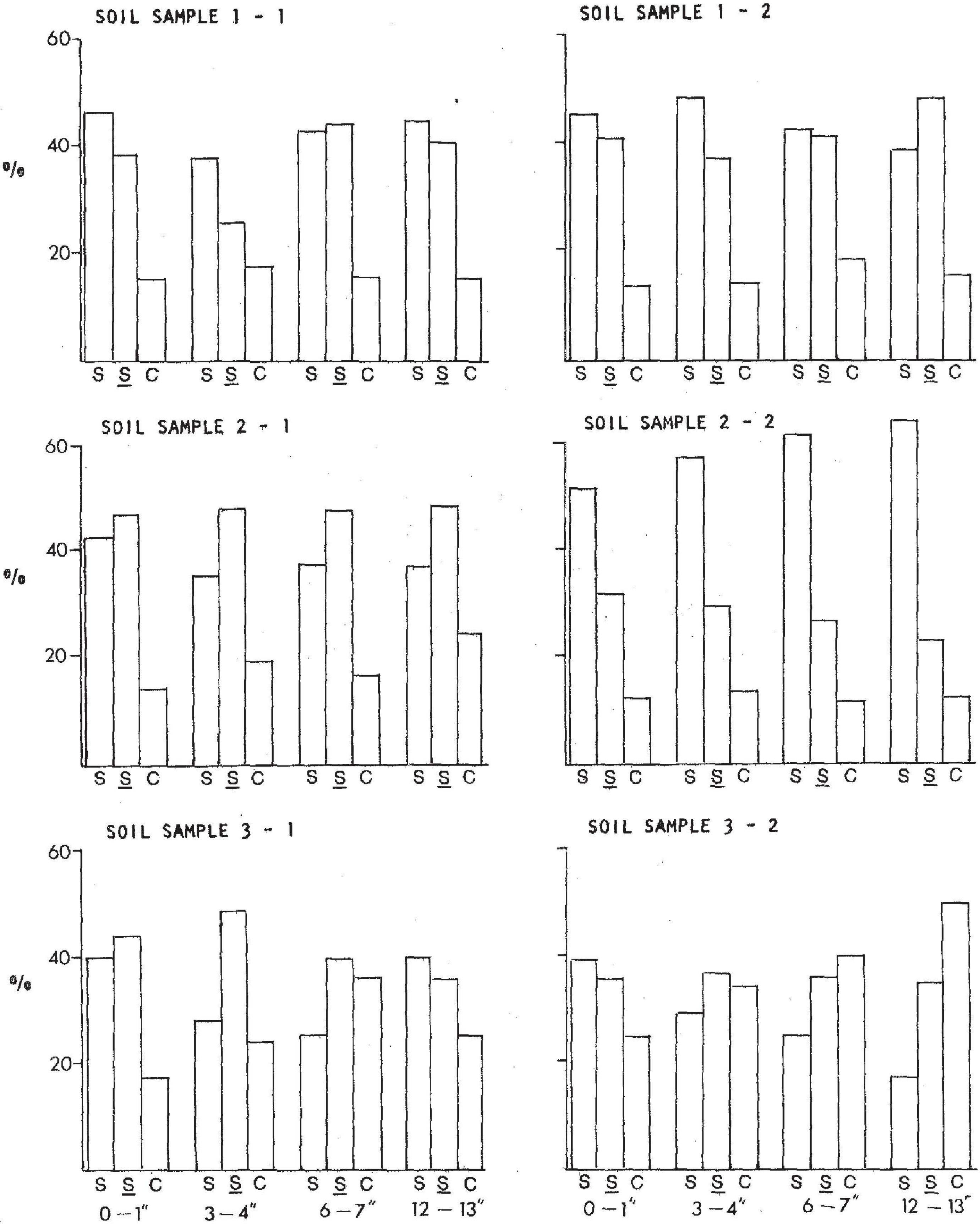
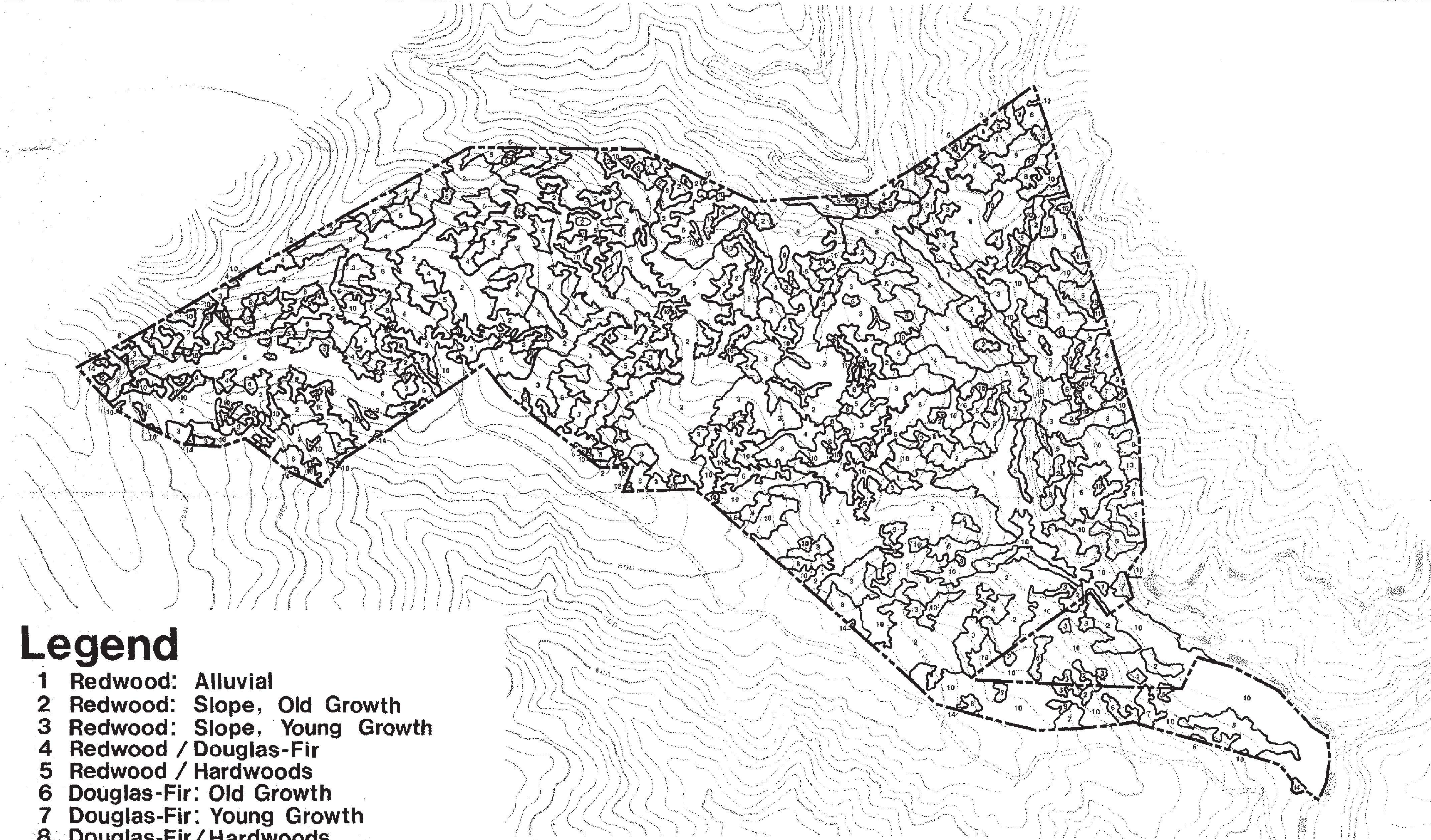


Fig. 12. Particle size distribution in soils sampled along Redwood Creek (S=sand; S=silt; C=clay).



Legend

1 Redwood: Alluvial
2 Redwood: Slope, Old Growth
3 Redwood: Slope, Young Growth
4 Redwood / Douglas-Fir
5 Redwood / Hardwoods
6 Douglas-Fir: Old Growth
7 Douglas-Fir: Young Growth
8 Douglas-Fir / Hardwoods
9 Douglas-Fir / Brush
10 Hardwoods
11 Brush
12 Grassland / Brush
13 Hardwood / Brush
14 Grassland
L Landslide

Vegetation Types
Muir Woods National Monument

McBride, Fiedler, Jacobs, Lang, Martin, & Milliken
University of California, Berkeley 1978