VEGETATION ECOLOGY OF THE BALD HILLS OAK WOODLANDS OF REDWOOD NATIONAL PARK

REDWOOD NATIONAL PARK

RESEARCH AND DEVELOPMENT

Sugihara and Reed

TECHNICAL REPORT

SEPTEMBER 1987

21

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VEGETATION ECOLOGY OF THE BALD HILLS OAK WOODLANDS OF REDWOOD NATIONAL PARK

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and
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Redwood National Park Research and Development
Technical Report Number 21

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South Operations Center
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ABSTRACT

Bald hills oak woodlands are a unique and diverse element of the redwood region's flora. Three distinct types of oak stands exist within Redwood National Park, based on tree size and age distribution:

1) Young dense, even-aged stands with up to 12,000 stems/ha.
2) Clustered stands of 740-2,550 moderately sized trees/ha.
3) All-sized stands composed of all size and age classes.

Seven community types based on floristic composition occur in specific habitats:

1) *Quercus/Symphoricarpos* - mesic, dense woodlands.
2) *Quercus/Dactylis* - mesic, open woodlands.
3) *Quercus/Cynosurus* - xeric woodlands.
4) *Quercus/Delphinium* - moist areas within xeric woodlands.
5) *Arrhenatherum/Sherardia* - glades among woodlands.
6) *Philadelphus/Cystopteris* - stream channels.
7) *Ribes/Phacelia* - rock outcrops.

Oak reproduction during the post-settlement period has been primarily by vegetative sprouting. Acorns are periodically abundant with high viability, but little successful acorn regeneration has been seen.

Since European settlement, approximately one-third of the bald hills vegetation within the park has converted to conifer forest. This trend is regionwide and threatens the existence of bald hills oak woodlands. Controlled by fire until settlement, Douglas-fir encroachment has been most rapid in oak woodlands and slower in open prairies. Unless present management practices are changed, rapid encroachment is expected to continue.

Re-establishment of frequent fire is expected to control Douglas-fir encroachment, while restoring a natural process. Four management alternatives for restoring and maintaining oak woodlands are presented:

1) No action.
2) Prescribed burning only.
3) Manual removal of Douglas-fir only.
4) Manual removal with prescribed burning.

ACKNOWLEDGEMENTS

We would like to thank Douglas Warnock, Don Reeser and Mary Hektner for their continued support of this study over several years. We would also like to thank the many Resource Management, Technical Services and Research Scientist personnel who reviewed and commented on various drafts, especially Jim Popenoe, Lee Purkerson, John Sacklin and Steve Veirs. We are indebted to Bob Powers, U.S.F.S.-P.S.W., for his constructive comments and suggestions. Jim Lenihan helped gather field data, provided essential computer analysis for the stand and vegetation type classifications and assisted with interpretions. Sherry Romanini provided technical assistance with word processing. Pam Muick, Joe McBride, Steve Barnhardt, Dave Aame and Jim Griffin contributed encouragement, enthusiasm and valuable professional guidance and support for the final phases of this study.

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INTRODUCTION

Bald hills oak woodlands and prairies are unique resources in Redwood National Park (RNP). Open grasslands and oak woodlands occur naturally among the dense coastal redwood (*Sequoia sempervirens*) forests and afford unique, unobstructed views down the Redwood Creek basin to the ocean. Easily accessible and rich in both natural and cultural resources, oak woodlands and prairies provide substantial wildlife habitat and support the greatest plant species diversity of any vegetation type within the park. Speaking of the bald hills of Humboldt and Mendocino counties, Jepson (1910) says, "He who is to supplement technical training in landscape work by studies of nature, could do no better than visit these mountains [bald hills]. There are not woodlands elsewhere in California that for studies of tree groups and contour and color surpass these." Historically, these bald hills were some of the most heavily used areas in the region. Unfortunately, this use has altered them as well. Restoration of the picturesque oak woodlands and prairies to a more natural state is within our capabilities. As such, they can provide an enjoyable and educational park experience for generations to come.

Oregon white oak (*Quercus Garryana*) is the only California oak species that extends far beyond the state boundaries, occurring from British Columbia to the Santa Cruz Mountains of California (Griffin and Critchfield 1972). The tree form of *Q. Garryana* is the only native oak in Washington and British Columbia and the principal oak of Oregon (Silen 1958). Reaching optimum development in the Willamette Valley of Oregon, *Q. Garryana* dominates woodlands occupying over 400,000 ha in northwestern Oregon (Franklin and Dyrness 1973).

In the North Coast Ranges of California, *Q. Garryana* is a minor component of several forest types and the dominant species in the northern oak woodland (Munz and Keck 1973, Sawyer et al. 1977, Whittaker 1960). Oregon white oak is associated with poorer forest sites on southwest exposures, steep slopes and thin-soiled areas with frequent rock outcrops (McCulloch 1940). Douglas-fir (*Pseudotsuga Menziesii*), tan oak (*Lithocarpus densiflorus*), black oak (*Quercus Kelloggii*) and madrone (*Arbutus Menziesii*) grow with Oregon white oak, forming extensive groves or small clusters associated with glades or small grassy openings (Jepson 1910). Griffin (1977) describes the northern oak woodland as having two distinct elements: one a continuation of the interior foothill woodland and the other the structurally distinct, geographically isolated coastal community type known as "bald hills" oak woodlands. The latter are distinguished by a patchy mosaic pattern of dominance by either oak or grass, not the balanced mixture of oak and grass found in savannah-like California woodlands (Clark 1937, Figures 1 and 2).

Bald hills oak woodlands occur in California's North Coast Ranges from Humboldt and Trinity counties south to Napa County. Approximately 19 percent of the 2.8 million ha in these counties support this oak/grass

Figure 1. Oak Woodlands and Schoolhouse Peak. This view across the Copper Creek watershed toward Schoolhouse Peak shows the characteristic bald hills oak/grass mosaic. The vegetation type distribution was mapped in this area and is shown in Figure 14.

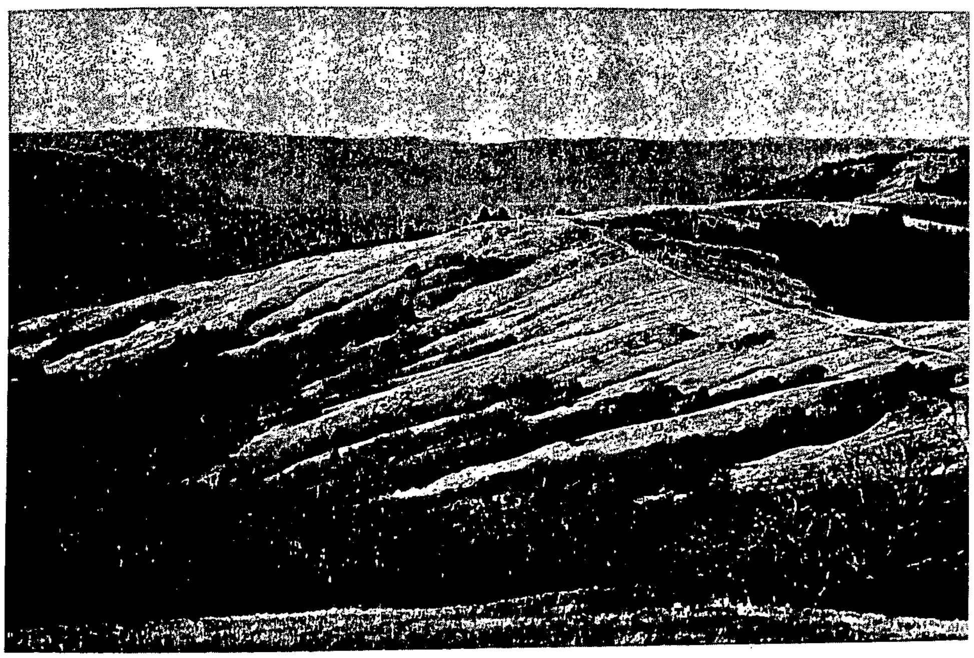


Figure 2. Bald Hills Vegetation. This view down the ridge from near Schoolhouse Peak looking towards the ocean shows bald hills prairies along the ridge, oak woodlands extending downslope and conifer forest below prairies and oaks.

vegetation (Wieslander and Jensen 1948, Storie and Wieslander 1952). Occurring between 75 m and 1600 m elevation throughout the region, best woodland development is found along ridgetops in Humboldt and Mendocino counties. The bald hills oak woodlands within the park are near the northern end of the range. Southward in the Coast Ranges, *Q. Garryana* woodlands and associated grasslands become more extensive.

Floristically and ecologically, the coastal bald hills prairies and oak woodlands were largely undescribed before this study. Saenz and Sawyer (1986) report a floristic difference between grasslands and adjacent oak woodlands due to a "canopy effect" at their study area within Redwood National Park. Hektner et al. (1983) describe the influence of grazing and burning on bald hills grasslands. Thilenius (1968) describes Oregon white oak woodlands at elevations from 120 to 240 m in the Willamette Valley of Oregon. He considers the woodlands seral and derived from oak savannahs by the exclusion of fire. Thilenius further defines four plant communities primarily by differences in shrub layers. Waring and Major (1964) use environmental gradients in defining the distributional limits of plant communities, including oak woodlands, in southern Humboldt County. They conclude that soil moisture is more significant for determining distributional patterns than nutrient, light or temperature gradients.

OBJECTIVES

The studies reported here were designed to determine the needs and options for management of the park's oak woodlands. Part 1 of this report describes and classifies the composition and structure of oak woodland vegetation as it presently exists. Part 2 treats historic changes in vegetation and the influence environmental factors had on these changes. These studies sought to determine whether the system was now stable or if further changes could be expected. The extent and patterns of vegetation change during the post-settlement period were mapped. Factors which modified vegetation patterns were studied and where they were human induced, methods for restoring natural conditions were investigated. Part 3 summarizes and discusses the first two parts and then proposes management alternatives. The need for monitoring long-term effects of treatments is introduced. Anticipated vegetation response to various treatments and expected effectiveness in meeting objectives are also discussed. Theory, method, results and interpretation for each phase of the study are treated together. This format allowed documentation in greater detail which will be useful in interpreting the effectiveness of management techniques.

SCOPE OF STUDY

The scope of this study was restricted to plants, plant processes and plant ecology. Consideration of the other biotic and abiotic factors which comprise the ecosystem were considered in this report only as related to vegetation. Although prairies were associated communities and could not be completely separated, the primary emphasis of these studies was on oak woodlands. Oak stand and vegetation classifications included small grassy glades within the woodlands but not the large, adjacent prairies. The vegetation dynamics section of this report treated the prairies where the Douglas-fir encroachment processes were similar.

Related vegetation studies are currently being done in the park and reported elsewhere. Prairie studies are being conducted by Roy Martin and Mary Hektner (Hektner et al. 1983). Soil relationships to vegetation patterns are being studied by Jim Popenoe and Nancy Sturhan. Second-growth conifer forest studies have been conducted by Muldavin et al. (1981), Lenihan et al. (1982), Lennox et al. (1982) and Lennox (1983). Vegetation communities in logged and unlogged old-growth redwood forests are described by Lenihan (1983), Lenihan (1986), Veirs (1982) and Veirs and Lennox (1982). Further research needs are identified in Appendix 1.

STUDY AREA

The 250 hectares of oak woodland and 800 hectares of grassland comprising the study area are located within the Redwood Creek basin of RNP in Humboldt County and were included within the 1978 park expansion (Public Law 95-250). The bald hills ecosystem within the park lies 8 to 22 km from the coast and 85 to 95 km south of the Oregon border (Figure 3). Redwood Creek flows from the southeast to the northwest and empties into the ocean near Orick, California.

The area of RNP in which this type of vegetation occurs is also known as the Bald Hills (see map in Back Cover Pocket.) In an effort to avoid confusion, Bald Hills (upper case) refers to the specific area within RNP and bald hills (lower case) refers to the regional vegetation type.

Climate

The regional climate is Mediterranean. A strong oceanic influence is present at lower elevations and in the northwestern portion of the study area where summer fog is common. The oceanic influence decreases at higher elevations and on southeast-facing, interior slopes. Annual precipitation averages 178 to 203 cm (Coghlan 1984). Ninety percent of this precipitation occurs between October and May. The annual amount of snowfall is variable. Ridgetops receive an average of 25 cm per year and riverbottoms less than 2 cm per year. Mean daily high temperature in July is 25°C with temperatures rarely exceeding 38°C. Mean daily low is 2°C in January with temperatures below -7°C rare. Winds are generally light but may reach 110 kph on exposed ridgetops in winter and spring (Humboldt State University 1974).

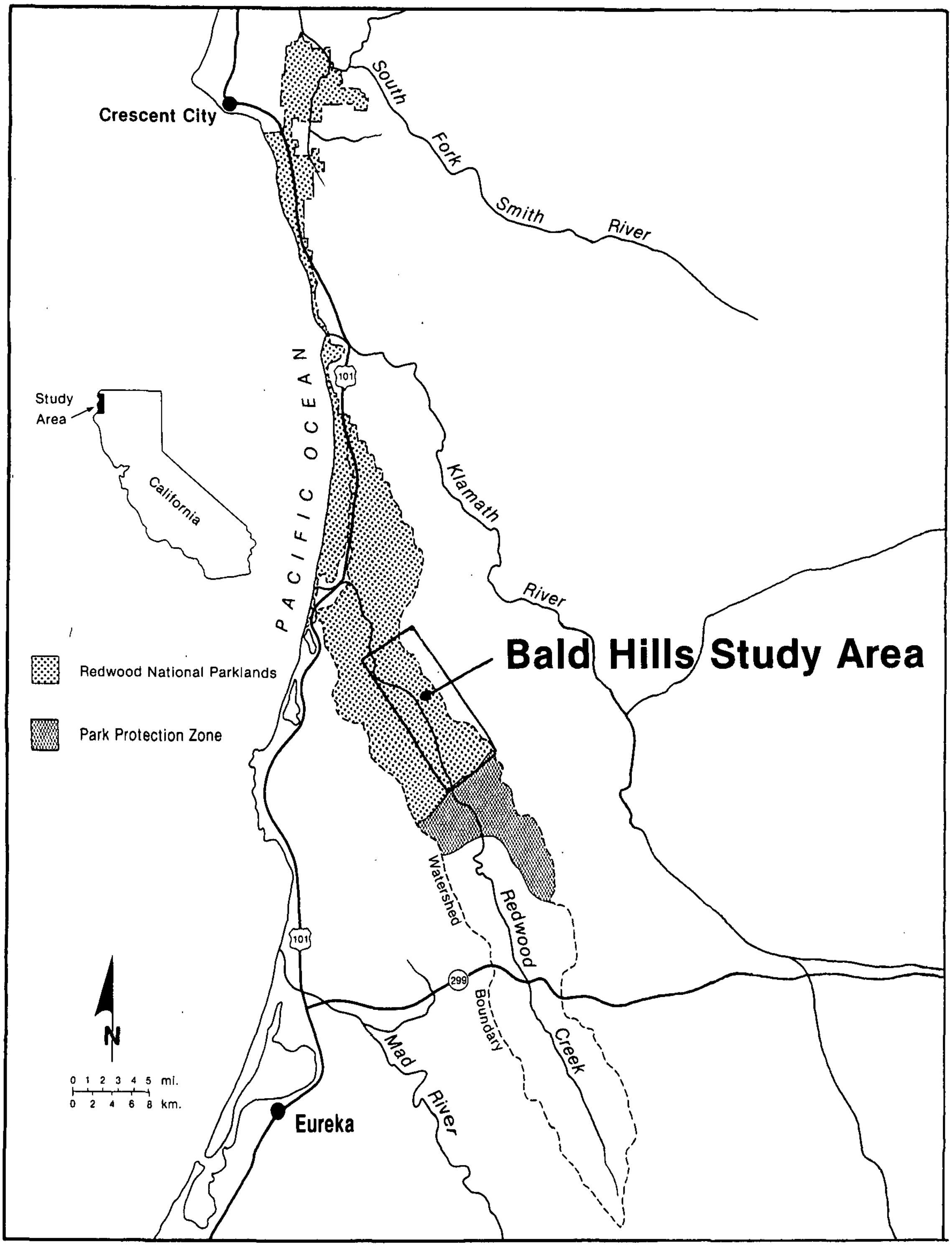


Figure 3. Location of Redwood National Park and the Bald Hills Study Area.

Topography

The topography of the bald hills consists of two forms. The first is the ridge crest with smooth, rolling hills supporting oak/prairie vegetation. The second is the steep hillside usually dominated by grasslands to the northwest and becoming increasingly oak dominated to the southeast. Within RNP, bald hills vegetation is located along the ridge crest between Redwood Creek and the Klamath River drainage. Steep drainages, extending down sub-basin divides into southwest-facing valleys below, take the form of deeply-incised channels with smooth, rounded, usually well-vegetated banks. Oak stands often border grasslands along creeks. Elevations of the grass/woodland mosaic range from 75 m on the banks of Redwood Creek to 945 m at Schoolhouse Peak on the northeastern ridgetop above Redwood Creek.

Geology

The geologic substratum of the area is partly residuum from highly sheared Franciscan siltstone, sandy siltstone, and graywacke sandstone and partly colluvium from these same materials (Gordon 1980). The landscape is characterized by numerous earthflows.

Soils

Soil Vegetation Survey map unit boundaries in the area follow vegetation patterns of prairie, oak woodland and conifer forest. Woodland soils were mapped in the Tyson series with Yorkville and Kneeland series in the grasslands and predominantly Hugo series in adjacent conifer stands (Alexander et al. 1961). Cooper (1972) states that these vegetation patterns represented the edaphic climax for the soil types present. He also found Yorkville soils unsuitable for conifer forests. Tyson soils were found to occasionally support Douglas-fir but not to the exclusion of oaks.

RNP soils are currently being remapped and redescribed using current Soil Conservation Service standards. A complex pattern of Inceptisols, Alfisols and Ultisols underlay the woodlands as well as adjacent forests and grasslands. Subsoil properties largely reflect geologic substratum and relief. Forest soils lack the umbric epipedon found in woodland and prairie soils, but subsoils of all three have a similar range of properties. Recent detailed soil mapping has not shown consistent patterns which account for the present forest/woodland/grassland boundaries (Popenoe 1986).

Wildlife Use

The oak woodlands provide food and habitat for many animals. Barrett (1980) documents over 60 species of mammals which have ranges that overlap with Oregon white oak and potentially use the oak in some way. Deer, elk, bear, insects, gophers, mice, squirrels and many bird species use the leaves, acorns, young shoots or the entire tree for food or habitat. Davenport (1982) reports use of the oak woodlands in RNP by breeding birds. Predators, such as bobcats and coyotes, feed on small mammals living in the oak woodlands. Increasing numbers of deer, elk and bears have been observed in the oak woodlands and prairies around Schoolhouse Peak since 1982.

HISTORICAL USE

Native Americans occupied the Bald Hills of RNP for at least 6,000 years before their decimation and eventual removal in 1864 (Benson 1983, Bickel 1979, Hayes 1985). Archeological evidence indicates that several locations in the Bald Hills were utilized as villages, seasonal camps or ceremonial sites. Prairies and oak woodlands provided edible seeds and bulbs, and basketry materials. Native Americans regularly set fire to the prairies and oak woodlands, profoundly affecting the vegetation patterns of the area (Thompson 1916, King and Bickel 1980, Lewis 1973). Fire was used to maintain the open woodlands and prairies, make food gathering easier and stimulate plant growth to attract wildlife. Periodic burning continued with early white settlement but was eventually discontinued and replaced by a policy of wildfire suppression (Stover 1983).

Coastal communities developed to supply the gold mining activities inland prompting heavy use of the "Trinidad Trail". This primary pack trail ran north from Trinidad along the coast to Big Lagoon, turned east to cross Redwood Creek near the present Tall Trees grove, ascended to the crest of the Bald Hills near Elk Camp and followed the ridge, ultimately descending into the Hoopa Valley (Greene 1980). Isaac Wistar, an early pack trader, carried supplies over this route. His first impression of the bald hills in 1849 are noteworthy (Wistar 1937).

> These people [mule packers] informed me that after getting clear of the redwoods some miles ahead, at a block house called Elk Camp, the trail led for several days over high rolling grassy mountains, known as the Bald Hills, where grass and water were abundant but Indians numerous and hostile. In due time I reached Elk Camp, which was attractive not merely by contrast with the muddy and gloomy depths of the redwood forest where no sun's rays could penetrate, but as the threshold and entrance to one of the finest tracts of country in California. The region known as the Bald Hills stretches along on both sides of the Klamath from the inland margin of the great seacoast belt of redwoods for perhaps 100 miles by the rivers course to the base of the higher snow-covered range of the Cascades, or as they are called in California, the Coast Range. Elk then roamed over them in bands of hundreds,

> or perhaps thousands, finding the ideal conditions preferred by them. Deer abounded in all the brushy ravines, while bear and bighorn were plenty in the surrounding mountains. Water was found in every hollow, luxuriant grass grew everywhere, and timber was nowhere more distant than a few hours' ride. There can be few places in the world that furnish such a combination of circumstances favorable to the hunter or the cattle-owner, as there exist in respect to soil, climate, water, wood, pasture and scenery.

Proximity to a ready market in the gold mines led to the development of a livestock industry on homesteads in the Bald Hills. Early homesteaders concentrated on raising cattle, horses and mules. Between 1865 and the 1940's, the regional wool industry flourished and sheep ranching was the dominant activity in the Bald Hills (Greene 1980). Except for a small area near Schoolhouse Peak, which last held sheep in 1962-63, none of the prairies now within the park has been grazed by sheep since 1949 (Lane 1983). Cattle succeeded sheep when sheep grazing became unprofitable. Some of the current ranchers in the area believe the number of deer increased due to land clearing activities from lumbering and, subsequently, the coyote population also expanded. Heavy predation on lambs was a problem. Other ranchers feel the declining wool and mutton market prompted the change. Still others maintain the higher cost of fencing to keep sheep out of logged areas as compared to cattle caused the change. The actual reason for the shift to cattle may have been a combination of all of these factors (King and Bickel 1980). Grazing was officially discontinued by the National Park Service in 1982, but trespass grazing continues.

Upstream of the park, extensive white oak woodlands were cut and cleared but the extent of large-scale oak harvesting in the park is unknown (Stover 1987). Some oaks were thought to have been cut during homesteading. Elsewhere, Oregon white oak wood was utilized for fence posts, furniture and fuel (Silen 1958). Logging of adjacent redwood and Douglas-fir forests has been the primary factor affecting forest vegetation in the Redwood Creek basin since the 1940's. The main effects of this logging on the oak woodlands have been associated roadbuilding and the resulting increased erosion.

PART 1: VEGETATION DESCRIPTION

Effective management of natural area vegetation requires basic knowledge of the existing vegetation patterns and composition. Prior to 1982, a complete description of vegetation was difficult to obtain due to the impacts of grazing. Since 1982, the National Park Service has allowed the vegetation of RNP's Bald Hills oak woodlands to develop ungrazed for the first time in over a century. This baseline study provided the essential description of existing vegetation required for accurate assessment of management needs and development of techniques. This study was designed in two phases. The first was a description of oak stand types and the second was a classification of oak woodland plant communities. The primary intent of Part 1 of this report was to document the present condition of the park's intact oak woodlands.

STAND CLASSIFICATION

Objectives

The primary objectives of the stand classification were to:

1) determine the diversity of oak stand types.
2) quantitatively define these stand types in terms of age and size structure.
3) discuss stand origin and development, and anticipate further stand development.

The scope of this phase was limited to description of existing oak stand patterns and discussion of possible management implications.

Methods

Prior to sampling in the spring of 1982, field reconnaissance was conducted to determine representative plot locations. Fifty-three 0.1 ha (20 m x 50 m) plots were selected to represent the diversity of stand types and elevations. Plots were located in floristically and structurally uniform areas. Total canopy, shrub and herbaceous cover were estimated to the nearest 5 percent. Elevation, slope, aspect and location on aerial photographs were recorded. Diameter at breast height (DBH) was measured for each tree. Live and dead trees were recorded separately. Trees were placed into designated size classes of four centimeter increments (ie. 0-4 cm, 4-8 cm, 8-12 cm, etc.) up to 48 cm. The actual diameter was recorded for trees larger than 48 cm.

Following determination of stand structural types, their distribution was mapped. Mylar overlays were used on 1:6000 scale color aerial photographs for field mapping. A composite map was then prepared from the field maps, using the 1:24,000 scale 1975 U.S. Geological Service Coyote Peak NW Orthophotoquad as a base.

Twenty representative young *Q. Garryana* trees were cut in the winter of 1981-82 to obtain age, growth rate and other stand information. Coring was attempted but found to be very difficult and did not always yield adequate information. Cross-sections were also obtained from windfalls, stumps of known history and trees cut for other projects such as fence construction. A larger number of cross-sections would have been desirable, but park policy restricted the number and size of trees that could be cut. Cross-sections were taken from the base of the tree at ground level and at breast height, about 1.5 m. Sections were sanded and rings counted, noting the presence of fire scars. Two sizes of oaks were cut. It was noted that the larger sizes had abundant epiphytic moss and lichens while the smaller were lacking or had few epiphytes.

Results

Three oak stand types were defined on the basis of stand structure, canopy and shrub cover and the number and size of trees present (Table 1). Figures 4, 5 and 6 graphically depict typical diameter distributions for each stand type, using data from actual plots. All plots within each stand type had distributions similar to the ones shown. Figure 7 shows the distribution of stand types within the study area. Figures 8, 9 and 10 are photographs taken of representative stands for each type.

TABLE 1. CHARACTERISTICS OF OAK STAND TYPES.

Stand	Average Percent Cover By Layer					Percent of
Type	Canopy	Shrub	Herb	Stems/Ha	DBH (cm)	Woodlands
Young Dense	90	46	58	4,500-12,000	< 12	15
Clustered	86	2	80	740-2,550	10-30	60(70)
All-Aged	76	1(30)	85	60-530	seedling to > 100	15

Three stand types were differentiated:

1) Young dense stands containing 4,500 to almost 12,000 stems/ha comprised approximately 15 percent of the woodlands. Two narrow bands of this type extended upslope from the base of an extensive woodland to the ridgetop, through stands of larger trees. Trees were typically 5 to 10 m tall, 25 to 50 years old and less than 12 cm DBH (Figures 4 and 8). Canopy cover averaged 90 percent and shrub cover, 30 to 70 percent.

2) Clustered stands containing 740 to 2,550 stems/ha of uniformly-sized,

multiple-stemmed trees, made up nearly 60 percent of the oak woodland acreage within the park. DBH ranged from 10 to 30 cm (Figures 5 and 9). Stands ranged from 80 to 120 years old, but ages within stands were fairly uniform. Canopy cover averaged 80 to 95 percent and shrub cover was low, 1 to 5 percent.

3) All-aged stands composed of a wide size range but dominated by relatively few large trees made up about 15 percent of the park's oak woodlands. This was the only stand type that included many size classes. Trees were mostly single-stemmed, ranging in size from seedlings to trees greater than 1 m DBH (Figures 6 and 10). The age range was equally wide, with seedlings to trees over 350 years occurring in the same stand. These stands were typically found on the xeric woodland fringes adjacent to open grasslands, and formed distinctive mosaic patterns with grasslands. Within all-aged oak stands, canopy cover averaged 76 percent and contained 60 to 530 stems/ha. Shrub cover was very low, 0 to 2 percent, except on exposed rock outcrops where it reached 30 percent.

Another ten percent of the oak woodlands had even-aged, clustered trees with widely scattered large trees also present. Except for the large trees, these stands were typical of clustered stands.

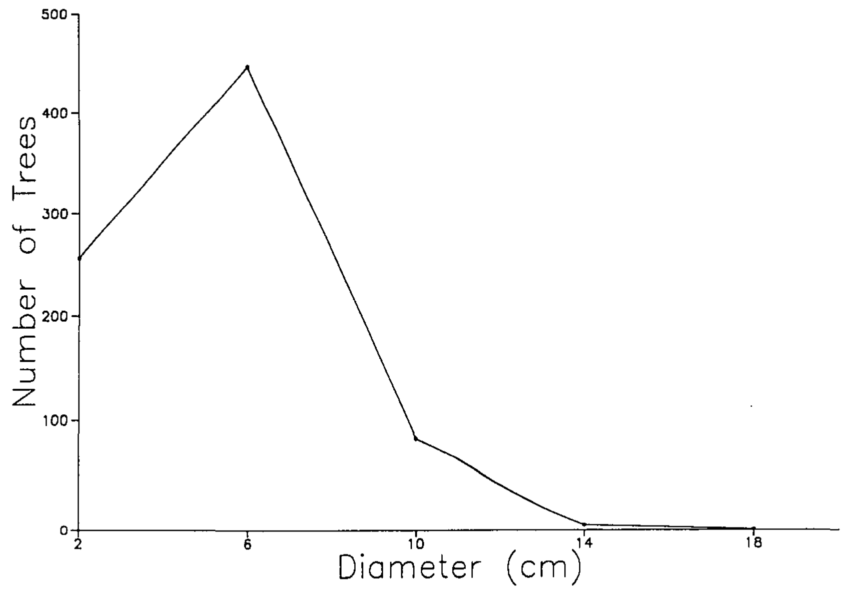


Figure 4. Stand Structure - Small Dense Stand. A typical oak diameter distribution in a small dense stand (0.1 ha) is shown. This stand (Plot #763) originated following a major fire 35 years before sampling was done. The mean tree diameter (5.2 cm) for Plot #763 is similar to the mean (5.3 cm with a 99% confidence interval of 4.8-5.8) for all 10 small dense stands sampled.

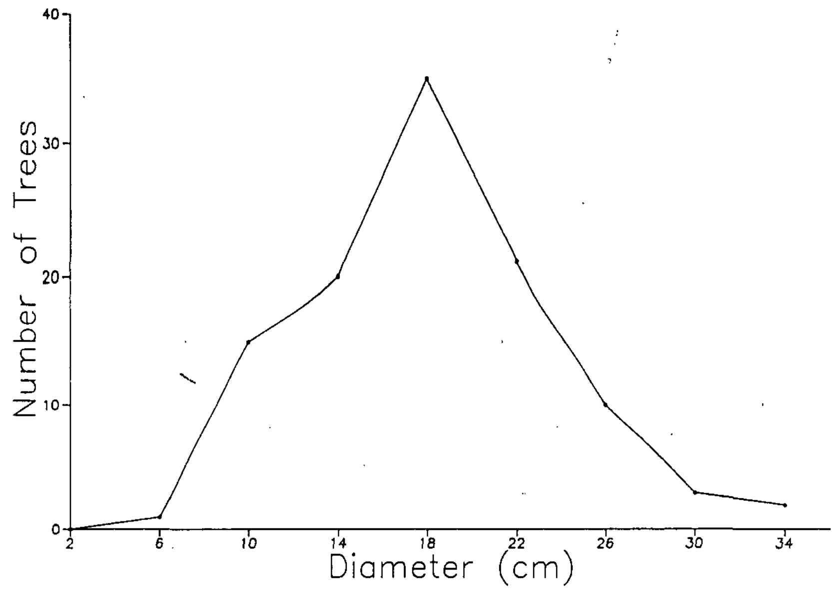


Figure 5. Stand Structure - Medium Clustered Stand. This is a typical oak diameter distribution in the 0.1 ha clustered stands 70 to 100 years old (Plot #740). The mean tree diameter (18.7 cm) for Plot #740 is close to the mean (16.7 cm with a 99% confidence interval of 14.4-18.9) for all 22 medium clustered stands sampled.

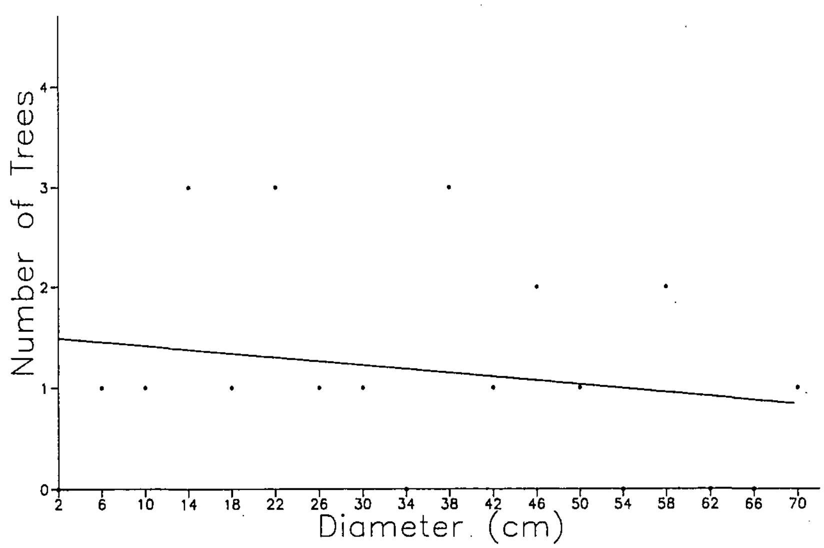


Figure 6. Stand Structure - All-Aged Stand. This shows a typical oak diameter distribution in a 0.1 ha all-aged stand (Plot #711). A few scattered, very large trees often occur, but all sizes (and ages) are usually present. The mean tree diameter (32.5 cm) of Plot #711 is close to the mean (35.4 cm with a 99% confidence interval of 31.1-40.7) of the 21 all-aged stands sampled.

Figure 7

DISTRIBUTION OF STAND STRUCTURAL TYPES IN THE BALD HILLS OAK WOODLANDS

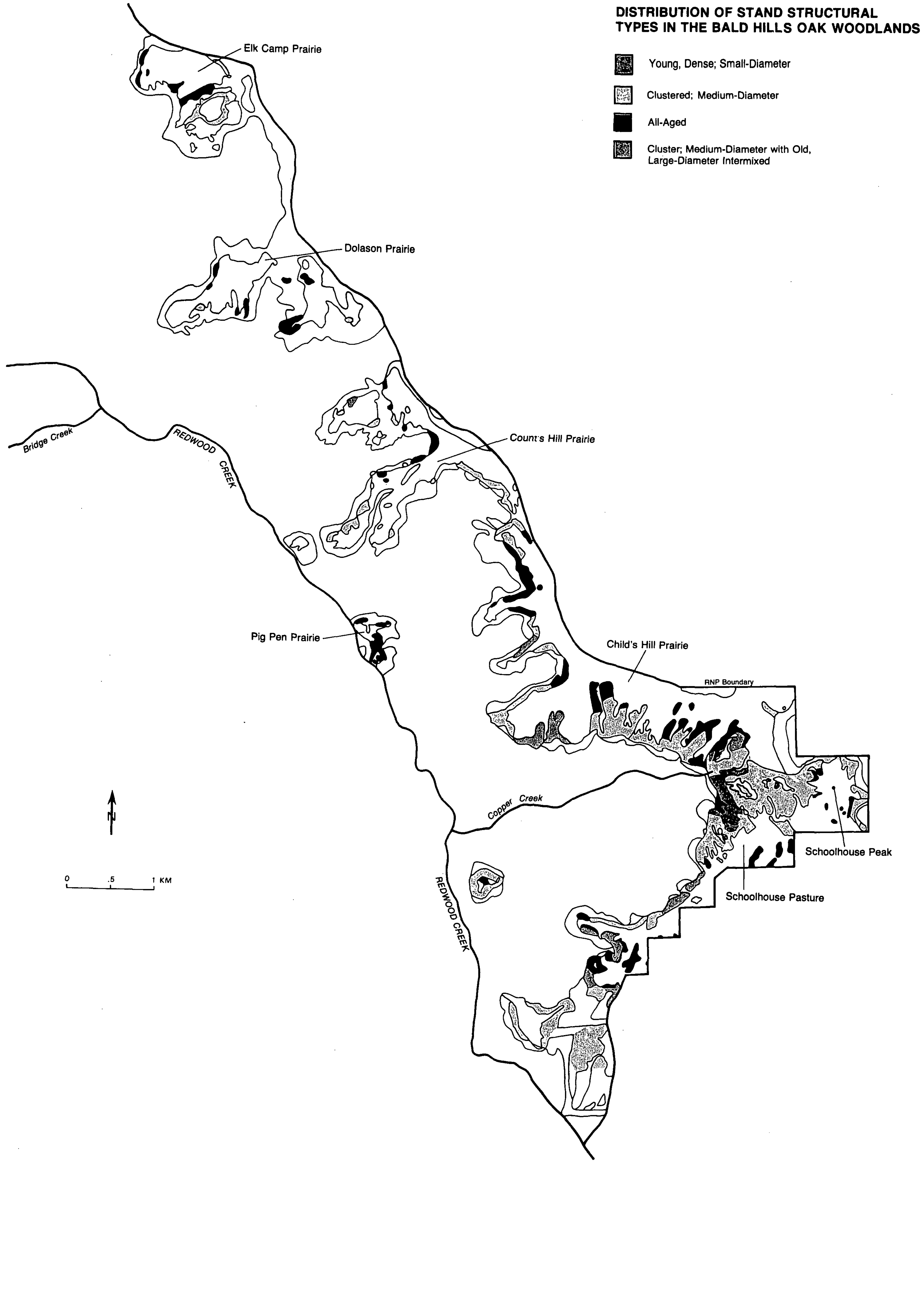
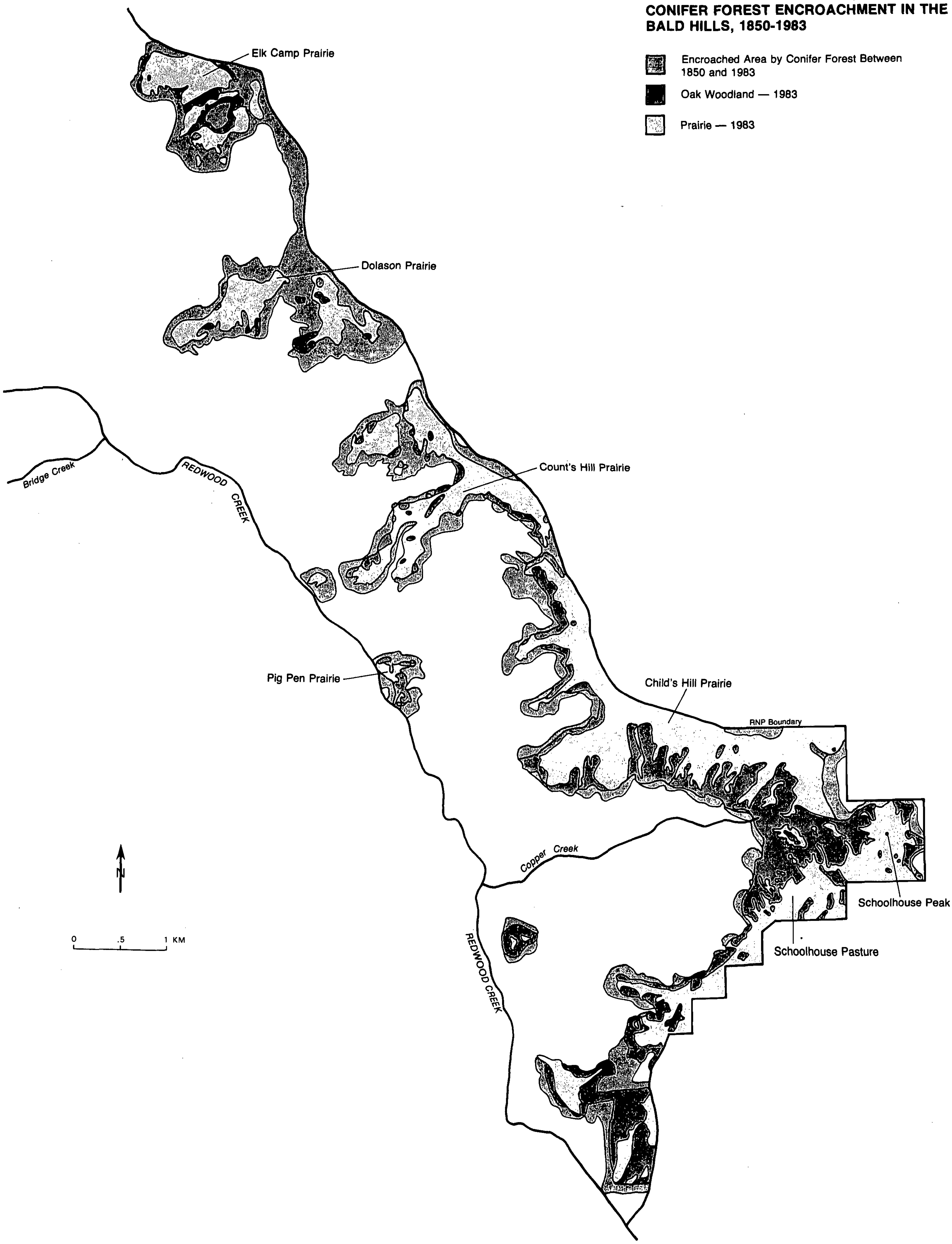
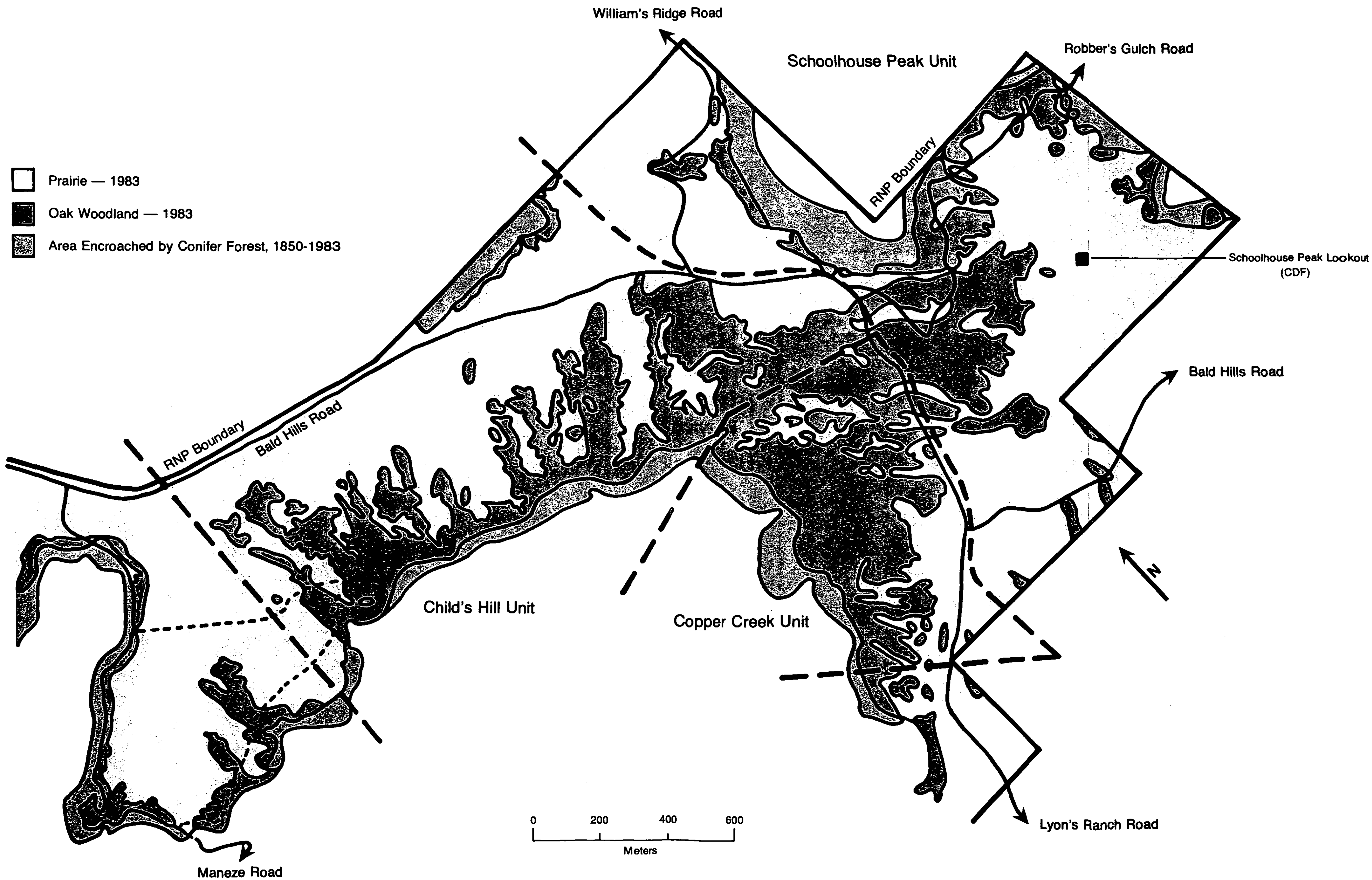


Figure 15

CONIFER FOREST ENCROACHMENT IN THE BALD HILLS, 1850-1983



Child's Hill, Copper Creek and Schoolhouse Peak Units



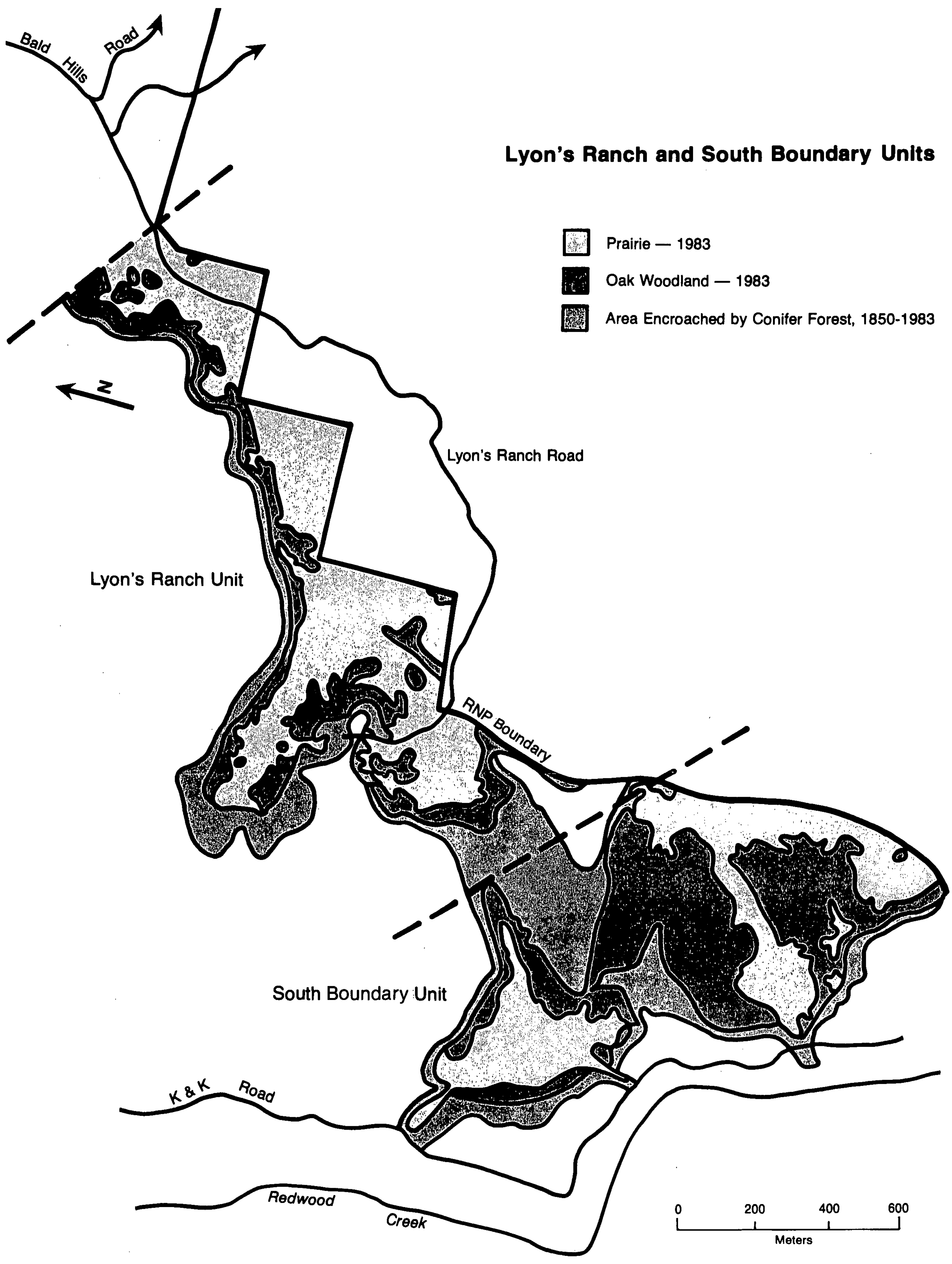

Lyon's Ranch and South Boundary Units
Prairie — 1983
Oak Woodland — 1983
Area Encroached by Conifer Forest, 1850-1983
Bald Hills Road
N
Lyon's Ranch Road
Lyon's Ranch Unit
RNP Boundary
South Boundary Unit
K & K Road
Redwood Creek
0
200
400
600
Meters

Figure 8. Small Dense Stand. This stand of small individual trees sprouted after a fire 35 years before the photograph was taken. The fire killed most aerial stems of the former stand.

Figure 9. Clustered Stand. This closed canopy clustered oak stand approximately 70 years old may have originated from sprouts around the bases of trees which were either cut or otherwise killed.

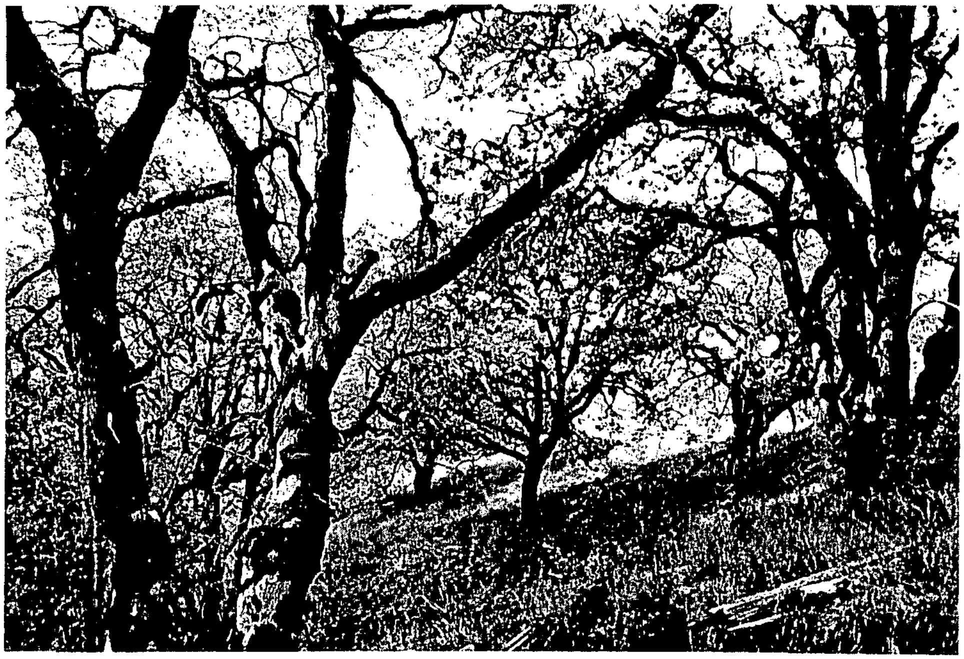


Figure 10. All-Aged Stand. This all-aged stand has a dense canopy and scattered individual trees of all sizes and up to 300 years old.

Herbaceous cover under young dense stands averaged 58 percent. Herbaceous cover in both the clustered and all-aged stands was much higher at 80 and 85 percent, respectively. Both the latter were characterized by the presence of high grass cover in the herb layer and a few tall shrubs.

Table 2 displays the data obtained from cross-sections in two young dense stands. In each stand the larger trees, with epiphytes, were 35 years and older and averaged 10.5 cm DBH. Smaller trees averaged 5.3 cm DBH, lacked epiphytes and were 33 years old or younger. Two distinct fire scars appeared in the rings corresponding to 1945 and 1948. The two sampled young dense stands contained 11,450 and 7,910 stems/ha. The number of years required for growth from base to breast height ranged from 2 to 10 years, averaging 5.3 years. Older trees which had survived the fires (i.e. greater than 34 years old) were clearly dominant, being much taller and more vigorous.

Interpretation

Three statistically distinct stand types were found: young dense, clustered, and all-aged. The first two types were stands of recent origin, young but having a high density of stems or older with lower density but having a uniform size and age (Figures 4 and 5). These implied origin from a single event or time period rather than continuous reproduction at a sustained rate. The third stand type was distin-

TABLE 2. OREGON WHITE OAK CROSS-SECTION DATA FROM TWO YOUNG DENSE STANDS.

Date of Base	Age at 1.5 Meters	Years to 1.5 Meters	DBH (cm)	Fire Scars (Date)
Stand 1				
1955	15	10	3.0	-
1953	20	7	4.0	-
1952	24	4	4.5	-
1950	26	4	5.0	-
1949	26	5	8.0	-
1948	29	3	6.5	-
1947	26	7	6.0	-
1930	41	9	7.5	-
1928	44	8	12.5	1945,48
1920	50	10	10.0	1945,48
Stand 2				
1957	15	8	2.0	-
1953	25	2	2.2	-
1950	26	4	4.1	-
1948	28	4	7.6	-
1948	30	2	10.4	-
1944	30	6	7.6	-
1938	40	2	9.1	1948
1937	40	3	12.7	1948
1936	41	3	14.2	-

guished by having many size and age groups represented (Figure 6). This required sustained establishment over a long period of time without stand-replacing catastrophic events.

Mean tree diameters with 99 percent confidence intervals were calculated for each stand type. These intervals were non-overlapping, indicating statistical significance for the mean diameters. Other comparisons were not appropriate because the stand distributions were not normal in a statistical sense.

Trees of the young dense stands (Figures 4 and 8) became established during short, well-defined periods. Fire scars found in the older trees preceding establishment suggested that fire was a significant factor in stand origin. Further study of fire history in surrounding stands revealed six scarring fires between 1927 and 1948 (see Fire History). This partially accounted for the wide range of ages found here. Rapid growth rates from base to breast height suggested sprout rather than seedling origin.

Clustered stands made up most of the oak woodlands in RNP. Tree size varied between stands, but one size class usually dominated any clustered stand (Figures 5 and 9). These trees were clustered but not attached above the ground. Trees were "forest form", that is, they had few lower branches, indicating that they had developed as a dense canopy (Thelinius 1968).

Sustained regeneration resulted in the third structural type, all-aged stands composed of trees of all ages and size classes (Figures 6 and 10). Graphing the diameter data collected for this type resulted in a long, flat distribution. All-aged stands occurred on the woodland margins and in patches in the grasslands. These stands did not form the open oak-grass savannahs typical elsewhere in California. Instead, these had up to 95 percent canopy cover and often occurred in a mosaic with grasslands. Individuals were distinct to the base and only rarely clustered into close groups. Branching pattern was typical of open grown oaks with many stout lower branches.

Comparing the graphs of diameter distributions of small dense with clustered stands (Figure 11) revealed similar curve shapes but with size and number of trees differing greatly. The older, larger, clustered individuals simply occupied greater space in a closed canopy stand than the younger, smaller trees of the dense type. For both types, the graph peak was well-defined and trees were tightly grouped. In contrast, Figure 12 compared the sharply peaked clustered type with the flatter, all-size stand which had only a few trees in any one size class and represented a very wide variation of ages.

COMMUNITY CLASSIFICATION

Objectives

Several plant assemblages were discernable in the oak woodlands during the stand classification sampling. Further vegetation sampling and analysis were necessary to define these assemblages. Grazing had been discontinued the previous fall and grasses reached heights up to 1.5 m, in contrast to 5 to 10 cm grazed height. The objective of this part of the study was to classify and describe the oak woodland plant communities.

Methods

Field reconnaissance of the entire study area preceded sampling. Fifty-six relevé plots, averaging 750 m^2, were placed in homogeneous vegetation within uniform habitats (Mueller-Dombois and Ellenberg 1974). A list of vascular plant species was compiled for each plot. Cover was estimated for the canopy, shrub and herbaceous layers, and each species using the Braun-Blanquet (1932) cover scale. Cover classes were:

+ = < 1%	2 = 5 - 25%	4 = 50 - 75%
1 = 1 - 5%	3 = 25 - 50%	5 = 75 - 100%

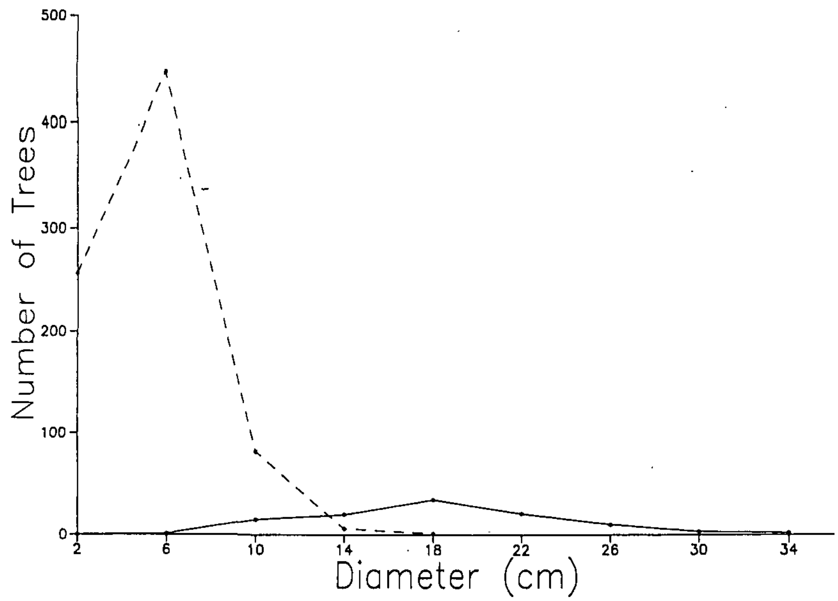


Figure 11. Stand Structure Comparison Between a Dense and a Clustered Stand. Comparisons of oak diameter distribution in typical 0.1 ha small dense (---) and clustered (____) stands both show the well-defined peak characteristic of event originated stands.

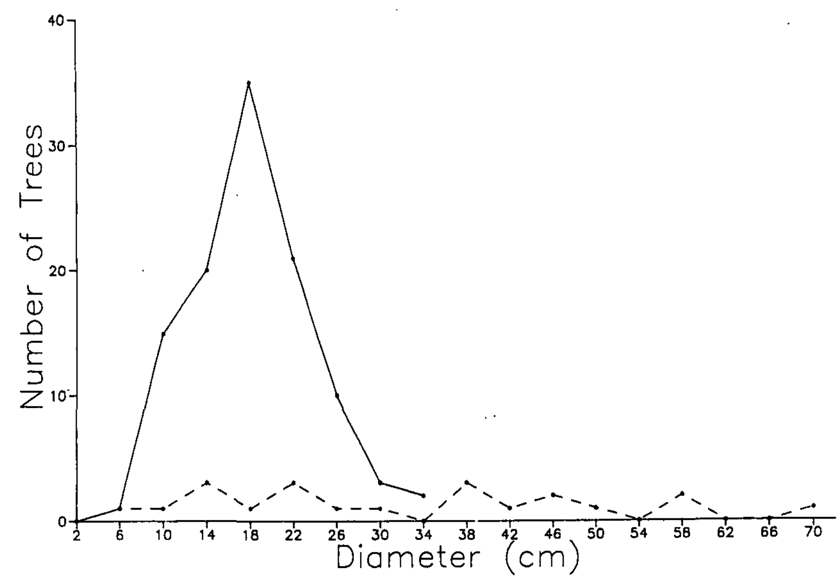


Figure 12. Stand Structure Comparison Between a Clustered and an All-Aged Stand. Comparison of oak diameter distributions in 0.1 ha clustered (____) and all-aged (---) stands shows the clustered stand having the sharp peak of event origination and the all-aged stand the flat distribution of a continuously reproducing woodland.

Stand type, slope, aspect, slope position, topographic configuration and elevation of each plot were recorded. Moisture index (Whittaker 1960) was calculated for each plot based on topographic relations of the sites. Sampling was conducted from May to July of 1983, coinciding with the flowering and fruiting periods of most species. Nomenclature followed Munz and Keck (1973). Voucher specimens are on file in the Redwood National Park herbarium in Orick, California.

Floristic characterization was based on species cover, presence and fidelity. Presence was calculated as percent occurrence in the stand groups. Fidelity indicated how restricted a species was to a given vegetation type. Determination of fidelity classes followed Westhoff and van der Maarel (1978). Character species were those which exhibited a definite preference for a certain vegetation type and were important in distinguishing between types.

One hundred thirty-five species with frequencies greater than five percent were entered into TWINSPAN, a computer analysis procedure in the Cornell Ecology Program (CEP) series (Hill 1979a). TWINSPAN was a program for two-way indicator species analysis, a polythetic divisive method for community classification. The program was run with all default options except for the definition of pseudospecies cut-levels. Four cut levels were used:

level 1 = 1 - 5% cover	level 3 = 26 - 50% cover
level 2 = 6 - 25% cover	level 4 = 50 - 100% cover

The stand classification produced by TWINSPAN was interpreted at a division level where the stand groups best represented the vegetation types observed in the field.

Classified stands and one hundred thirty-five species were ordinated by detrended correspondence analysis using the DECORANA program in the CEP series (Hill 1979b) to reveal any additional dimension of the stand-group relationship. The DECORANA procedure was run with all default values and options. Comparisons of physiographic data with distribution of community types on the ordination graph and field observations produced environmental interpretations of plant community relationships. Plant community descriptions were then developed and used to classify and map the vegetation within the study area.

Results

A total of 292 oak woodland species were collected and identified (Appendix 2). This was the highest species diversity found in any vegetation type within RNP. The trees, shrubs and ferns were mostly native species with a small number of introduced species established only in limited locations. Seventy-seven percent of the forbs and 40 percent of the grasses were native. Overall, 74 percent of the species identified were native and 26 percent were introduced (Table 3).

TABLE 3. NATIVE AND INTRODUCED STATUS OF THE FLORA - BY LIFE FORM.

Life Form	Total Species	Percent Native (Number of Species)	Percent Introduced (Number of Species)
Trees	12	92 (11)	8 (1)
Shrubs	22	91 (20)	9 (2)
Ferns	11	100 (11)	0 (0)
Forbs	200	77 (154)	23 (46)
Grasses	47	40 (19)	60 (28)
	TOTAL: 292	Average: 74 (215)	Average: 26 (77)

Seven plant communities were identified by TWINSPAN analysis. Characteristic species for each community are presented in Tables 4 and 5. Table 4 is a synoptic table of high presence species with their modal cover and presence values by vegetation type. Within each life form category, species were ordered by relationships to one another. In general, species with mesic habitats were followed by those occurring in more xeric habitats. Table 5 lists the character species for each vegetation and their degree of fidelity and presence. The distribution of classified stands, relative to each other, in floristic ordination space is shown in Figure 13. Table 6 presents environmental features of the areas supporting the seven vegetation types. The vegetation type distribution found in part of the study area on the slope below Schoolhouse Peak is shown in Figure 14.

The plant community names were a combination of two species. The first was a dominant member of the main structural element of the type (e.g. *Q. Garryana* in a type characterized by a well-developed canopy). The second was a character species with high fidelity and presence. Species referred to as important associates were those with high modal cover and presence. See Appendix 2 for a list of common and scientific names.

Quercus/Symphoricarpos (Qu/Sy): This woodland type was found midslope with extremely dense stands of small-diametered oaks. The herb layer was dominated by a mixture of perennial forbs. *Symphoricarpos rivularis* formed most of the dense, low shrub layer. Important associates in the herb layer included *Polystichum munitum, Satureja Douglasii, Fragaria vesca* and *Bromus carinatus*. *Ligusticum apiifolium, Rubus vitifolius, Cynoglossum grande, Cerastium arvense* and *Festuca occidentalis* were commonly encountered species characterizing this type.

Quercus/Dactylis (Qu/Da): The mesic woodland type was found on lower concave slopes associated with stands of clustered, medium-sized oaks. Dominated by a mixture of several perennial forbs and a few perennial grasses, important associates included *Dactylis glomerata, Satureja Douglasii, Osmorhiza chilense, Fragaria vesca, Sanicula crassicaulis* and *Vicia americana*. *Galium Nuttallii, Lonicera hispidula* and *Stachys*

TABLE 4. SYNOPTIC TABLE OF HIGH PRESENCE OAK WOODLAND SPECIES*.

The first figure is the modal cover**. The second figure is the species presence for all plots within each vegetation type.

LIFE FORM Species (Number of Plots)	Vegetation Types*** *Qu/Sy* (9)	 *Qu/Da* (12)	 *Qu/De* (12)	 *Ph/Cy* (4)	 *Ri/Ph* (4)	 *Qu/Cy* (6)	 *Ar/Sh* (9)
TREES							
Pseudotsuga Menziesii	*1-0.89*	*1-0.75*	*1-0.58*			*1-0.50*	
Acer macrophyllum				*1-1.00*			
Quercus Garryana							
seedlings	*2-1.00*	*1-0.92*	*1-1.00*	*1-1.00*	*1-1.00*	*1-1.00*	
trees	*5-1.00*	*5-1.00*	*5-1.00*	*4-1.00*	*3-1.00*	*5-1.00*	
SHRUBS							
Symphoricarpos rivularis	*2-1.00*			*1-1.00*	*1-0.75*		
Rhus diversiloba	*1-1.00*	*1-0.92*			*2-1.00*	*1-0.67*	
Holodiscus discolor				*2-1.00*	*2-0.75*		
Philadelphus Lewisii				*3-1.00*	*3-0.50*		
Ribes Roezlii	*1-0.56*				*2-1.00*		
Rosa pisocarpa				*1-1.00*	*1-0.50*		
Amelanchier pallida				*1-0.75*			
Osmaronia cerasiformis				*1-1.00*			
Rubus vitifolius	*1-0.89*			*2-0.50*	*1-0.50*	*1-0.50*	

LIFE FORM Species (Number of Plots)	Vegetation Types***						
	Qu/Sy (9)	*Qu/Da* (12)	*Qu/De* (12)	*Ph/Cy* (4)	*Ri/Ph* (4)	*Qu/Cy* (6)	*Ar/Sh* (9)
GRASSES							
Trisetum cernuum	1-0.89	1-0.58	1-0.58	1-0.50			
Dactylis glomerata	1-0.89	2-1.00	1-0.75	1-0.50	1-0.50	1-0.83	
Melica subulata	1-1.00	2-1.00	2-0.92	1-1.00		2-0.67	1-0.67
Bromus carinatus	2-1.00	1-1.00	1-0.92	1-0.50	1-0.50	1-0.50	2-0.67
Bromus sterilis			1-0.83		1-0.75	1-1.00	
Elymus glaucus	1-1.00	1-1.00	2-1.00	1-1.00	2-0.75	2-1.00	1-1.00
Avena barbata					1-1.00		
Agrostis Hallii	1-1.00	1-0.58	1-0.50	1-0.50		1-1.00	1-0.78
Cynosurus echinatus	1-0.56	1-1.00	1-0.92	1-1.00	1-1.00	3-1.00	2-1.00
Poa pratensis	1-0.56		1-0.75			2-1.00	1-0.89
Holcus lanatus	1-0.89	1-0.50	1-0.58	1-0.75		2-1.00	2-1.00
Arrhenatherum elatis		1-0.58	1-0.83	1-0.50	1-0.75	2-1.00	3-1.00
Bromus diandrus					2-1.00	1-0.67	1-0.67
Festuca viridula			1-0.67		1-0.75		2-0.89
Aira caryophyllea					1-0.50		1-0.89
Bromus mollis						1-0.50	1-1.00
FERNS							
Polystichum munitum	2-0.89		1-0.58	1-0.75	1-0.50		
Cystopteris fragilis				1-1.00			
Cheilanthes gracillima					1-1.00		
Polypodium Glycyrrhiza				1-0.75			
Pteridium aquilinum					1-1.00		3-0.56
FORBS							
Galium Nuttallii		1-0.92					
Satureja Douglasii	3-0.89	2-0.92					
Polygala californica		1-0.50					
Ligusticum apiifolium	1-1.00		1-0.50				
Fragaria californica	2-1.00	1-1.00		1-0.50		1-0.50	
Chlorogalum pomeridianum	1-0.78	1-0.83		1-0.50	1-0.75		
Cynoglossum grande	1-0.89						
Lathyrus vestitus	1-0.67	2-0.67	1-0.58	1-1.00			
Phacelia heterophylla					2-1.00		
Circaea alpina	1-0.56			1-1.00			
Montia perfoliata	1-0.78		2-1.00	1-0.75	1-1.00		
Trillium chloropetalum	1-1.00		1-0.50	1-1.00			
Silene californica				1-0.50	1-1.00		
Delphinium trolliifolium			4-0.83	2-1.00	2-0.50		1-0.56
Galium Aparine	1-1.00	1-0.92	2-1.00	1-1.00	2-1.00	1-1.00	
Osmorhiza chilensis	1-0.89	2-1.00	1-1.00	1-1.00	1-0.50	1-1.00	
Sanicula crassicaulis	1-1.00	2-1.00	1-0.92	2-1.00	1-1.00	2-1.00	
Brodiaea Ida-Maia	1-1.00	1-0.67	1-0.67	1-0.50	1-1.00	1-0.50	1-0.78
Vicia americana	1-0.89	2-0.83	1-0.92	1-0.50	1-0.50	1-0.83	1-0.67
Cerastium arvense	1-0.89						
Caucalis microcarpa		1-0.92	1-0.58	1-1.00	2-1.00	1-0.67	1-0.89
Marah oreganus	1-1.00		1-0.75	1-1.00	1-1.00	1-0.50	1-1.00
Ranunculus occidentalis		1-0.83	1-0.92	1-0.75	1-0.50	1-0.83	1-0.89
Taraxacum officinale			1-0.50	1-0.50		1-1.00	
Hypochoeris radicata			1-0.50		1-1.00	1-1.00	1-0.67
Cirsium vulgare		1-0.50				1-0.83	1-1.00
Plantago lanceolata		1-0.75		1-0.50		1-1.00	1-1.00
Rumex Acetosella			1-0.75		1-1.00	3-1.00	2-1.00
Sherardia arvensis							1-0.89

* Species with presence >0.50 in any vegetation type are included.

** Braun-Blanquet (1932)

*** *Qu/Sy* = *Quercus/Symphoricarpos*
Qu/Da = *Quercus/Dactylis*
Qu/De = *Quercus/Delphinium*
Ph/Cy = *Philadelphus/Cystopteris*
Ri/Ph = *Ribes/Phacelia*
Qu/Cy = *Quercus/Cynosurus*
Ar/Sh = *Arrhenatherum/Sherardia*

TABLE 5. FIDELITY AND PRESENCE TABLE FOR OAK WOODLAND VEGETATION TYPES.

The first figure is the degree of fidelity*. The second figure is the species presence for all plots within each vegetation type.

Species	Vegetation Types**						
	Qu/Sy	*Qu/Da*	*Qu/De*	*Ph/Cy*	*Ri/Ph*	*Qu/Cy*	*Ar/Sh*
Geranium oreganum	5-0.56						
Tauschia Kelloggii	5-0.44						
Angelica tomentosa	5-0.44						
Festuca occidentalis	4-0.78						
Aster radulinus	4-0.44						
Heracleum lanatum	4-0.33						
Aquilegia formosa	4-0.56						
Rubus vitifolius	4-0.89						
Ligusticum apiifolium	4-1.00						
Cynoglossum grande	4-0.89						
Cerastium arvense	4-0.89						
Satureja Douglasii	3-0.89						
Lonicera hispidula		5-0.75					
Galium Nuttallii		5-0.92					
Polygala californica		5-0.50					
Iris Douglasiana		4-0.50					
Stachys rigida		4-0.75					
Dentaria californica			5-0.58				
Lithophragma affine			4-0.42				
Delphinium trolliifolium			3-0.83				
Acer macrophyllum				4-1.00			
Rosa pisocarpa				4-1.00			
Amelanchier pallida				4-0.75			
Osmaronia cerasiformis				4-1.00			
Tellima grandiflora				4-1.00			
Dodecatheon Hendersonii				4-0.75			
Brodiaea Bridgesii				4-0.50			
Cystopteris fragilis				4-1.00			
Polypodium Glycyrrhiza				4-0.75			
Rumex crispus				4-0.75			
Ribes Roezlii					5-1.00		
Avena barbata					5-1.00		
Cheilanthes gracillima					5-1.00		
Phacelia heterophylla					4-1.00		
Silene californica					4-1.00		
Melica Hartfordii					4-0.50		
Apocynum androsaemifolium					4-0.50		
Danthonia californica						4-0.50	
Lolium perenne						4-0.67	
Carex fracta						4-0.33	
Taraxacum officinale						4-1.00	
Brodiaea pulchella						4-0.50	
Sherardia arvensis							5-0.89
Trifolium subterraneum							5-0.56
Aira caryophyllea							4-0.89
Bromus mollis							4-1.00
Lotus micranthus							4-0.78
Viola praemorsa							4-0.78
Trifolium dubium							4-0.33
Trifolium microdon							4-0.56
Epilobium minutum							4-0.67
Pteridium aquilinum							3-0.56

* From Westhoff and van der Maarel (1978):
5 = exclusive taxa
4 = selective taxa
3 = preferential taxa

** *Qu/Sy* = *Quercus/Symphoricarpos*
Qu/Da = *Quercus/Dactylis*
Qu/De = *Quercus/Delphinium*
Ph/Cy = *Philadelphus/Cystopteris*
Ri/Ph = *Ribes/Phacelia*
Qu/Cy = *Quercus/Cynosurus*
Ar/Sh = *Arrhenatherum/Sherardia*

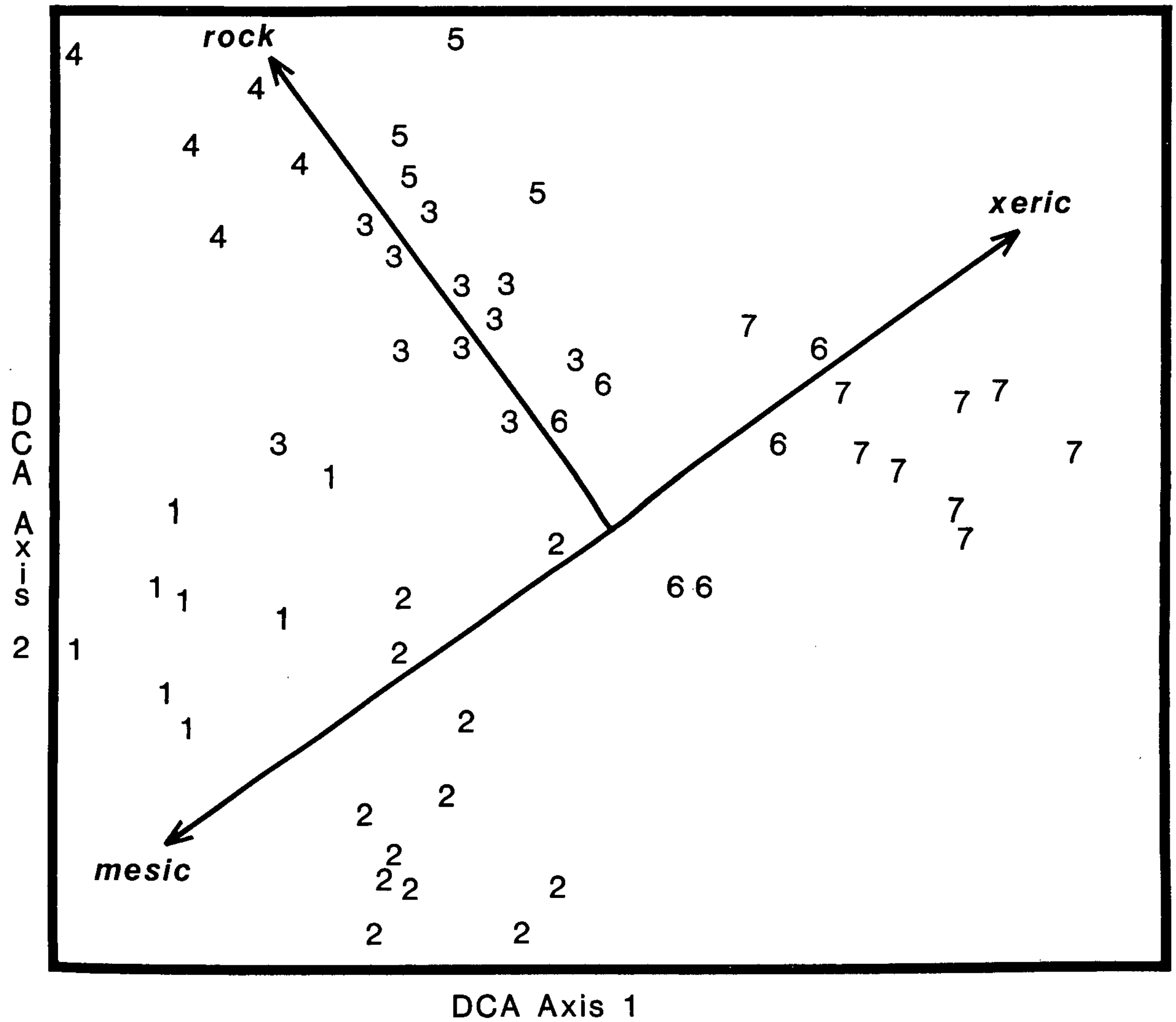


Figure 13. Ordination. The relationships between vegetation types and plots to each other are shown in two-dimensional space. DCA Axis 1 represents the mesic/xeric distribution and DCA Axis 2 represents soil development with the upper left being rock outcrops and boulder strewn stream channels and the lower right well-developed soils.

1 = *Quercus/Symphoricarpos* - small dense woodlands
2 = *Quercus/Dactylis* - mesic woodlands
3 = *Quercus/Delphinium* - seasonally moist woodlands
4 = *Ribes/Phacelia* - rock outcrops
5 = *Philadelphus/Cystopteris* - stream channels
6 = *Quercus/Cynosurus* - xeric woodlands
7 = *Arrhenatherum/Sherardia* - open glades

TABLE 6. GENERAL CHARACTERISTICS OF OAK WOODLAND VEGETATION TYPES.

	Vegetation Types *						
	Qu/Sy	*Qu/Da*	*Qu/De*	*Ph/Cy*	*Ri/Ph*	*Qu/Cy*	*Ar/Sh*
Mean Plot Elevation (m)	710	250	785	755	785	715	750
Mean Slope (%)	30	35	35	35	30	25	35
Typical Exposure	WNW	SW	W	W	WSW	S	NW
Whittaker Moisture Index	7	5	8	1	8	8	7
Typical Slope Position	mid	lower	upper	upper	upper	upper	mid
Topographic Configuration	even	concave	concave	concave	convex	convex	concave/ convex
Stand Type	dense	medium	medium	**	**	widely spaced	absent
Oak Density (stems/ha)	4,500-12,000	740-2,500	740-2,500	**	**	60-530	0
Mean Canopy Cover (%)	83	87	82	53	49	87	0
Mean Shrub Cover (%)	30	1	1	85	55	1	0
Mean Herbaceous Cover (%)	84	69	84	50	35	91	96

* *Qu/Sy* = *Quercus/Symphoricarpos*
Qu/Da = *Quercus/Dactylis*
Qu/De = *Quercus/Delphinium*
Ph/Cy = *Philadelphus/Cystopteris*
Ri/Ph = *Ribes/Phacelia*
Qu/Cy = *Quercus/Cynosurus*
Ar/Sh = *Arrhenatherum/Sherardia*

** not restricted to any one stand type or density

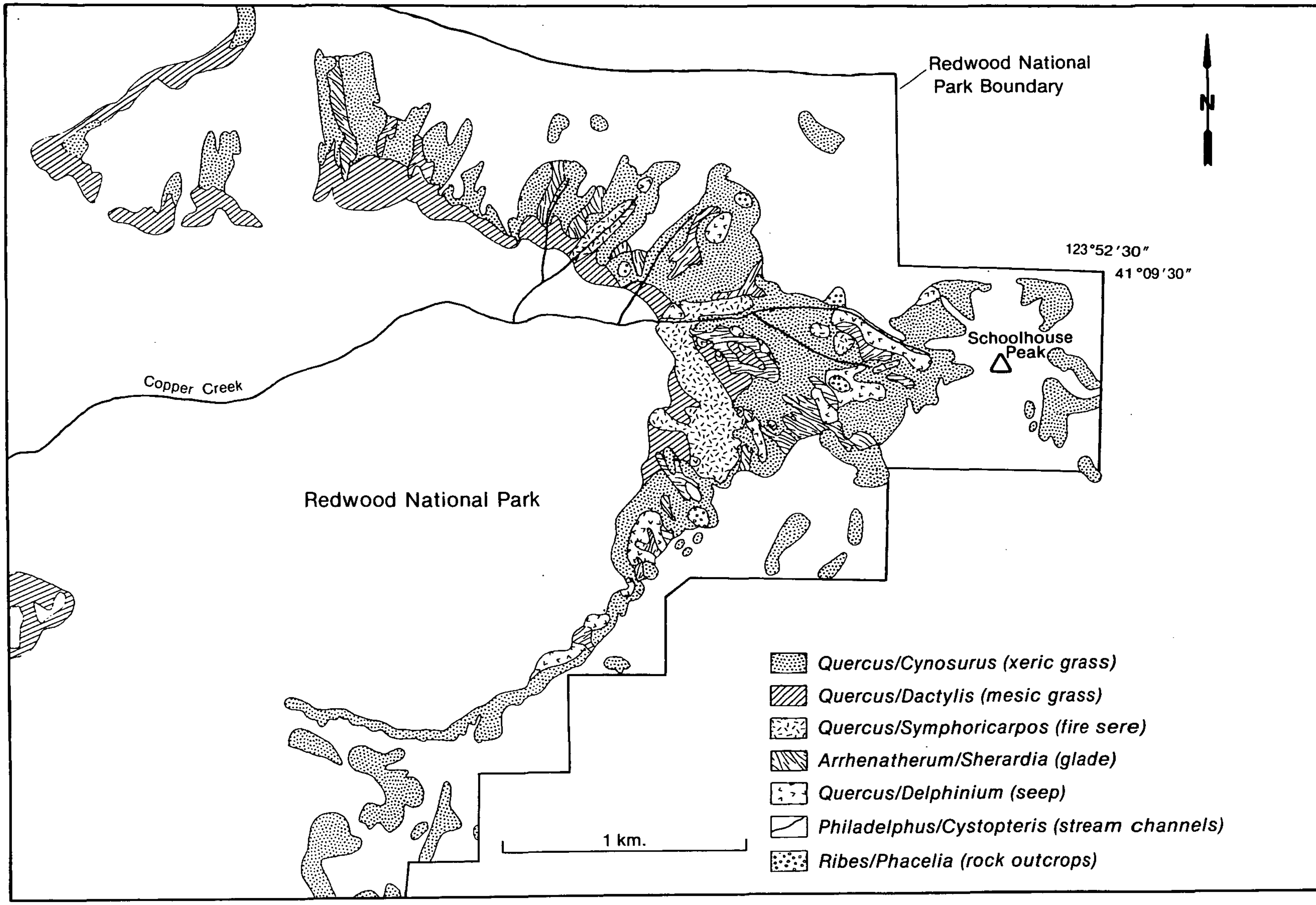


Figure 14. Vegetation Type Distribution Below Schoolhouse Peak.

rigida were common character species.

***Quercus/Cynosurus* (Qu/Cy)**: The main xeric woodland type was dominated by perennial and annual grasses with forb cover relatively low. Occupying the upper, convex, south-facing slopes with all-sized stands, this type represented the most xeric woodland in the park. It was also associated with heavily grazed areas. Important associates included *Cynosurus echinatus, Holcus lanatus, Elymus glaucus, Poa pratensis, Arrhenatherum elatius* and *Sanicula crassicaulis*. *Taraxacum officinale* was the most common character species.

***Quercus/Delphinium* (Qu/De)**: This woodland type was dominated by a mixture of perennial forbs with grass cover minimal. Found on upper, concave slopes in medium-diametered oak stands, this type was restricted to draws and moist spots on otherwise xeric slopes. *Delphinium trolliifolium* was the dominant species. Important associates included *Montia perfoliata, Galium Aparine, Melica subulata* and *Elymus glaucus*. *Dentaria californica* and *Lithophragma affine* were character species.

***Arrhenatherum/Sherardia* (Ar/Sh)**: Glades dominated by perennial and annual grasses were found as narrow openings running up the slope within the oak stands. These glades and the surrounding oaks formed the distinctive oak/grass mosaic of the bald hills oak woodlands. This community did not include the adjacent prairies, but was restricted to isolated openings among the woodlands. Important associates included *Arrhenatherum elatius, Holcus lanatus, Festuca viridula, Cynosurus echinatus* and *Rumex Acetosella*. *Sherardia arvense, Lotus micranthus, Viola praemorsa, Aira caryophyllea* and *Bromus mollis* were common character species.

***Philadelphus/Cystopteris* (Ph/Cy)**: The stream channel community was composed of a dense shrub layer and a sparse herb layer of perennial forbs. *Philadelphus Lewisii* and *Holodiscus discolor* dominated the shrub layer. *Sanicula crassicaulis* and *Delphinium trolliifolium* were important associates in the herb layer. Species characteristic of the type included the shrubs *Rosa pisocarpa, Amelanchier pallida*, and *Osmaronia cerasiformis*. *Cystopteris fragilis, Polypodium Glycyrrhiza* and *Tellima grandiflora* were characteristic of the herb layer.

***Ribes/Phacelia* (Ri/Ph)**: The rock outcrop type was composed of a moderately dense shrub layer and a scattered herb layer of perennial and annual forbs and grasses. *Ribes Roezlii* and *Rhus diversiloba* dominated the shrub layer. Important associates in the herb layer included *Galium Aparine, Caucaulis microcarpa*, and *Bromus diandrus*. *Phacelia heterophylla, Silene californica, Cheilanthes gracillima* and *Avena barbata* were the common character species.

Interpretation

As previously reported in Sugihara et al. (1987), three major woodland types accounted for most of the vegetative cover in the study area. The other four minor types were restricted to specialized habitats. Distribution of the three major types was related to topography and slope position. The *Quercus/Dactylis* and *Quercus/Symphoricarpos* communities were found on lower slopes and middle to upper north-facing slopes. Aspect, sheltered topography and frequent summer fog made these relatively mesic sites. The *Quercus/Dactylis* type was predominant on the lower slopes under clustered oak stands. On upper north-facing slopes, *Quercus/Symphoricarpos* occurred under very dense stands of small-diametered oaks. These stands originated following a series of fires in the 1920's, 30's and 40's (see Fire History). The two mesic woodland types were closely related floristically. The *Quercus/Symphoricarpos* type was possibly a fire sere of *Quercus/Dactylis*. The third major woodland type, *Quercus/Cynosurus*, was found under all-aged stands on upper, convex, south-facing slopes and along the ridgeline where moisture conditions are the most xeric. These areas were also heavily grazed.

The remaining four vegetation types were confined to specialized habitats. Openings among the oak stands, or glades, supported the *Arrhenatherum/Sherardia* type and included many species characteristic of grassland just outside the study area (Hektner et al. 1983), but were floristically distinct. Lack of canopy cover resulted in dominance by xeric woodland species in a mesic physiognomic position. Glades were floristically related to the xeric *Quercus/Cynosurus* woodland, but were not limited to xeric topographic positions.

The *Quercus/Delphinium* type was found on concave slopes within *Quercus/Cynosurus* woodlands. The *Philadelphus/Cystopteris* community occupied deeply-incised, boulder-strewn stream channels on upper slopes. Dry, exposed rock outcrops were occupied by the *Ribes/Phacelia* type. All of these communities were restricted to upper slopes. Redwood/Douglas-fir or mixed evergreen forest occupied similar sites on lower slopes.

Indirect ordination resulted in a clustering of plots in two-dimensional space, corresponding to the seven vegetation types (Figure 13). The left end of DCA Axis 1 represented denser stands, in more mesic locations, with possibly less historic grazing disturbance and a lower occurrence of introduced species. *Arrhenatherum/Sherardia* was found to the far right. These glades, along with the *Quercus/Cynosurus* woodlands sustained the greatest grazing impact of any place in the study area. The lower half of DCA Axis 2 represented well-developed soils. Rock outcrops and rocky stream channels appeared at the top of the ordination. The *Quercus/Delphinium* type occurred on rocky soils and are intermediate between rock outcrops and well-developed soils on the ordination graph.

Floristically, RNP's Oregon white oak woodlands were similar to those of the Willamette Valley of interior Oregon, although community types differed greatly in both structure and composition (Thilenius 1968). Shrubs dominated in all Willamette Valley plant communities but in the park only the *Quercus/Symphoricarpos* type, stream channels and rock outcrops supported well-developed shrub layers. The Willamette Valley savannahs developed widely separated individual oaks in contrast with the dense, closed canopy at all stages of succession in the bald hills. Succession was to oak forest and then to Douglas-fir forest in Oregon, whereas in the bald hills, succession was to mixed evergreen forest in the xeric interior areas and to *Sequoia/Pseudotsuga* at low elevation and coastal mesic sites (Griffin 1977).

PERMANENT PLOTS

Four 0.1 ha permanent plots were established in 1985 to monitor long-term changes in vegetation composition and structure over time. Plots were subjectively located in the *Quercus/Delphinium*, *Quercus/Symphoricarpos*, *Quercus/Cynosurus* and *Quercus/Dactylis* types. Fences were constructed around each plot to keep out trespass cattle. All of the trees in each plot were tagged, measured and mapped. Reproduction and herbaceous vegetation were sampled in 24 one m^2 subplots. Comparable sampling plots were set up within burned areas to determine the effects of the treatment on vegetation. Data and interpretations of burn sampling and permanent plots will be reported elsewhere when analyses are completed.

PART 2: VEGETATION DYNAMICS

John Carr (1891), an early miner travelling to the mines over the Trinidad Trail, noted that "one day, on coming out on a prairie, we beheld a great sight. The prairie seemes[sic] a large one; scattered all over it were big oak trees, giving it the appearance of an old orchard in the Eastern States, and, grazing quietly, were hundreds of elk, that seemed to take no more notice of us than so many tame cattle grazing in their pastures at home." For many reasons, this scene is no longer commonly encountered along the bald hills.

Since 1850, the processes shaping the vegetation systems in the Bald Hills have been modified. Frequent Native American burning was replaced by fire suppression in post-settlement times. Native wildlife use was replaced by livestock grazing between 1865 and 1982. Roads were built across prairies and into woodlands and forest exposing bare soil and accelerating erosion. Adjacent forests were logged, burned and restocked. Douglas-fir became more widespread in oak/prairie communities, and non-native plant species became more abundant (USDI 1987). Changes in land use often alter both species composition and the environmental factors which originally maintained the ecosystem. The oak woodlands have not returned to equilibrium because changing environmental factors continue to influence stand and vegetation dynamics. This section provides general information on *Q. Garryana*, describes several changes that have been observed, indicates the mechanisms producing them and discusses how the changes relate to management.

OAK REGENERATION

Problems in oak regeneration exist throughout California's oak woodlands. The classic scene of picturesque, open stands containing only large widely spaced trees does not represent a self-perpetuating stand. Sustained, low level regeneration, as evidenced by a continuum of tree ages, is indicative of successful reproduction. Only a few saplings are needed to replace mortality and perpetuate the stand. Many oak species are shade intolerant, so heavy regeneration under a dense canopy is not expected. For these species, which include Oregon white oak, regeneration would be concentrated on stand edges, gaps left when older trees die or in other natural openings within stands. Few seedlings or saplings were encountered in the stand and community classification sampling. Further study into the reasons for this situation were necessary.

Oregon white oak reproduces both sexually, by acorn, and asexually, by sprout, but few studies document either. Differentiating reproduction of acorn origin from that of sprout origin is difficult. Differences in growth rates between the two methods are often quite distinctive, with sprouts usually growing much faster (Scheffer 1959). Most stands in the park are even-aged and display this evidence of sprout origin. The trees they sprouted from appear to have been single-stemmed, so these may have originally grown from acorns. Sexual reproduction does not appear to have played an important role in oak regeneration in post-settlement times, but reasons are unknown. Effective regeneration is dependent on many factors and the success of seedlings, regardless of origin, could be affected by management practices. Determining the factors stimulating oak reproduction may allow development of a better model for oak woodland stand structure.

Acorn Production and Seedling Development

Oregon white oak belongs to the white oak subgenus, *Lepidobalanus* (Tucker 1980). Acorns from this group mature in only one season. Two other oaks occurred infrequently in the bald hills stands, but neither was in this subgenus. Canyon live oak (*Q. chrysolepis*) is in the intermediate oak subgenus, *Protobalanus*, and California black oak (*Q. kelloggii*) is in the *Erythrobalanus*, the black oak subgenus. Acorn maturation in these two latter groups is biennial. Since natural crosses are only between species in the same subgenus, Oregon white oak in the park are probably genetically pure.

Oregon white oak acorns fall in September and October and are usually dispersed within a short distance from the parent tree (USDA 1965). Heavy seed crops are usually produced every two or three years, generally with very high germination rates (USDA 1974). Germination is in the late fall or early spring. Seedling growth is slow and mortality is often high. Sapling growth is also slow (Silen 1958). Shoot dieback whether due to animal damage or environmental conditions occurs frequently, resulting in plants with shoots much younger than roots (Liming and Johnson 1944, Merz and Boyce 1956).

Coblentz (1980) reports considerable variation in acorn production over three years in the same Oregon white oak stands but did not investigate causes. He suggests that drought stress may have affected crop size. The reasons for inconsistent crops have not been extensively studied for any of the western oaks, but several studies on eastern white oaks show trends that may apply to the white oak subgenus in general. Goodrum et al. (1971) find acorn crop abundance for a number of eastern oaks can not be accurately predicted from previous crops. They suggest that the ability of an individual tree to produce few or many acorns is an innate characteristic. Burns et al. (1954) postulate that variation in seed production due to hereditary differences almost completely obscures variation due to tree size and growth rate.

Sharp and Chisman (1961) recognize that while flowering in the white oak subgenus may be innate, acorn set and development is induced. They document that dry, desiccating winds during male flowering and pollen dispersal, and killing freezes and extremely low air temperatures during blooming and fruit setting can influence crop size. In white oak studies in Pennsylvania, Sharp and Sprague (1967) find poor acorn crops occurring when mean daily air temperatures increased continuously from April through May. Good acorn crops are produced when temperatures increase rapidly during mid-April and decrease early in May. They speculate this combination of temperatures allows female floral development to catch up with male so that female maturation coincides with maximum pollen dispersal.

Male catkins mature first in the topmost branches followed by a rapid downward progression of emergence. Trees which have shed pollen can be identified by observing the 50 percent increased leafy growth by the day after pollen dispersal (Sharp and Sprague 1967). Actual pollen shedding takes only three to four days, so favorable weather is critical (Watt 1979). Prolonged heavy rain can abort male flowers without pollen dispersal, but relative humidity and cumulative monthly rainfall seem unimportant (Sharp and Chisman 1961).

Branch exposure also affects seed crops. Verme (1953) finds greatest acorn production in the portion of the crown directly exposed to sunlight. Acorn production in white oaks from exposed crown areas is five times greater than production on lower unexposed crown areas. Shade curtails acorn production on lower branches of oaks with high fruiting potential (Sharp and Sprague 1967). Open grown trees show considerable variation, but those producing acorns have larger crops per unit area of crown than any of the smaller crowned trees growing in closed stands of similar age (Gysel 1956). Coblentz (1980) finds 40 percent greater acorn production in savannah form Oregon white oaks in the Willamette Valley than in closed stands. This suggested that closed canopy clustered stands in the park may be less productive than more open stands, due to heavy shading. Current acorn production may be less than historic levels due to stand structure changes.

Even in years when acorns are abundant, the entire crop may be consumed (Silen 1958). Studies document high wildlife and domestic livestock acorn consumption (Dayton 1931, Barrett 1980, Hedrick and Keniston 1966). Predation on young seedlings is also high. Studying valley oak (*Q. lobata*) regeneration in the Santa Lucia Mountains, Griffin (1976) finds when deer and cattle are excluded, birds, gophers and other rodents still eliminate most seedlings. After noting numerous seedlings pulled down into gopher holes and almost no survival among test seedlings, Griffin questions how oaks ever successfully regenerate with so many seedling problems. Conditions in the Oregon white oaks appear to be similar. Coblentz (1980) finds small mammals consume 61 percent of the acorns in savannah exclosures and 96 percent from exclosures in the closed canopy forest.

Heavy cover of introduced annual forbs and grasses in valley oak woodlands increases seedling mortality (Holland 1976). Holland concludes that small mammal predator reduction efforts coupled with increased cover of seed bearing annual plants results in larger seed eating rodent and bird populations and increased pressure on the acorn crop.

Cook (1959) documents an immediate reduction in rodent numbers following fire in oak woodlands in Oregon. Binder and Vrieze (1981) find temporary decreases in small mammal populations in Redwood National Park after prescribed fire in a coastal prairie. Reduction in small mammal populations after periodic fires or by predation could increase survival in acorn and sprout reproduction. Heavy gopher activity was evident after a prescribed oak woodland fire consumed litter. No estimates of population size or species involved were made either before or after the fire. Visual evidence suggested that small mammals may play an important role in acorn and seedling predation in the park.

Acorn Germination

Introduction. Plumb (1980) reports acorns to be quite sensitive to heat and even sunlight can quickly damage exposed acorns lying on the ground. Because of this heat sensitivity, prescribed burning in the oak woodlands may affect acorn germination and seedling survival. Since the park was planning experimental burns in oak stands, a study of potential fire effects on acorn germination was conducted in 1982. Differences in mean germination rates were suspected between ground-collected acorns in areas that experience low intensity surface fire and those from unburned areas. Acorns collected from burned areas were scorched or charred but not consumed. Acorns still in trees were also collected and assessed for heat damage.

Methods. Approximately 700 Oregon white oak acorns were collected on October 20, 1982 within or near prescribed fire control lines ("black lines") installed two days earlier in the Copper Creek drainage. The acorns were gathered from the 15 foot wide black lines because rainy weather prevented completion of the burn that year. Acorns were also collected from trees with branches extending over burned areas and from ones distant from the burn. Obviously damaged or insect ridden acorns were eliminated from the sample and all acorn caps were removed. The pericarp (outer covering) was removed from some samples to test whether this procedure would affect germination. Acorns were placed on moist paper towels in trays and covered loosely with additional paper towels. Acorns were checked frequently for six weeks. Germination for *Q. Garryana* normally takes 3-5 weeks with no dormancy period required (USDA 1974). Germinated acorns were recorded and removed from the trays.

Results and Interpretation. All acorns collected from the oak canopy germinated, regardless of treatment (Table 7). The low intensity surface fire used to install the black lines did not appear to negatively affect acorns in the canopy. This condition might change when a full-scale prescribed burn is conducted. Acorn collection heights, flame lengths and heat production were not measured. Branches growing nearer to the ground, as found in ungrazed areas, may show greater effects.

Mean germination for unburned acorns was consistently high, 98.5

TABLE 7. GERMINATION TEST OF THE 1982 ACORN CROP.

	Total Number	Germinated*	Germination Rate
UNBURNED ACORNS			
Collected From Ground			
Pericarp Removed	119	118	99.2%
Pericarp Intact	92	88	95.6%
Collected From Trees	114	114	100.0%
SUBTOTAL	325	320	98.5%
BURNED ACORNS**			
Collected From Ground			
Pericarp Removed	61	32	52.6%
Pericarp Intact	116	45	38.8%
Collected From Trees	92	92	100.0%
SUBTOTAL	269	169	62.8%

* Germination was tested from 11/1/82 to 12/11/82.

** Collected from prescribed fire "black lines".

percent. Griffin (1987) indicates many physically or insect-damaged acorns do germinate, so had these been included in the study, a fairly high germination rate for unburned acorns might still have resulted. He points out, however, that some of the damaged acorns produce inferior seedlings that do not survive. Little gain was realized from pericarp removal for unburned acorns.

There was a significant reduction in viability of ground-collected acorns that had been scorched or charred. Pericarp removal slightly increased germination for burned acorns. Oregon white oak acorns may be less sensitive to heat than those Plumb tested since 44 percent of the burned acorns in this study germinated. The temperature and duration of heat exposure may be components influencing heat damage in acorns. A confounding factor may have influenced this portion of the study, however. Mold grew on all of the nongerminating burned acorns that had the pericarp removed. The effects mold had on germination and whether fire and/or the rain before collection had an influence on mold formation could not be determined. The unburned ground-collected acorns did not mold. Mold is also reported in samples of ground-collected black oak acorns (McDonald 1968).

The 1983 acorn crop was light and many trees did not produce acorns.

The 1984 acorn crop was very light with almost no acorns observed on any trees. The 1985 crop was moderate and the 1986 crop light. A visual estimate scale for assessing acorn crops described by Graves (1980) lists four acorn crop conditions:

- Class #1 - trees have no visible acorns
- Class #2 - trees have acorns visible only on close examination
- Class #3 - acorn crops are readily visible but don't cover the entire tree
- Class #4 - acorn crops are also readily visible but cover the entire tree to the point where limbs appear to sag from the weight of the acorns

The four classes are subjective, but correlate closely with actual acorn collection data (Graves 1980). Using the visual estimate scale and basing crop estimates on notes and memory of conditions, average seed crops in the area below Schoolhouse Peak since 1982 were categorized as:

1982 - class #3-#4	1984 - class #1	1986 - class #2
1983 - class #2	1985 - class #2-#3	

The visual method usually assigns a crop rating based on estimates of several hundred trees. Due to the wide disparity in local Oregon white oak acorn crops, these estimates are probably reasonable and could allow general comparisons to be made within and between species in other areas for the specified years.

No acorns were collected for germination studies in 1983 or 1984 due to low production. About 150 acorns were collected on October 18, 1985 in the same general area as those collected in 1982. All acorns were ground-collected the day after a low intensity surface prescribed fire, again from burned and unburned areas. Germination tests were not conducted. Many acorns germinated under office conditions, so viability was suspected to be high. Mean acorn length and girth measurements were 2.4 cm and 1.5 cm, respectively. Although no length, girth or weight measurements were recorded for the 1982 crop, there appeared to be significant differences in these parameters, as well as abundance, when compared with subsequent years. The 1982 acorns seemed larger and may have weighed more than the 1985 crop. Powers (1968) reported a mean weight of 6.03 g for Oregon white oak acorns based on samples collected in one year.

The low reproduction rate of *Q. Garryana* was clearly not caused by low germination potential since almost all unburned acorns germinated. Considerable annual variation in acorn crops was found, but adequate numbers of acorns were produced frequently enough to allow the potential for regeneration by acorns. Ground-collected acorns had a slightly lower viability in this study than canopy-collected acorns, possibly due to fungal or insect attack while on the ground. Burning caused the greatest decrease in germination and may also have increased susceptibility to fungal attack. Even with burning, a large number of oak seedlings should have been found. Predation on acorns and young seedlings or high natural mortality due to environmental factors were probably the primary causes of the low observed regeneration rates in the oaks. Further investigations of acorn production and influences of small mammals (or other predators) would be useful.

Vegetative Sprouting

Another form of reproduction in Oregon white oak is vegetative sprouting. Griffin (1980) states that sprouting in deciduous white oaks is less vigorous than in other California oaks. Jepson (1910) reports weak stump sprouting in large old Oregon white oak trees, but finds sprouts more common in younger trees. In contrast, Roy (1955) documents that larger stumps produce greater numbers of larger, faster growing sprouts. Silen (1958) finds such widespread oak sprouting in Oregon that sprouts are considered a potential regeneration method after logging.

Plumb (1980) determines bark thickness as the single most important factor in fire sensitivity for five other California oaks. Where oaks are sensitive and top-killed, resprouting is common. A higher percentage of valley oaks (*Q. lobata*) sprout after high intensity crown and surface fire than after lower intensity fire (Griffin 1980). Valley oaks with dead crowns appear to sprout sooner, have longer sprouts and produce more sprouts per trunk than trees with live crowns. After prescribed fires in the park, vigorous sprouting was common among Oregon white oaks with living crowns. Variation in sprouting due to fire intensity has not been studied in the apparently more fire tolerant Oregon white oak. The relationships between bark thickness, fire intensity and sprouting have not been determined for Oregon white oak.

Sprouts originate from the base of trees and along the main trunk after burning. Excavations in the park have shown that the oaks often form stout rhizomes or runners which extend several meters through the humus before emerging. Jepson (1910) describes this type of sprouting in California black oak cut at the base, but not for Oregon white oak. Sudworth (1908) mentions a network of creeping roots (rhizomes) from which suckerlike stems originate for Brewer oak (*Q. Garryana* var. *breweri*). He says this shrubby variety of Oregon white oak reproduces extensively by root sprouting. No similar reference was made for the taller tree form. Muller (1951) mentions Brewer oak root sprouting and also discussed rhizomes which criss-cross with several others so that proximity of shoots is not always indicative of parentage. An examination of sprouting in the park showed that this rhizomatous reproduction in the tree form resulted in two different patterns. Clusters of up to 5 m in diameter were produced or scattered individuals resulted. The individual trees which appeared quite distinct from each other and the parent tree were actually sprouts. This previously unreported phenomenon for the tree form of Oregon white oak has had a profound effect on the development and structure of the park's oak stands.

Reduced fire frequency in the park has contributed to a lack of consistent stimulus for vegetative sprouting. Conversely, Oregon white oak woodlands in Oregon are interpreted as being overly dense due to the lack of fire to thin them (Thilenius 1968). Although the lack of fire seemed to have had an opposite effect on these two stands, that was not the case. Sprouting stimulated by one fire was controlled by subsequent fires. Seedling and some canopy tree mortality also occurred. The immediate effect on stand structure was a small reduction in the number of canopy trees and a large flush of basal sprouting. When the fire frequency was high enough to control sprouting on a continual basis, the stand produced new canopy trees by the occasional survival of individuals. This was probably the case under the pre-settlement fire regime, although the original trees may have grown from acorns. However, when fires occurred sporadically, as was the case in the last century, flushes of sprouts had considerable impact on stand structure. Developing sprouts not controlled by later fires led to increased stand density after each fire/sprouting event. This sequence probably produced at least some of the stand structures now present in the park.

The extremely dense oak stands and uniform clustered stands, which account for most of the oak woodland acreage within the park, were composed of trees which appeared to have fairly uniform size and age. This was, in fact, the case in the stands that were cut and aged (Table 2). The growth rate was rapid in the young trees, averaging 28 cm per year. It took an average of only 5.3 years to reach breast height, much more rapid than for seedlings grown from acorns. This suggested that the stands were event originated, resulting from some factor, or combination of factors, that allowed massive one time sprout production. The factor may have been land management or an event such as a high intensity fire.

The young, dense stands near Schoolhouse Peak originated following a fire which left fire scar records in surviving trees. It was not possible to determine whether the parent trees were of seed or sprout origin, but the present trees grew from sprouts. Trees resulting from stump sprouting are often clustered. This condition was not found in dense stands where the trees were regularly distributed but was evident in most larger sized stands. Lack of clustering in dense stands may be explained by the sprout runners found extending meters from the tree base before emerging from the ground.

All stands except the all-aged were composed of uniform size and age classes. This would not be the case had reproduction been by seed unless there had been no previous stands in the area (which there were) or the canopy trees had been killed. If the canopy trees had been killed, massive sprouting would have followed and the sprouts outgrowing the seedlings to dominate the stand. For these reasons, vegetative sprouting was probably the most widespread method of oak regeneration in the woodlands of the park.

CONIFER FOREST ENCROACHMENT

Problem

Prairies and oak woodlands in the park are less extensive than in previous times. Even casual observation of the Bald Hills prairies and oak woodlands revealed Douglas-fir in varying densities throughout these areas. Prairie margins, roadcuts and landslides were actively being colonized by Douglas-fir. Dense stands of young Douglas-fir bordered many of the prairies and oak woodlands. Scattered, large Douglas-fir and the dense young fir stands were readily seen within the oak woodlands. Floristic and structural evidence of prior occupation by oak or grass dominated communities was obscured by long-term dominance of a site by conifers. The oaks decomposed, leaving little visual evidence of the rich species diversity in oak understory.

Many factors influenced the gradual movement of Douglas-fir onto formerly non-conifer sites. If Douglas-fir has long encroached in this manner, then it may have colonized other areas which had supported bald hills vegetation. Understanding the process of conifer invasion will allow the Park Service to propose adequate and appropriate management for the encroached areas and bring the problem to the attention of others.

Objectives

A multifaceted investigation was set up to determine the general pre-settlement and current vegetation patterns of prairie/oak woodland and conifer forest. This study was designed to answer the following questions:

1) Are conifers encroaching into the oak woodlands and prairies as suspected? If so, is the encroachment natural or the result of past management?

2) Is Douglas-fir encroachment accelerating in the oak woodlands? If it is, what is the pattern and how and why has it changed?

3) Has the ecosystem reached a new balance or are boundaries expected to continue changing? What factors once maintained stable boundaries and what happened to upset these conditions?

4) Can the forest/bald hills ecotone be restored to a pre-settlement state? If not, how much can be restored and to what condition? How can the ecosystem be maintained?

Methods

The rate and extent of encroachment was determined by mapping and aging Douglas-fir and redwood stumps surrounding the existing prairies and oak woodlands. The approximate cutting dates for logged areas in the park, available from timber company records, were transferred to park maps. Annual growth rings were counted on Douglas-fir stumps at the edge of the prairie or oak woodland. Counting continued into the conifer forest until ages corresponding to the date of settlement, 1850, or stumps of mature redwood trees were encountered. The age and species of stumps were mapped on mylar overlays on 1:6000 scale color aerial photographs. The 1850 conifer boundary was drawn after considering the species, distributional patterns and ages of the stumps.

In areas where no logging had occurred, the 1850 boundary was determined by species composition and the size, age and branching pattern of individual Douglas-fir trees. Trees with open grown branching patterns surrounded by younger, dense, forest form trees indicated active encroachment of non-conifer areas. Distributional patterns were correlated with historical and environmental characteristics of the areas. Location of Native American villages and early descriptions of the area helped refine boundaries (Goddard 1914).

The amount of area currently occupied by oak woodlands and prairies and those sites determined to have been either oak woodland or prairie in 1850 were estimated using a polar planimeter to measure field mapped units drawn on overlays of 1:6000 scale aerial photographs. The difference between the 1850 and present (1983) boundaries was also calculated. This figure represented the area of oak/prairie vegetation that had converted to established conifer forest after 1850.

The density of Douglas-fir in the present oak stands was also estimated and mapped. This was done to correlate the current rate and pattern of conifer encroachment with the distributional patterns of the floristic and stand types. The following scale was used to assess the conifer encroachment:

0 - no apparent Douglas-fir
1 - few to 5% total coverage by area by Douglas-fir
2 - 5 to 25% coverage by Douglas-fir
3 - > 25% coverage by Douglas-fir
4 - Douglas-fir codominant in canopy.

Results

Approximately one-third of the Bald Hills vegetation within Redwood National Park converted to coniferous forest between 1850 and 1983 (Figure 15). Table 8 shows the changes in area of Bald Hills prairies and oak woodlands during post-settlement times. Detailed maps of individual units are given in Appendix 3. Half of the remaining oak

TABLE 8. AREA OF BALD HILLS OAK WOODLANDS AND PRAIRIES.

Unit Name	1850 Hectares	1983 Hectares Oak	1983 Hectares Prairie	1983 Hectares TOTAL	Hectares Lost	Percent Reduction 1850 to 1983
Gann's	40	0	6	6	34	85
Elk Camp	41	22	7	29	41	29
Dolason	136	6	51	57	79	58
Count's Hill	167	11	99	110	57	34
Maneze	135	19	78	97	38	28
Child's Hill	172	55	101	156	16	9
Copper Creek	66	32	24	56	10	15
Schoolhouse	95	34	57	91	4	4
Lyon's Ranch	72	19	41	60	12	17
South Boundary	72	31	22	53	19	26
Tick	28	3	13	16	12	43
Pig Pen	18	3	8	11	7	39
TOTAL	1,042	235	507	742	300	29

woodlands were mapped as containing sufficient densities of established Douglas-fir (> 25% coverage) to eventually dominate the canopy. Encroachment appeared to be continuing at a high rate with no indication of stopping.

Three striking features of the 1850 Bald Hills boundaries not characteristic of current vegetation patterns were recorded:

1) The 1850 boundaries followed topographic features such as ridgetops and sudden slope breaks. In most cases the conifer forest was restricted to locations below steep slope breaks and to more north-facing aspects along ridgetops.

2) In 1850, the forest boundaries appeared to have been relatively stable over fairly long periods (at least several hundreds of years). This was demonstrated by the occurrence of extremely large old-growth redwood stumps in several areas immediately adjacent to post-settlement Douglas-fir invasion.

3) In 1850, the conifer stands immediately adjacent to the Bald Hills were dominated by large redwood, many of which were 3-5 m DBH.

<u>Interpretation</u>

Many factors have influenced vegetation changes. Domestic livestock use increased grazing intensity and changed grazing patterns. Cattle and sheep frequently displaced native ungulates such as elk and deer. Different feeding habits, more animals and increased trampling changed vegetation significantly. Heady (1972) feels overgrazing before 1905 had more influence in altering California's grassland composition than overburning. Livestock selectively graze perennial natives because these species stay green longer into the summer than the introduced grasses which are predominantly annuals. With reduced vigor in native species and greater bare ground due to hoof disturbance, aggressive introduced species thrived, increasing total coverage. Both cattle and sheep grazing in the bald hills encouraged establishment of non-native plants. As in many grazed California plant communities, introduced plants replaced natives. Livestock grazing probably kept the oak understory more open and subject to rapid invasion than during undisturbed successional development (Stein 1980). Native plants may become more competitive as the effects of grazing decline. Martin and Hektner (unpublished data) found dramatically increased relative cover for some native species where cattle grazing has been excluded on open ridgetop prairies within the study area.

Logging of adjacent conifer forests produced severe impacts, both directly and indirectly. Removal of the tall, thermally buffering forest canopy changed temperature, light and wind conditions in the entire area. Vegetation removal changed the soil climate sufficiently that soil classifications must be modified (Popenoe 1987). Access road construction through prairies and oak woodlands exposed bare roadcuts which Douglas-fir rapidly colonized. Silvicultural programs following logging promoted Douglas-fir establishment in the open woodlands. Douglas-fir and Monterey pine (*Pinus radiata*) were deliberately planted in plantations on several Bald Hills prairies.

Changes in fire frequency, intensity and pattern influenced vegetation patterns. Differential species fire tolerance to regular burning produced fairly stable vegetation patterns. Prolonged changes in this pattern allowed closed canopy oak stands to develop and less fire tolerant species to compete successfully. Aggressive species, such as Douglas-fir, became dominant in widespread areas where they had not been competitive under the previous fire regime.

Changes in vegetation altered the environment in ways that produced further vegetation modification. Dense Douglas-fir stands shaded out oak woodland and prairie species. Oak/grass systems supporting about 300 species were replaced by Douglas-fir forests having limited understory floras.

Pure Douglas-fir stands succeeded to redwood/Douglas-fir forests in several decades on mesic sites, while on xeric sites, the process may take a few centuries. Redwood saplings were common in stands colonized 80 years ago in conifer invaded portions of Gann's and Elk Camp prairies. After logging of the 60 to 100 year old Douglas-fir stands which had invaded former oak woodland/prairie sites, regeneration was to conifer forest. Thus, Douglas-fir invasion was not a temporary change, but a permanent conversion from oak woodland/grassland to conifer forest.

FIRE

Fire History

Historically, fire has played an important role in the ecology of the Bald Hills. Frequent fire controlled the continuous establishment of Douglas-fir until post-settlement times. Recent land management has excluded the regular occurrence of fire. This seemingly minor environmental change has caused unprecedented change in vegetation processes by allowing conifers to survive the thin-barked stage when they are sensitive to fire (Harmon 1984). Surviving Douglas-fir overtop and shade out existing oak woodlands, convert the site to conifer forest and eventually to *Sequoia/Pseudotsuga* forest. Plumb and McDonald (1981) feel that fire is necessary under natural conditions to perpetuate oak woodlands. This is especially needed where oaks compete with faster growing conifers. If conditions are allowed to continue, lack of fire could result in conifer domination of most of what was once bald hills vegetation.

Some aspects of the pre-settlement environment differed significantly from today's environment. Lightning fires have occurred throughout California grasslands for as long as grasslands have existed (Heady 1972). The Native Americans occupying the area for several thousand years, burned the bald hills periodically, possibly every year or two (Thompson 1916, Lewis 1973, King and Bickel 1980). Burning stimulated growth of native woodland species and controlled Douglas-fir invasion of the prairies. Early settlers continued burning for a short time, but in the twentieth century this policy was replaced by one of fire suppression. Fires starting in this region, and those burning in from other areas, have been drastically reduced in size and frequency. Cessation of burning allowed a temporary increase in species diversity because shade tolerant, fire susceptible species were no longer excluded. The development of a closed conifer canopy, however, has led to an overall impoverishment of the flora. Cole (1977) feels that fire suppression is particularly harmful and has resulted in an overall reduction of genetic resources.

Six documented lightning-ignited fires originated in RNP's Bald Hills area between 1960 and 1984 (USDI 1985). Eight man-caused or undetermined source fires were noted for this area during the same time span. The largest of the recent wildfires occurred in 1955. Approximately 150 ha of prairie and oak woodland near Schoolhouse Peak were burned in a 9,000 ha escaped "controlled burn" from the Klamath River basin. Visual evidence, mainly fire scars and dead trees, still seen in the present oak woodlands indicated that this wildfire was very intense and top-killed or severely damaged many oaks.

Methods. To determine fire frequency and role which fire has played in existing oak stands, oak cross-sections were examined from three stands. The upper stand was located on the mid-elevation slope near Schoolhouse Peak. In the middle of a large portion of intact oak woodland, the stand contained a high density of young trees. The second stand was lower on the slope near Maneze, bordered by both prairie and logged conifer forest. Douglas-fir was codominant with oak in this stand. The third stand was a low elevation site near Tick Prairie. Cross-sections were also obtained from trees cut at other times and locations (i.e. during fence building, pre-park firewood cutting and fire trail construction). More than 50 cross-sections have been obtained from small to medium size oaks. Some Douglas-fir were cored to assist in determining ages and fire history. Coring oaks was tried, but did not provide adequate fire information. One wedge was obtained from a medium size, fire scarred tree.

Results. Trees up to 30 cm DBH up to 100 years in age, depending on site conditions. Within sampled stands, however, trees were found to be in a single age class. Figure 16 shows the composite fire histories for each of the three sites. The small dense oak stands near Schoolhouse Peak originated following fires in 1945 and 1948. Addi- tional fires occurred in this area in 1927, 1929, 1937 and 1939 for a total of six fires in 31 years. The longest interval between fires was ten years. Since 1948, only one scarring fire, in 1967, was detected. Prescribed fires burned portions of this area in 1981 and 1985. One cross-section obtained in this area showed complete healing after several fires even though no external evidence of fire had been apparent before the tree was cut.

At the second site, the stand originated after 1905 and oaks displayed fire scars from 1930 and 1948. Dense Douglas-fir formed a complete canopy that was beginning to overtop the oak canopy when sampling was done. Based on age data, the oldest Douglas-fir trees originated following the 1948 fire and seedlings were still being established on the prairie boundary. The rapidly growing Douglas-fir canopy was starting to shade out the oaks which were at least 43 years older.

At Tick Prairie, fire scars from 1959 were found on cross-sections which also contained fire scars from 1886, 1900 and 1905 (Figure 17). Here, as in the Schoolhouse Peak area, trees older than the predominant size class displayed scars which immediately predated the origination of that size class.

Interpretation. The origins of both Douglas-fir and oak stands were related to the presence or absence of fire. Flushes of oak sprouting were stimulated by burning. Branchless growth form trees (forest form), originate from a uniform date following a fire. Clustered individual stems and rapid initial growth rate suggest that stands established as long ago as 1875 may have been of sprout origin. Small oaks were top-

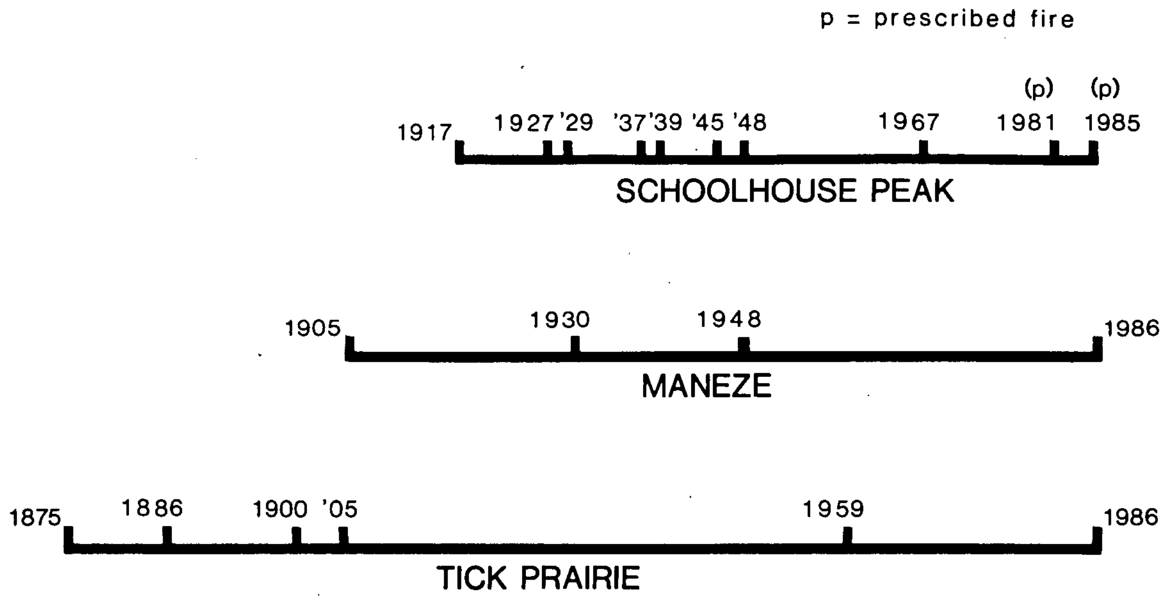


Figure 16. Composite fire histories for sampled areas near Schoolhouse Peak, Maneze and Tick Prairie. The left ends of the lines represent the estimated date of stand origin. The right ends indicate the date of sampling. Dates along the lines represent fire scars.

killed by fire but sprouted back vigorously. The long-term effect of reduced fire frequency has produced even-aged oak stands and allowed continued Douglas-fir encroachment.

After 1948, significant changes in the vegetation occurred. The individual trees in what are now dense oak stands originated from that period. Prior to that time, they may have been low dense sprout clusters which were top killed during fires and resprouted afterward. The origin of these patches may have been sprouting following a previous catastrophic fire or early cutting for firewood or fenceposts. Another change was survival of the continuously established Douglas-fir within the oak woodlands. Douglas-fir persisted in the absence of fire. The oldest Douglas-fir stands in the areas studied originated in the mid-1940's. Some of the Douglas-fir encroachment was controlled by fire prior to 1948, but has been allowed to proceed unchecked since.

This fire history information documented only parts of the post-settlement period. Cross-sections from large, old oak trees would be necessary to determine pre-settlement fire history. However, few of these trees remain in the park and as no cutting was done, no record was obtained. A technique used elsewhere required the cutting wedges from fire-scarred cat faces. This technique was not used since the oaks here have the ability to completely heal over, leaving no external evidence of the scar (Figure 18).

Figure 17. Cross-section of *Quercus Garryana* tree showing complete healing of fire scars from four separate fires. No scaring was evident on the outside of the tree.

Effects of Burning

1981 Prescribed Burn. In early September 1981, a 1.8 ha prescribed burn was conducted in the oak woodlands to evaluate vegetation response. This was a combination of low intensity backing and head fires. Rate of spread averaged 0.6 to 0.9 m/min. Generally, flame lengths averaged 0.6 to 0.9 m and flame height 0.3 m reaching a maximum of 0.9 to 1.2 m. Relative humidity averaged 55 percent, dry bulb temperature 19°C and wind was from the south at 0 to 3.2 kph. Douglas-fir and Oregon white oak trees were monitored to observe the effects of scorch and fire. Twenty oak and 22 Douglas-fir were photographed, tagged and described immediately following the fire and ten months later. Trees and shrubs were monitored for dieback and sprouting during the following summer (Table 9).

Ten months following the 1981 prescribed fire, 13 of 14 Douglas-fir trees with 70 percent or greater scorch were dead. Seven of eight with less than 70 percent scorch were living. Almost all of the Douglas-fir less than 3 m tall were killed. All *Q. Garryana* less than 3 m tall were

Figure 18. Fire scars in the process of healing on the bases of two *Quercus Garryana* trees near Schoolhouse Peak.

TABLE 9. RESPONSE OF TREE AND SHRUB SPECIES TO FIRE - AFTER 10 MONTHS.

Species	Sprouting	Condition of Main Stem
Pseudotsuga menziesii (up to 70% scorch)	no	live (87.5)
Pseudotsuga menziesii (over 70% scorch)	no	dead (92.2%)
Quercus Garryana (up to 3 m tall)	yes	dead
Quercus Garryana (over 3 m tall)	yes	live
Holodiscus discolor	yes	dead
Corylus cornuta	yes	dead
Lonicera hispidula	yes	dead
Ribes Roezlii	yes	dead
Rubus vitifolius	yes	dead
Symphoricarpos rivularis	yes	dead
Rhus diversiloba	yes	dead

top-killed but sprouted back vigorously from the base. All oaks taller than 3 m lived with little apparent damage and little sprouting. Annual plant species had relatively low cover. Little long lasting visual evidence of burning in this area was noted (i.e. heavily scorched trees or bare areas). Rapid sprouting and heavy herbaceous growth obliterated most of the obvious effects except for dead Douglas-fir trees. Some scarring of oak trees did occur under this low intensity fire. Oak leaves in the burned area turned brown within two weeks, but persisted on the trees long after leaves on trees in unburned areas had dropped.

All tree and shrub layer species except Douglas-fir responded to fire by vigorous sprouting except Douglas-fir. The most important effect of a higher frequency of low intensity fire would be the elimination of Douglas-fir.

Following the burn, native forbs were observed to dominate the herbaceous vegetation while cover of introduced grasses and forbs appeared to decrease. Perennial plants with underground rootstocks or bulbs flourished as did legumes, especially lupines. Frequent fire will likely favor native perennial species over introduced annual species.

1985 Prescribed Burn. In October of 1985, a 32 ha prescribed burn was conducted in the oak woodlands below Bald Hills Road near Schoolhouse Peak. The fire was conducted under conditions which produced very low fire intensities. Average relative humidity was 54 percent and the temperature averaged 15°C. Ignition began in the early evening when wind was from the northwest at 4.8 to 9.6 kph. Average flame height for the backing fire was 15 to 30 cm. The rate of spread was 0.3 to 0.6 m per minute. In open woodlands with small, sparse Douglas-fir, the fire burned lightly but uniformly. Areas with abundant Douglas-fir, stream channels and open grasslands burned poorly or not at all. Heavy dew before and during the burn prevented the normally dry grass from carrying a good backing fire. Under the oak canopy, the grass burned well because it was protected from the dew. Again, visual evidence of the prescribed burn was short-lived due to low fire intensity. No changes in oak leaves were observed for this burn. All leaves fell soon after the fire, making the burned area difficult to distinguish.

The fire was a combination of low intensity head and backing fires. Head fires were used to burn the grass, but in some areas even head fires would not carry. Backing fires were mainly run beneath the oaks. Biomass under the oak canopy ranged from 10.3 to 15.5 metric tons per ha. Biomass for the glades ranged from 5.6 to 11.2 metric tons per ha. Biomass beneath Douglas-fir trees in the burn ranged from 19.3 to 31.6 metric tons per ha. Although biomass under the young Douglas-fir was the highest, the more compact mat of needles did not burn.

Due to the low fire intensity, Douglas-fir taller than about 3 m or greater than 5 cm DBH were frequently not killed. Ages of trees in that size class ranged from 10 to 20 years, depending on site conditions (Figure 19).

Herbaceous vegetation was sampled during June and July of 1985, before the scheduled burn. Five plots were sampled in different types of vegetation: *Quercus/Symphoricarpos*, *Quercus/Delphinium*, *Quercus/Cynosurus*, *Arrhenatherum/Sherardia* and under a dense stand of young Douglas-fir. Overall plot cover and grass, forb, shrub and canopy cover were estimated to the nearest 5 percent. General plot information of

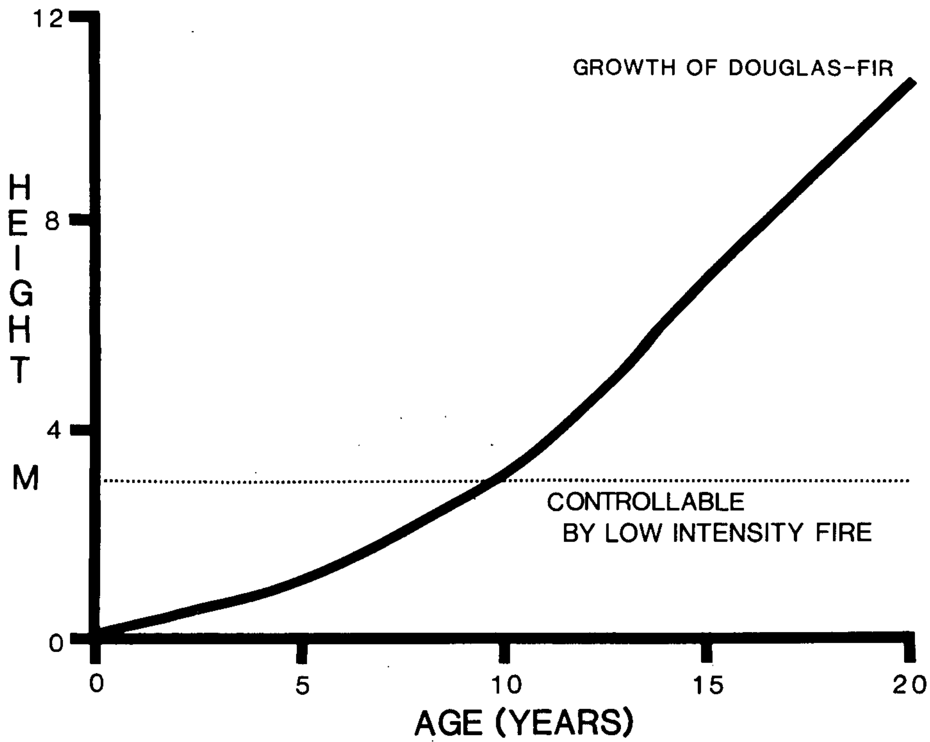


Figure 19. Rapid growth rate after seedling establishment results in Douglas-fir being treatable by fire for only about 10 years.

slope, aspect, slope position and topographic configuration were recorded for each plot. A complete species inventory, including cover values, was compiled for each plot.

Subplot sampling consisted of 1 m^2 quadrats randomly placed along three or four line transects for a total of 24, m^2 quadrats within each vegetation type. Overall quadrat cover and the cover of the grass, forb and shrub layers were estimated to the nearest 5 percent and the number of tree seedlings counted. The total cover for each plant species found within the square sampling frame was recorded. Cover values were determined using a modified Domin Index (Evans and Dahl 1955):

1 = rare	5 = 5 - 10%	9 = 50 - 75%
2 = occasional	6 = 10 - 20%	10 = 75 - 90%
3 = 0 - 1%	7 = 20 - 33%	11 = 90 - 100%
4 = 1 - 5%	8 = 33 - 50%	

Controls for the burn sampling were the permanent plots. Both the burn plots and the permanent plots were resampled in June 1986 and are scheduled for resampling in 1987. The results will be presented elsewhere when analysis has been completed.

Photopoints were set up along the lower perimeter of the burn before the fire, retaken after the fire and again in the fall of 1986. Photographs were also taken of each burn plot before and after the prescribed burn and again in 1986. These slides are on file in Orick in the Vegetation Management photofiles.

1986 Prescribed Burn. In late September and early October 1986, a 58 ha prescribed burn was conducted in the woodlands near Schoolhouse Peak. The entire 1981 burn site was reburned in this fire. Blacklines were installed and open grass areas (55 percent of the total area) were burned the next day. Fire did not carry through the grass and forbs under the oak canopy. After five warm days, conditions under the oak canopy were conducive to carrying fire so the burn was completed. Heavy leaf fall between and during the burns increased the fuel loading beneath the oaks. Altogether, 92 percent of the area burned. The unburned areas were isolated from the backing fire by moist drainages under the oak canopy. Two permanent plots located in the prescribed burn area were not burned.

The grassland fire was mainly a backing fire which spread at a rate of 0.6 to 1 m per minute. Winds were out of the northwest at 10 to 12 kph with gusts over 16 kph. Average flame lengths were 0.3 to 0.6 m. Relative humidity averaged 72 percent and the temperature was about 12°C for this morning fire. The oak woodland fire was also a backing fire which was allowed to creep downslope. Grassy areas that had burned five days before, reburned more completely. Average flame lengths were less than 0.5 m and the rate of spread was 0.3 to 0.6 m per minute. Douglas-fir up to 6 m flared up and burned under the conditions of the second fire. Winds from the east at 5 to 8 kph dropped to less than 1 kph in the late afternoon. The average relative humidity varied from 39 percent to 61 percent and the temperature varied from 27°C down to 18°C for this fire which was ignited in the afternoon and burned into the next morning.

Photopoints were set up along the perimeter of the burn to document how effectively the fire burned Douglas-fir. Additional photopoints were installed to follow oak sprouting in the area which had also burned in 1981. Slides are on file in the Orick Vegetation Management photo files.

Interpretation

Maintaining the Bald Hills requires long-term control of Douglas-fir encroachment. Efficient control dictates a high fire frequency to kill young, encroaching trees while they are susceptible to low intensity surface fires. To achieve that goal, a fire frequency of at least every ten years is necessary. Based on the experimental prescribed burns, two prescribed fires during the susceptible period would be practical and achieve effective control. A five year interval would control Douglas-fir and the flush of oak sprouting stimulated by the previous fire, as well as provide adequate burn coverage.

Based on the effects of the prescribed fires, the following effects were projected if a sustained prescribed burning program was implemented:

1) Except for Douglas-fir, all woody plant species native to the woodlands sprout when top-killed by fire.

2) Herbaceous vegetation in the oak understory should respond to fire by a shift in the composition from grass domination toward forb domination. This was noted following the 1981 burn. Overall composition shifted from a mixture of introduced and native species toward native domination.

3) Oak regeneration by basal sprouting would be stimulated by fire, resulting in a flush of brushy oak clusters. These sprouts would be susceptible to mortality during subsequent fires. The time required for oaks to grow past the fire sensitive stage varies from site to site and with the intensity of the fire. Young oaks are sensitive to fire for at least the ten years during which Douglas-fir is also susceptible, but oaks sprout and Douglas-fir does not. The effects of continual oak sprouting and reburning are not fully known. Sprouting may be inversely proportional to tree size. Therefore, the sprouting response following fires might decrease with the maturation of the canopy trees.

4) Oak stand density should be reduced by a long-term, consistent fire program. This is due to mortality of some canopy trees and control of fire simulated sprouting by subsequent fires. Inconsistent or temporary cessation of fire would allow growth and development of the sprout flush from previous fires and may significantly alter stand structure for decades. Once a large scale burning program is initiated in the oak woodlands, continued burning is necessary.

5) New Douglas-fir establishment would be controlled by the occurrence of periodic fire. Established Douglas-fir must be removed before the areas can be maintained by light burning.

6) Without the re-introduction of fire into the Bald Hills ecosystem, oak woodlands cannot be maintained and conversion to conifer forest will continue.

PART 3: DISCUSSION AND MANAGEMENT ALTERNATIVES

Restoration and long-term management of natural ecosystems requires not only knowledge of present and historic conditions and processes, but application of these processes to modify existing ecosystems using history as a guideline. Part 1 of this report quantified existing vegetation. Part 2 covered the changes in pattern, composition and some important processes. Here, in Part 3 the transition is made from description to interpretation and from observation to manipulation. This part summarizes the first two parts and discusses research information from the resource manager's perspective.

VEGETATION HISTORY

Interpreting prehistoric vegetation dynamics requires long-term vegetation information which can be obtained through analysis of fossil pollen. West (1983) presents pollen data obtained from bog cores on Pilot Ridge, 60 km southwest of Schoolhouse Peak, in the upper Redwood Creek watershed. The level of oak pollen, indicating relative abundance of oak trees, remains relatively stable for at least 5,000 years. The time period of this study roughly corresponds to known occupation of the bald hills by Native Americans.

The pollen record reflects two types of vegetation changes. Two major charcoal layers or lenses correspond to peaks in grass pollen and decreases in arboreal pollen. At least one fire is of a magnitude to eliminate all conifers from the pollen record for 100 to 200 years. Lesser amounts of charcoal in most samples indicate the likelihood of repeated low intensity ground fires which do not destroy arboreal vegetation. West feels that it is likely that at least some of these fires were caused by Native Americans.

The second vegetation change is probably the result of climatic change. Species composition in the pollen record changes 2,700 to 2,800 years ago. The appearance of mixed evergreen species, notably tan oak, follow a climatic shift to a cooler, moister period. During this period, the relative abundance of Douglas-fir pollen increases while that of oaks slightly decrease (West 1983).

An understanding of historical vegetation patterns was developed by interpreting existing vegetation patterns, aging existing and harvested trees, considering human influences and applying knowledge of vegetation dynamics. Also considered were the responses of individual plant species and the system as a whole to a changing environment. Interpretations were based on reviewed literature, studies reported here and an understanding of the ecosystem gained from several years of observation.

Minor fluctuations probably always occurred on bald hills/conifer forest ecotones. A major concern of the Park Service is the large scale acceleration of forest encroachment into prairies and oak woodlands. Post-settlement encroachment was mapped to determine the rate of encroachment and natural distributional patterns. A target date of 1850 was used to represent the change in human influence with European settlement and removal of Native Americans. Native American activities prior to 1850 were treated in this report as natural processes. Much vegetation modification during the post-settlement period resulted from differences in land use between Native Americans and settlers. Changing land use resulted in environmental change which influenced vegetation composition, structure and succession.

Pre-settlement Bald Hills vegetation differed from present vegetation in several important ways. The prairie/oak woodland system extended from Elk Camp continuously along the Bald Hills ridge to what is now the southern park boundary. South-, southwest- and west-facing slopes supported prairies and oak woodlands, some extending from ridgetop down to the banks of Redwood Creek. The interface between Bald Hills vegetation and that of the surrounding redwood forests was abrupt, often corresponding with natural topographic features. Large redwoods, up to 5 m DBH, bordered open prairies and oak woodlands. Spur ridges and other abrupt slope breaks acted as natural breaks to frequent fires set by Native Americans.

This system was in an equilibrium controlled by the regular occurrence of fire, which influenced distribution, composition and structure of the resulting vegetation. Fire was the primary agent preventing heat intolerant conifer seedlings from successfully colonizing the bald hills. Fire also exerted strong influence on vegetation structure and composition in the oak woodlands. Bulb and rhizome-forming species, sprouting trees and shrubs, and species with fire adapted seed strategies flourished, while plant species which were not adapted to surviving fire were eliminated. The Bald Hills oak woodlands still support a well-developed, diverse flora with species richness exceeding that of any other ecosystem within the park.

Oak stands were probably dominated by large old individuals and composed of trees of all sizes. These differed from savannahs of interior California by having a closed canopy at all stages of development. Glades were intermingled with the oaks forming the characteristic bald hills mosaic of grass and oak which is still found. Large big-leaf maple (*Acer macrophyllum*) and California bay (*Umbellularia californica*) trees occurred in clusters on stream channels and on rock outcrops. There has probably been little change in the distribution of oak stands relative to grasslands because the primary method of oak regeneration has been by vegetative sprouting and the rate of sprouting success is high. Rossi (1980) feels periodic Native American burning thinned oak stands or caused areas to remain open, but probably was not an important factor altering the abundance or regional distribution of oaks. The proportion of oak woodland and prairie relative to conifer forest has decreased due to invasion by Douglas-fir.

Domestic livestock affected vegetation by increasing grazing pressure, changing grazing patterns and introducing exotic plant species. The cattle and sheep which replaced native browsers altered large animal impacts on vegetation through differences in feeding habits and greater trampling of the sod, exposing more bare soil. Newly introduced plant species thrived under conditions of livestock grazing, taking over much habitat from native species.

Considerable effects from logging of adjacent conifer forests were seen. Removing the tall, shade producing canopy of adjacent conifer forests changed temperature, light and wind conditions. Access road construction through prairies and oak woodlands exposed bare roadcuts which were colonized by Douglas-fir. Silvicultural programs following logging promoted conifer establishment in the open woodlands.

Changes in frequency, intensity and pattern of fire greatly influenced vegetation patterns. Differences in species tolerance of regular burning allowed vegetation patterns to develop. Long-term changes in this pattern allowed less fire tolerant species to compete more successfully. Aggressive fire intolerant species became dominant where they had not previously survived.

Changes in vegetation altered the environment in ways that caused further vegetation changes. Establishment of dense Douglas-fir stands resulted in intense shading which, in turn, caused a reduction in soil temperature and eliminated plant species of the oak and prairie communities. In the Bald Hills, this was a widespread pattern. Oak/grass systems were replaced by Douglas-fir stands. Pure Douglas-fir stands here succeeded to redwood/Douglas-fir forests. Redwood saplings were found in prairies colonized by Douglas-fir 80 to 100 years ago.

PRESENT VEGETATION PATTERNS

Near the coast, Oregon white oak occurred in bands between the bald hills prairies and redwood forests, forming finger-like projections into the grasslands. The oak/grass mosaic became the dominant vegetation pattern to the southeast where the adjacent forests were mixed evergreen or redwood/Douglas-fir.

The three general types of oak stands occurring in the Bald Hills were differentiated by age and size structure and by the size and spacial distribution of individual trees:

1) Small, dense stands composed of uniformly small-diametered, evenly spaced individual trees had high densities.
2) Closed canopy, clustered stands had trees distributed in clumps with each stand having uniform ages and sizes.

3) All-aged stands had a broad range of sizes, were widely spaced and had trees up to 1 m in diameter, the largest size in any stand type.

Seven vegetation types within the oak woodlands were described, classified and mapped. Three types occurred in open woodlands and four in specialized habitats:

1) *Quercus/Symphoricarpos* - mesic dense woodland.
2) *Quercus/Dactylis* - mesic open woodland.
3) *Quercus/Cynosurus* - xeric open woodland.
4) *Quercus/Delphinium* - seeps within xeric open woodland.
5) *Arrhenatherum/Sherardia* - glades within woodlands.
6) *Philadelphus/Cystopteris* - stream channels.
7) *Ribes/Phacelia* - rock outcrops.

Of the seven vegetation types, mesic woodlands (particularly *Quercus/Dactylis*) were the most threatened by Douglas-fir encroachment. Stream channels, rock outcrops and any other discontinuity of the herbaceous cover also had Douglas-fir seedlings becoming established. At low elevations within the fog zone and on concave slopes, Douglas-fir invasion reduced the number of vegetation types and oak area covered by oak woodland. Only the open stands supported intact oak woodland and even these areas were actively invaded. Management of these encroached areas is considered important if the resource is to be successfully maintained. Considerable clearing to re-establish stream channel and outcrop oak types in mesic areas would be required.

Douglas-fir encroachment in the bald hills expanded primarily from forest margins, roadcuts and on knolls. Prairies were becoming fragmented and oak woodlands overtopped. Fragmentation has occurred extensively at Gann's and Dolason prairies and to a lesser extent on the remaining prairies. This conversion is permanent under present conditions. Since European settlement, about one-third of the park's Bald Hills has become conifer forest. One-half of the remaining oak woodlands presently has enough Douglas-fir established to permanently convert to conifer forest.

Forest encroachment poses an distinct threat to park oak woodland vegetation. Fluxuations between prairie, woodland and conifer forest have probably always occurred. However, there was no indication that this large scale, regionwide conversion has occurred before. Much of the increase in conifer encroachment on the bald hills has be directly attributed to recent human activities. In the past, fire was the factor which limited forest invasion, but now encroachment progresses unchecked. To preserve and maintain the bald hills vegetation, Douglas-fir encroachment must be controlled. Re-introducing fire to the ecosystem would prevent Douglas-fir from colonizing grasslands and oak woodlands. Reversal of this trend is possible and maintenance practical.

In 1981, 1985 and 1986, prescribed fires effectively removed young Douglas-fir and pushed oak stand structure and woodland species composition toward pre-settlement conditions. However, fire does not remove all Douglas-fir. Until the advanced Douglas-fir forest invasion is controlled, intensive management is necessary to maintain the resource. Management will be less complex once Douglas-fir is controlled, with only burning every few years necessary for maintenance.

MANAGEMENT ALTERNATIVES

The park's goals for vegetation management are first, the restoration and, second, the maintenance of oak woodlands and prairies in the condition that prevailed when the area was first visited by white man (USDI 1987). While this goal may not be fully achieved, the ecosystem can be preserved through active vegetation manipulation. Fire can maintain the oak woodlands as a vegetation type, but the resulting stand structures and vegetation components will be governed by processes active today.

The following management alternatives are proposed for the Bald Hills oak woodlands and prairies of RNP. Each proposal is presented with the consideration that restoration and maintenance of the oak woodlands as a natural ecosystem is the goal. Management alternatives for prairies without oaks are included, but discussions are limited to maintaining their distinction from associated conifer forests.

Restoring and maintaining community integrity and re-establishing natural vegetation processes are long-term management options for the Bald Hills. The most immediate threat to the existence of bald hills vegetation communities is uncontrolled encroachment of Douglas-fir forest. These recommendations are made with the assumption that livestock grazing will not be re-introduced into the park. The scope of these alternatives is limited to manipulation of vegetation processes. During the first few years, an intensive program of monitoring will be necessary for any of these management activities. This type of program is without precedent, and valuable information could be obtained for managing RNP's Bald Hills, and oak/grass communities throughout California and the Pacific Northwest.

No Action

No action on the part of the Park Service is passive management except for continued suppression of fire. Conifer encroachment will continue, probably resulting in loss of most oak woodlands in the park within the next few decades. Prairies are less rapidly encroached but, eventually, substantial areas would also convert to forest. Long-term maintenance of oak woodland and prairie ecosystems would not be accomplished with this alternative.

Prescribed Burning Only

This option simulates burning practices of the Native Americans resident prior to European settlement. Once a prescribed fire program is initiated, it must be considered on-going and continued without lengthy breaks. Heavy sprouting resulting from fires may form dense thickets if not controlled by subsequent fires. To achieve management objectives, all areas should be treated on a ten year cycle. This frequency will control both oak sprouting and Douglas-fir re-establishment. Due to less than complete coverage of any single fire, two prescribed fires are recommended to achieve the minimum required. A five year frequency with active monitoring of sprouting is suggested as a starting point. The frequency can be adjusted, if necessary, as indicated by the monitoring results.

Prescribed fire was effective in controlling encroachment into areas with a well-developed herbaceous layer. Douglas-fir greater than 3 tall were not usually killed in surface fire. Douglas-fir in high densities, regardless of size, were not killed because the low intensity surface fire did not carry through stands under the prescribed fire conditions. Burning can be effective in maintaining most woodlands but was not effective in restoring woodlands with dense or large Douglas-fir already established.

Prescribed burning could have major effects on plant species composition and oak regeneration. Long-term effects of regularly-occurring, controlled burning in the oak woodlands include the formation of all-aged oak stands with widely spaced and larger individuals dominating (Sugihara and Reed 1987). Shrubs and trees other than oaks and conifers (tan oak, madrone etc.) could be restricted to a lower growth form than presently found, due to continual top-killing and resprouting. Bald hills boundaries with conifer forests can be maintained in stable positions, if burned regularly.

Burning open prairies will be necessary where Douglas-fir becomes established. This will be needed mainly along prairie margins and other invasion sites. At this time no treatment is specifically proposed for open prairies not invaded by Douglas-fir.

Manual Removal of Douglas-fir Only

Manual Douglas-fir removal can restore woodlands with established Douglas-fir. Manual removal can be accomplished by cutting, girdling, poisoning or any other method which physically removes Douglas-fir as a competitive species. Girdling is effective and practical where dense Douglas-fir stands are under the oak canopy or individual Douglas-fir tower over the oak canopy. This treatment is "naturally" occurring near Schoolhouse Peak. Numerous bear-girdled trees with diameters greater than 45 cm have been observed. Bears are effective, and certainly economical, but they have not systematically treated the area. Bears have not frequently girdled the smaller size Douglas-fir trees now established, so treatment is inadequate.

Where Douglas-fir is not dense and trees are not extremely large, cutting may be the easiest and most efficient removal method. Cutting is often less expensive and faster than girdling, but may be impractical for dense thickets and large individuals. Cutting is the most rapid method for removing live Douglas-fir and the evidence of conifer encroachment.

Following either cutting or girdling, large numbers of dead trees are left in treated areas, so slash disposal must be considered. Girdling provides snags for use as wildlife habitat, but extremely large numbers have a noticeable negative visual impact. Both girdling and cutting produce slash which persists for many years. Girdling kills trees slowly over several seasons and may stimulate "stress crops" of cones, resulting in a flush of seedlings. With cutting, slash is on the ground immediately. A combination of cutting and girdling is probably the most efficient means of manual removal. Slash burning can be done in conjunction with cutting to reduce residues.

Without some means of preventing further conifer establishment after manual removal, all of these treatments would have to be repeated periodically to maintain the woodlands. Herbicides are an alternative method, but remain highly controversial.

Manual Removal With Prescribed Burning

Manual removal in combination with prescribed burning can restore and maintain large areas with diverse invasion patterns. A combination of girdling and cutting can be used to control Douglas-fir not effectively treated by burning. Low intensity, controlled, surface fire can then be used to remove small individuals which become established. If the initial program of stabilization is followed by effective maintenance by frequent burning, repeated manual removal should not be necessary. This combination of methods can reduce the primary limitations of individual methods. Well-established stands of Douglas-fir which are not treatable by fire alone can be removed manually and fire then used to maintain the oaks. Prescribed fire can also reduce slash produced by the cutting and girdling. Combinations of methods with site specific application will probably produce the best results.

Fire can be used to effect long-term control of Douglas-fir and the flush of Douglas-fir regeneration which may occur following girdling. Repeated frequent burning is necessary to control oak sprouting and Douglas-fir re-establishment. Other long-term benefits of a sustained burning program such as restoring stand development and species composition would also be accomplished.

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APPENDIX 1 - FURTHER VEGETATION RESEARCH NEEDS

1) Short-term effects of a single fire on the ecosystem are well-documented, but long-term effects and these of repeated fires on stand density and structure are unknown. The recommendations made here were based on projections made using available information. Continued monitoring and refinement of techniques is mandatory in the initial years of any management program.

2) Many Douglas-fir stands have such dense canopies that there is virtually no understory. Sample plots have been set up to monitor development of the understory when the Douglas-fir canopy is removed and light intensity at ground level is increased. These plots should be monitored until the species composition stabilizes.

3) In the few years that livestock grazing has been absent from the Bald Hills, many vegetation changes have occurred. Already, cover of the annual, non-native grass dogtail (*Cynosurus echinatus*), is lower. Grass heights are no longer clipped low, but often reach heights of 1 to 1.5 m, effectively shading out the short annuals. Grazing and browsing by native wildlife are expected to increase in the future. If greater seedling survival occurs in the absence of cattle grazing, stand density and structure may reflect greater acorn regeneration. The effects of these factors are likely significant but are, as yet, unknown.

4) Changes in distribution patterns and composition of the vegetation types may occur with discontinuation of domestic livestock grazing, Douglas-fir removal and re-introduction of fire. This pattern is expected to equilibrate as a stable mosaic but may differ from the patterns described in this study. Documentation of changes should continue on a long-term basis.

5) Little is known about the interactions between open prairies and oak woodlands. Some fluctuation does occur, such as oaks spreading into prairie and the elimination of oaks from the prairie margin by intense fire, landslides and disease. Because the focus of the present study was on the more dramatic conifer forest encroachment, this issue was not addressed.

6) The reproductive success of Oregon white oak by acorn is not well-documented. Much research is required to adequately understand the importance of acorn reproduction. In some areas of the 1985 burn where Douglas-fir had been cut, understory vegetation lacking and gopher activity low, many oak seedlings were found. The rate of gophers colonization of this new habitat is unknown but may affect acorn and seedling survival.

7) The type and significance of oak sprouting found in the park is different from that described anywhere else. This has significant ecological effects and is an important topic for further study.

8) Evidence of the existence of former grassland species persists for a long time as opal phytoliths (Miles and Singleton 1975). This method of tracing vegetation history has not been attempted for the park vegetation but may prove to be a valuable source of information concerning pre-settlement vegetation distribution and composition.

9) Further evidence of past vegetation can be obtained by studying fossil pollen. It is not known if there are any appropriate study sites in the area, but if any can be found, the results may be important.

APPENDIX 2 - OAK WOODLAND SPECIES LIST

TREES

n *Abies grandis* (Dougl.) Lindl.	Grand Fir, Giant Fir
n *Acer macrophyllum* Pursh.	Big-Leaf Maple
n *Alnus oregona* Nutt.	Red Alder
n *Arbutus Menziesii* Pursh.	Madrone
n *Lithocarpus densiflorus* (H. & A.) Rehd.	Tan Oak
i *Pinus radiata* D. Don.	Monterey Pine
n *Pseudotsuga Menziesii* (Mirb.) Franco.	Douglas-fir
n *Quercus chrysolepis* Liebm.	Canyon Live Oak
n *Quercus Garryana* Dougl.	Oregon White Oak
n *Quercus Kelloggii* Newb.	California Black Oak
n *Salix* L. spp	Willow
n *Umbellularia californica* (H. & A.) Nutt.	California Bay

SHRUBS

n *Amelanchier pallida* Greene.	Serviceberry
n *Baccharis pilularis* D.C.	Coyote Brush
n *Berberis Aquifolium* Pursh.	Oregon Grape
n *Corylus cornuta* Marsh.	Hazelnut
n *Holodiscus discolor* (Pursh.) Maxim.	Ocean Spray
n *Lonicera hispidula* Dougl.	Honeysuckle
n *Osmaronia cerasiformis* (T. & G.) Landon	Indian Plum
n *Philadelphus Lewisii* Pursh.	Mock Orange
n *Prunus virginiana* L.	Western Chokecherry
n *Rhamnus Purshiana* D.C.	Cascara, Sagrada
n *Rhus diversiloba* T.& G.	Poison Oak
n *Ribes Roezlii* Regel.	Sierra Gooseberry
n *Ribes sanguineum* Pursh.	Red Flowering Currant
n *Rosa gymnocarpa* Nutt. in T. & G.	Wood Rose
n *Rosa pisocarpa* Gray	Cluster Rose
n *Rosa spithamea* Wats.	Ground Rose
i *Rubus laciniatus* Willd.	Cut-leaf Blackberry
n *Rubus leucodermis* Dougl. ex T.& G.	Western Raspberry
n *Rubus parviflorus* Nutt.	Thimbleberry
i *Rubus procerus* P.J. Muell.	Himalaya-berry
n *Rubus vitifolius* Cham. & Schlecht.	California Blackberry
n *Symphoricarpos rivularis* Suksd.	Snowberry

FERNS

n *Athyrium Filix-femina* (L.) Roth.	Lady Fern
n *Cheilanthes gracillima* D.C. Eat. in Torr.	Lace Fern
n *Cystopteris fragilis* (L.) Bernh.	Brittle Fern
n *Dryopteris arguta* (Kaulf.) Watt.	Wood Fern

n	*Equisetum Telmateia* Ehrh.	Giant Horsetail
n	*Pityrogramma triangularis* (Kaulf.) Maxon.	Goldenback Fern
n	*Polypodium californicum* Kaulf.	California Polypody
n	*Polypodium Glycyrrhiza* D.C. Eat.	Licorice Fern
n	*Polystichum munitum* (Kaulf.) Presl.	Western Sword Fern
n	*Pteridium aquilinum* (L.) Kuhn.	Bracken Fern
n	*Selaginella Wallacei* Hieron.	Spike Moss

<u>FORBS</u>

n	*Achillea borealis* Bong.	Yarrow
i	*Achillea Millefolium* L.	Common Yarrow
n	*Adenocaulon bicolor* Hook.	Trail Plant
n	*Agoseris grandiflora* (Nutt.) Greene	Mountain Dandilion
i	*Anagallis arvensis* L.	Scarlet Pimpernel
n	*Angelica tomentosa* Wats.	California Angelica
n	*Apocynum androsaemifolium* L.	Dogbane
n	*Aquilegia formosa* Fisch. in D.C.	Columbine
n	*Arabis glabra* (L.) Bernh.	Tower Mustard
n	*Arenaria macrophylla* Hook.	Large-leaved Sandwort
n	*Artemisia Douglasiana* Bess. in Hook.	Sagebrush
n	*Aster radulinus* Gray.	Broad-leaf Aster
	Astragalus sp.	Milkvetch
n	*Barbarea orthoceras* Ledeb.	Winter-cress
i	*Bellis perennis* L.	English Daisy
n	*Brodiaea Bridgesii* Wats.	Bridges' Brodiaea
n	*Brodiaea congesta* Sm.	Ookow
n	*Brodiaea elegans* Hoover.	Harvest Brodiaea
n	*Brodiaea hyacinthina* (Lindl.) Baker.	White Brodiaea
n	*Brodiaea Ida-Maia* (Wood) Greene.	Firecracker Flower
n	*Brodiaea laxa* (Benth.) Wats.	Grass Nut
n	*Brodiaea multiflora* Benth.	Many Flowered Brodiaea
n	*Brodiaea pulchella* (Salisb.) Greene.	Blue Dicks
n	*Brodiaea venusta* (Greene) Greene.	Rose Firecracker Flower
n	*Calandrinia ciliata* (R. & P.) D.C.	Red Maids
n	*Calochortus tolmiei* H. & A.	Pussy Ears, Mariposa Lily
n	*Campanula prenanthoides* Durand.	California Harebell
n	*Cardamine oligosperma* Nutt.	Bitter-cress
n	*Carex fracta* Mkze	Fragile-Sheathed Sedge
n	*Carex praegracilis* W. Boott	Clustered Field Sedge
n	*Carex tumulicola* Mkze	Foothill Sedge
n	*Caucalis microcarpa* H. & A.	California Hedge-Parsley
i	*Centaurea melitensis* L.	Tocalote
n	*Cerastium arvense* L.	Field Chickweed
i	*Cerastium viscosum* L.	Mouse-Ear Chickweed
n	*Chlorogalum pomeridianum* (D.C.) Kunth.	Soap Plant
i	*Chrysanthemum Leucanthemum* L.	Ox-eye Daisy
n	*Circaea alpina* L.	Enchanter's Nightshade
n	*Cirsium pastoris* J.T. Howell.	Snowy Thistle
i	*Cirsium vulgare* (Savi.) Ten.	Bull Thistle

	Cirsium sp.	Thistle
n	*Collomia heterophylla* Dougl. ex Hook.	Varied-leafed Collomia
i	*Convolvulus arvensis* L.	Bindweed
n	*Cynoglossum grande* Dougl. ex Lehm.	Hound's Tongue
n	*Daucus pusillus* Michx.	Rattlesnake Weed
n	*Delphinium decorum* F. & M.	Coast Larkspur
n	*Delphinium nudicale* T. & G.	Red Larkspur
n	*Delphinium trolliifolium* Gray.	Poison Larkspur
n	*Dentaria californica* Nutt.	Milk Maids, Toothwort
i	*Digitalis purpurea* L.	Foxglove
n	*Disporum Smithii* (Hook.) Piper.	Fairy Bells
n	*Dodecatheon Hendersonii* Gray.	Shooting Star
n	*Epilobium ciliatum* Raf.	Ciliate Willow Herb
n	*Epilobium minutum* Lindl. ex Hook.	Minute Willow Herb
n	*Erigeron inornatus* (Gray) Gray.	Wild Daisy
n	*Eriogonum nudum* Dougl. ex Benth.	Wild Buckwheat
n	*Eriophyllum lanatum* (Pursh.) Forbes.	Common Wooly Sun-flower
i	*Erodium Botrys* (Cav.) Bertol.	Long-beaked Filaree
i	*Erodium cicutarium* (L.) L'Her.	Red-stemmed Filaree
n	*Erysimum capitatum* (Dougl.) Greene.	Wallflower
n	*Eschscholzia californica* Cham.	California Poppy
n	*Euphorbia crenulata* Engelm.	Spurge
n	*Fragaria vesca* L.	Strawberry
n	*Fritillaria lanceolata* Pursh.	Checker-lily
i	*Galium Aparine* L.	Bedstraw
i	*Galium divaricatum* Lam.	Lamark's Bedstraw
n	*Galium Nuttallii* Gray	Climbing Bedstraw
i	*Geranium dissectum* L.	Cut-leaved Geranium
i	*Geranium molle* L.	Cranesbill
n	*Geranium oreganum* Howell.	Oregon Geranium
n	*Gilia capitata* Sims.	Blue Field Gilia
n	*Gnaphalium japonicum* Thunb.	Japanese Cudweed
n	*Gnaphalium purpureum* L.	Purple Cudweed
n	*Habenaria elegans* (Lindl.) Boland.	Rein Orchid
n	*Heracleum lanatum* Michx.	Cow Parsnip
n	*Heuchera micrantha* Dougl. ex Lindl.	Alum Root
n	*Hieracium albiflorum* Hook.	White-flowered Hawkweed
n	*Hieracium cynoglossoides* Arv.-Touv. ex Gray.	Hound's Tongue Hawkweed
n	*Hieracium scouleri* Hook.	Scouler's Hawkweed
n	*Hydrophyllum occidentale* (Wats.) Gray.	California Waterleaf
i	*Hypericum perforatum* L.	Klamath Weed
i	*Hypochoeris radicata* L.	Hairy Cat's Ear
n	*Iris Douglasiana* Herb.	Douglas' Iris
n	*Iris tenuissima* Dykes.	Slender Iris
n	*Isopyrum stipitatum* Gray.	Siskiyou Rue-Anemone
n	*Juncus bolanderi* Engelm.	Bolander's Rush
n	*Juncus bufonius* L.	Toad Rush
n	*Juncus effusus* L.	Common Rush
n	*Juncus patens* E. Mey.	Spreading Rush
n	*Juncus tenuis* Willd.	Slender Rush

i	*Lapsana communis* L.	Nipplewort
n	*Lathyrus nevadensis* Wats.	Sierra Nevada Pea
n	*Lathyrus polyphyllus* Nutt. ex T. & G.	Many-leaved Pea
n	*Lathyrus sphaericus* Retz.	Smooth Pod Pea
n	*Lathyrus Torreyi* Gray.	Redwood Pea
n	*Lathyrus vestitus* Nutt. ex T. & G.	Common Pacific Pea
n	*Ligusticum apiifolium* (Nutt.) Gray.	Celery-leaved Lovage
i	*Linum bienne* P. Mill.	Narrow-leaved Flax
n	*Lithophragma affine* Gray	Woodland Star
n	*Lomatium dissectum* (Nutt. ex T. & G.) Math. & Constance.	Fern-leaved Lomatium
n	*Lomatium utriculatum* (Nutt.) Coult. & Rose.	Common Lomatium
i	*Lotus corniculatus* L.	Bird's Foot Trefoil
n	*Lotus micranthus* Benth.	Trefoil
n	*Lotus Purshianus* (Benth.) Clem. & Clem.	Trefoil
n	*Lupinus bicolor* Lindl.	Annual Lupine
n	*Lupinus latifolius* J. C. Agardh.	Broad-leaved Lupine
n	*Lupinus rivularis* Dougl. ex Lindl.	Riverbank Lupine
n	*Luzula comosa* E. May.	Common Woodrush
n	*Madia elegans* D. Don.	Common Tarweed
n	*Madia gracilis* (Sm.) Keck.	Gumweed
n	*Madia madioides* (Nutt.) Greene.	Woodland Tarweed
n	*Madia minima* (Gray) Keck.	Little Tarweed
n	*Marah oreganus* (Torr. and Gray) T.J. Howell.	Wild Cucumber
n	*Micropus californicus* F. & M.	Slender Cottonweed
n	*Microsteris gracilis* (Hook.) Greene.	Slender Star
n	*Mimulus guttatus* Fisch. ex D.C.	Monkey Flower
n	*Monardella villosa* Benth.	Coyote Mint
n	*Montia chamissoi* (Ledeb.) Dur. & Jacks.	Toad Lily
n	*Montia perfoliata* (Donn.) Howell.	Miners Lettuce
n	*Montia siberica* (L.) Howell.	Candy Flower
i	*Myosotis micrantha* Pall. in Lehm.	Forget-me-not
i	*Myosotis versicolor* (Pers.) Sm.	Forget-me-not
n	*Nemophila Menziesii* H. & A.	Baby Blue Eyes
n	*Nemophila parviflora* Dougl. ex Benth.	Small Flowered Nemophila
n	*Orthocarpus pusillus* Benth.	Dwarf Orthocarpus
n	*Osmorhiza chilensis* H. & A.	Mountain Sweet-cicely
n	*Osmorhiza occidentalis* (Nutt.) Torr.	Western Sweet-cicely
i	*Parentucellia viscosa* (L.) Caruel.	Yellow Parentucellia
n	*Perideridia Kelloggii* (Gray) Math.	Kellog's Yampah
n	*Petasites palmatus* (Ait.) Gray.	Coltsfoot
n	*Phacelia Bolanderi* Gray.	Bolander's Phacelia
n	*Phacelia heterophylla* Pursh.	Virgate Phacelia
n	*Phacelia nemoralis* Greene.	Shade Phacelia
n	*Phlox speciosa* Pursh.	Showy Phlox
n	*Phoradendron flavescens* (Pursh.) Nutt.	Mistletoe
i	*Plantago lanceolata* L.	English Plantain
n	*Plectritis congesta* (Lindl.) D.C.	Pink Plectritis
n	*Polygala californica* Nutt.	California Milkwort

n *Polygonum ramosissimum* Michx. — Yellow-flowered Knotweed
n *Potentilla gracilis* Dougl. ex Hook. — Cinquefoil
i *Prunella vulgaris* L. — Selfheal
n *Psoralea physodes* Dougl. — California Tea
i *Ranunculus muricatus* L. — Prickle-fruited Buttercup
n *Ranunculus occidentalis* Nutt. — Western Buttercup
n *Ranunculus repens* L. — Creeping Buttercup
i *Rumex Acetosella* L. — Sheep Sorrel
i *Rumex crispus* L. — Curly Dock
n *Sagina saginoides* (L.) Karst — Pearlwort
n *Sanicula crassicaulis* Poepp. ex D.C. — Snakeroot
n *Satureja Douglasii* (Benth.) Briq. — Yerba Buena
i *Scandix Pecten-Veneris* L. — Shepherd's Needle
n *Scoliopus Bigelovii* Torr. — Slink Pod
n *Scutellaria antirrhinoides* Benth. — Skullcap
n *Senecio integerrimus* Nutt. — Butterweed
i *Sherardia arvensis* L. — Field Madder
n *Silene antirrhina* L. — Snapdragon Catchfly
n *Silene californica* Durand. — California Indian Pink
i *Silene gallica* L. — Common Catchfly
i *Silybum Marianum* (L.) Gaertn. — Milk Thistle
i *Sisymbrium altissimum* L. — Tumble Mustard
i *Sisymbrium officinale* (L.) Scop. — Hedge Mustard
n *Sisyrinchium bellum* Wats. — Blue-eyed Grass
n *Smilacina racemosa* (L.) — False Solomom's Seal
n *Smilacina stellata* (L.) Desf. — Nuttall's Solomon's Seal
i *Sonchus asper* L. — Prickly Sow-thistle
i *Sonchus oleraceus* L. — Common Sow-thistle
n *Stachys rigida* Nutt. ex Benth. — Hedge Nettle
n *Stellaria crispa* Cham. and Schlecht. — Starwort
i *Stellaria media* (L.) Vill. — Common Chickweed
n *Synthyris reniformis* (Dougl.) Benth. — Snow Queen
i *Taraxicum officinale* Wiggers — Common Dandilion
n *Tauschia Kelloggii* (Gray) Macbr. — Kellog's Tauschia
n *Tellima grandiflora* (Pursh.) Dougl. — Fringe Cups
n *Tonella tenella* (Benth.) Heller — Small Flowered Tonella
i *Torilis japonica* (Houtt.) DC. — Japanese Hedge Parsley
n *Trientalis latifolia* Hook. — Star Flower
n *Trifolium albopurpureum* T. & G. — Common Indian Clover
n *Trifolium bifidum* Gray — Notch-leaved Clover
n *Trifolium cyathiferum* Lindl. — Bowl Clover
n *Trifolium dichotomum* H. & A. — Branched Indian Clover
i *Trifolium dubium* Sibth. — Shamrock
n *Trifolium eriocephalum* Nutt. — Wooly Headed Clover
n *Trifolium microcephalum* Pursh. — Small Headed Clover
n *Trifolium microdon* H. & A. — Valparaiso Clover
n *Trifolium oliganthum* Steud. — Few Flowered Clover
i *Trifolium praetense* L. — Red Clover
i *Trifolium repens* L. — White Clover
i *Trifolium subterraneum* L. — Subclover
n *Trifolium tridentatum* Lindl. — Tomcat Clover

n	*Trifolium variegatum* Nutt.	Dark Headed Clover
n	*Trillium chloropetalum* (Torr.) Howell	Wake Robin
n	*Vancouveria hexandra* (Hook.) Morr. & Dec.	Inside-out Flower
i	*Veronica arvensis* L.	Corn Speedwell
n	*Vicia americana* Muhl.	American Vetch
i	*Vicia benghalensis* L.	Vetch
i	*Vicia sativa* L.	Spring Vetch
n	*Viola adunca* Sm.	Western Dog Violet
n	*Viola glabella* Nutt.	Smooth Yellow Violet
n	*Viola praemorsa* Dougl. ex Lindl.	Astoria Violet
n	*Whipplea modesta* Torr.	Yerba de Selva
n	*Wyethia angustifolia* (D.C.) Nutt.	Narrow-leaved Mules Ears
n	*Zigadenus micranthus* Eastw.	Small Flowered Zygadene

GRASSES

n	*Agrostis Hallii* Vasey	Hall's Bentgrass
i	*Agrostis stolonifera* L.	Redtop
i	*Agrostis tenuis* Sibth.	Colonial Bentgrass
i	*Aira caryophyllea* L.	Silver Hairgrass
i	*Anthoxanthum odoratum* L.	Sweet Vernal Grass
i	*Arrhenatherum elatius* (L.) Presl.	Tall Oatgrass
i	*Avena barbata* Brot.	Slender Wild Oat
i	*Briza minor* L.	Small Quaking Grass
n	*Bromus carinatus* H. & A.	California Brome
i	*Bromus diandrus* Roth.	Ripgut Grass
n	*Bromus marginatus* Nees.	Large Mountain Brome
i	*Bromus mollis* L.	Soft Chess
i	*Bromus stamineus* Desv. in Gray	Thread Brome
i	*Bromus sterilis* L.	Sterile Brome
n	*Bromus vulgaris* (Hook.) Shear.	Narrow-flowered Brome
i	*Cynosurus echinatus* L.	Dogtail
i	*Dactylis glomerata* L.	Orchardgrass
n	*Danthonia californica* Bol.	California Oatgrass
i	*Elymus caput-medusae* L.	Medusa Head
n	*Elymus glaucus* Buckl.	Western Ryegrass
i	*Festuca arundinacea* Schreb.	Alta Fescue
n	*Festuca californica* Vasey	California Fescue
i	*Festuca dertonensis* (All.) Asth.& Graebn.	Six Weeks Fescue
n	*Festuca Elmeri* Schribn. & Merr.	Elmer's Fescue
n	*Festuca idahoensis* Elmer	Idaho Fescue
n	*Festuca megalura* Nutt.	Foxtail or Zorro Fescue
n	*Festuca microstachys* Nutt.	Nuttall's Fescue
i	*Festuca myuros* L.	Rattail Fescue
n	*Festuca occidentalis* Hook.	Western Fescue
i	*Festuca pratensis* Huds.	Meadow Fescue
n	*Festuca viridula* Vasey	Mountain Bunchgrass
i	*Holcus lanatus* L.	Velvetgrass
i	*Hordeum geniculatum* Allioni.	Mediterranean Barley
i	*Hordeum leporinum* Link.	Barley

n *Koeleria macrantha* (Ledeb.) Spreng.	Junegrass
i *Lolium multiflorum* Lam.	Italian Ryegrass
i *Lolium perenne* L.	Perennial Ryegrass
i *Lolium temulentum* L.	Darnel
n *Melica aristata* Thurb. ex Bol.	Awned Oniongrass
n *Melica Hartfordii* Bol.	Hartford's Oniongrass
n *Melica subulata* (Griseb.) Scribn.	Alaska Oniongrass
i *Phalaris aquatica* L.	Canarygrass
i *Phleum pratense* L.	Timothy Grass
i *Poa compressa* L.	Canadian Bluegrass
n *Poa pratensis* L.	Kentucky Bluegrass
i *Poa trivialis* L.	Rough-stalked Meadowgrass
n *Trisetum cernuum* Trin.	Nodding Trisetum

Nomenclature according to Munz and Keck (1973).
n = native species, i = introduced species.
Subspecies and varieties are not listed.

APPENDIX 3 : UNIT MAP PLATES

Gann's Unit

Elk Camp Unit

Dolason Unit

Count's Hill Unit

Maneze Unit

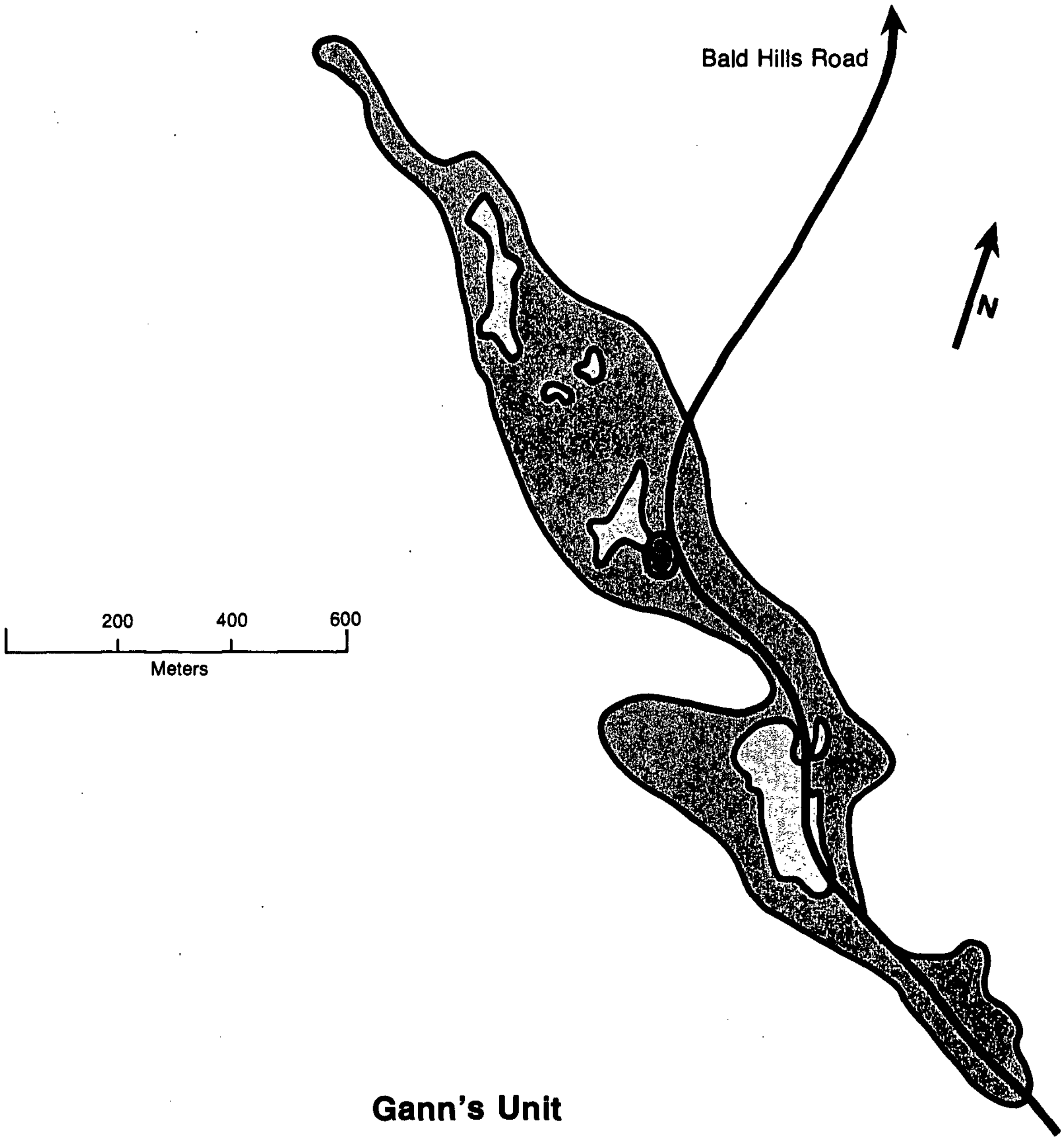
Child's Hill, Copper Creek and Schoolhouse Peak Units

Lyon's Ranch and South Boundary Units

Tick Unit

Pig Pen Unit

Delineation of prairie, oak woodland and areas encroached by Douglas-fir is based on mapping done in 1983. With rapid Douglas-fir growth rates in the region, these maps may not actually reflect current conditions. The areas shown as having been encroached by conifer forest were either prairie or oak woodland in 1850.

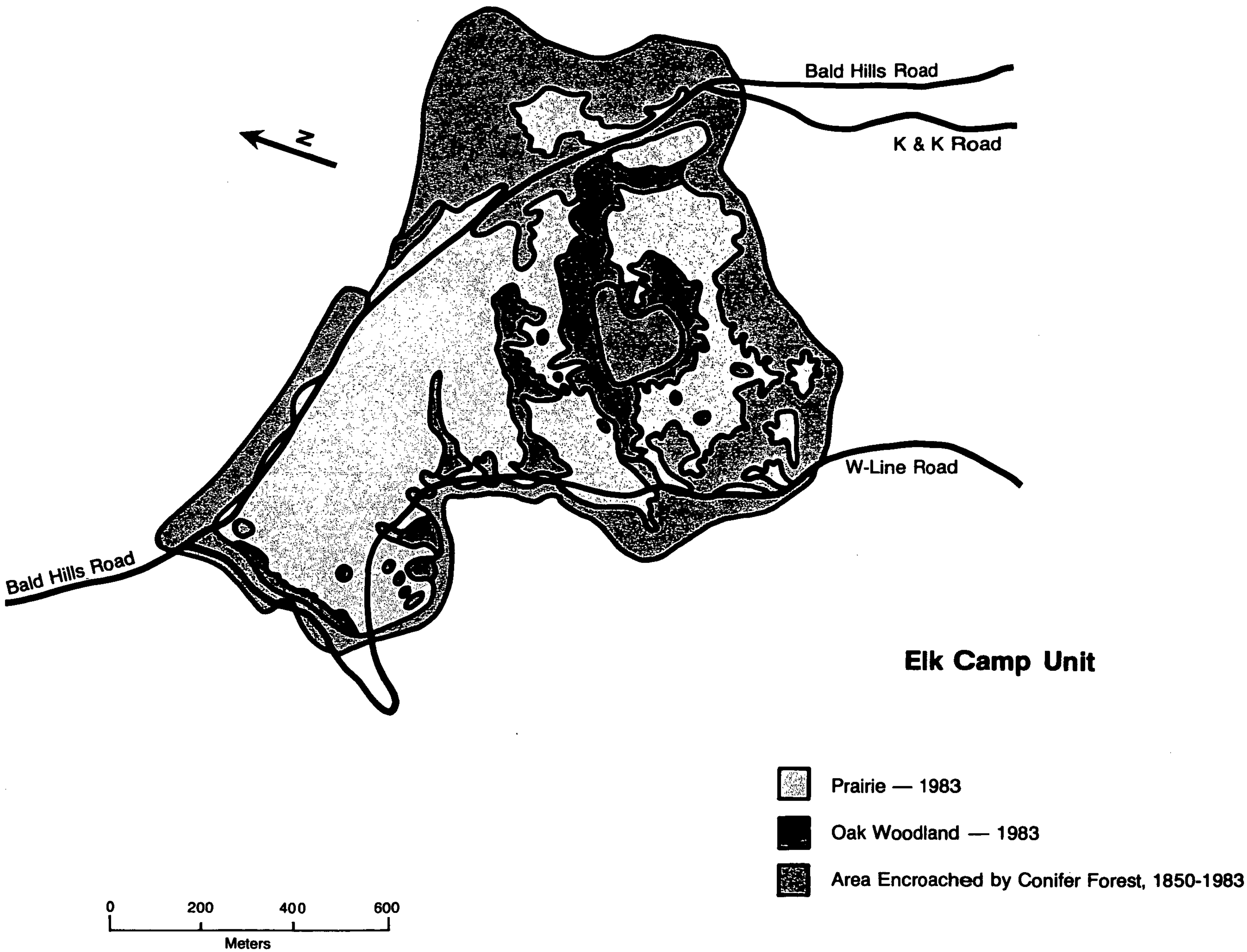


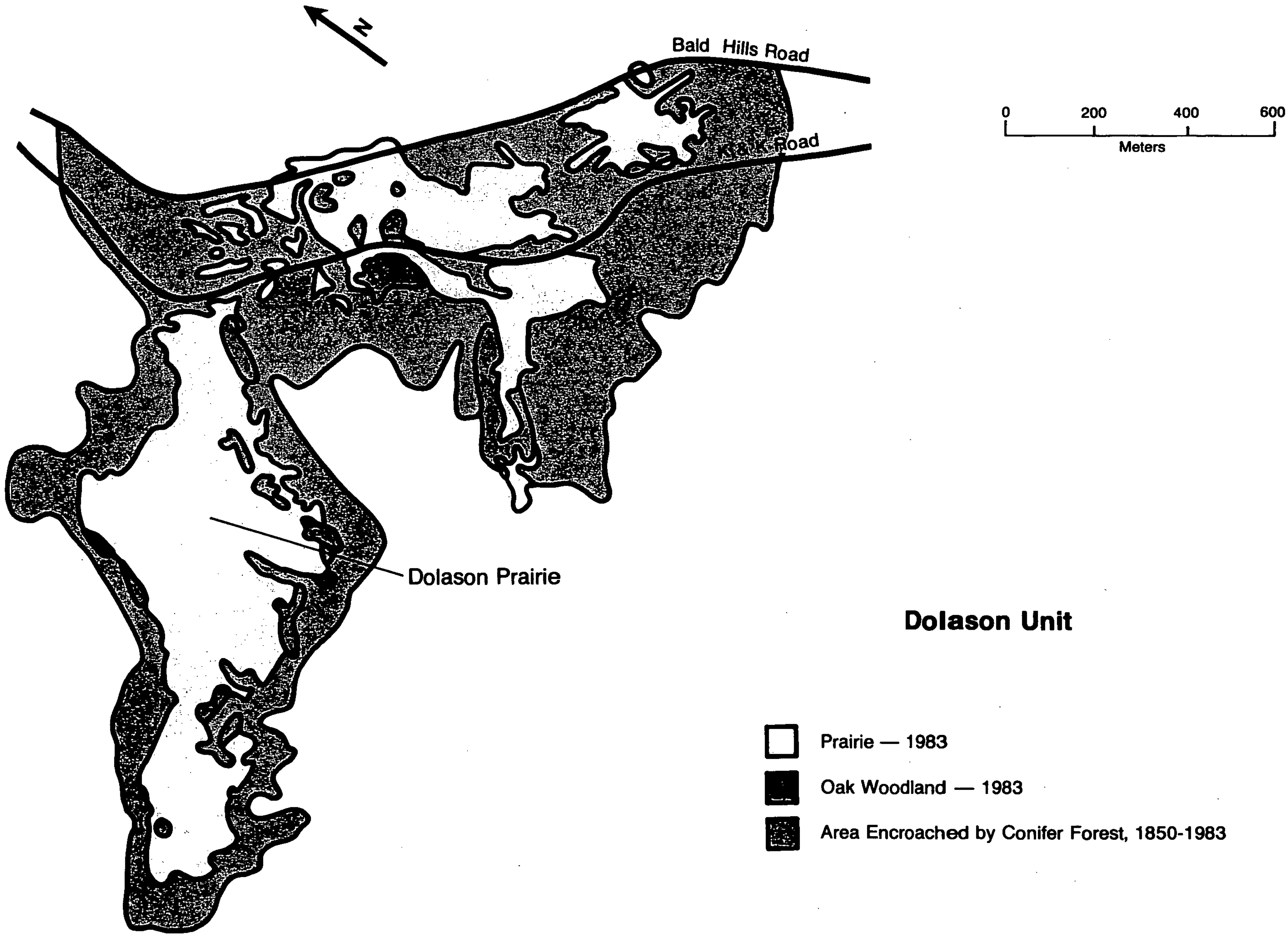
Gann's Unit

Prairie — 1983

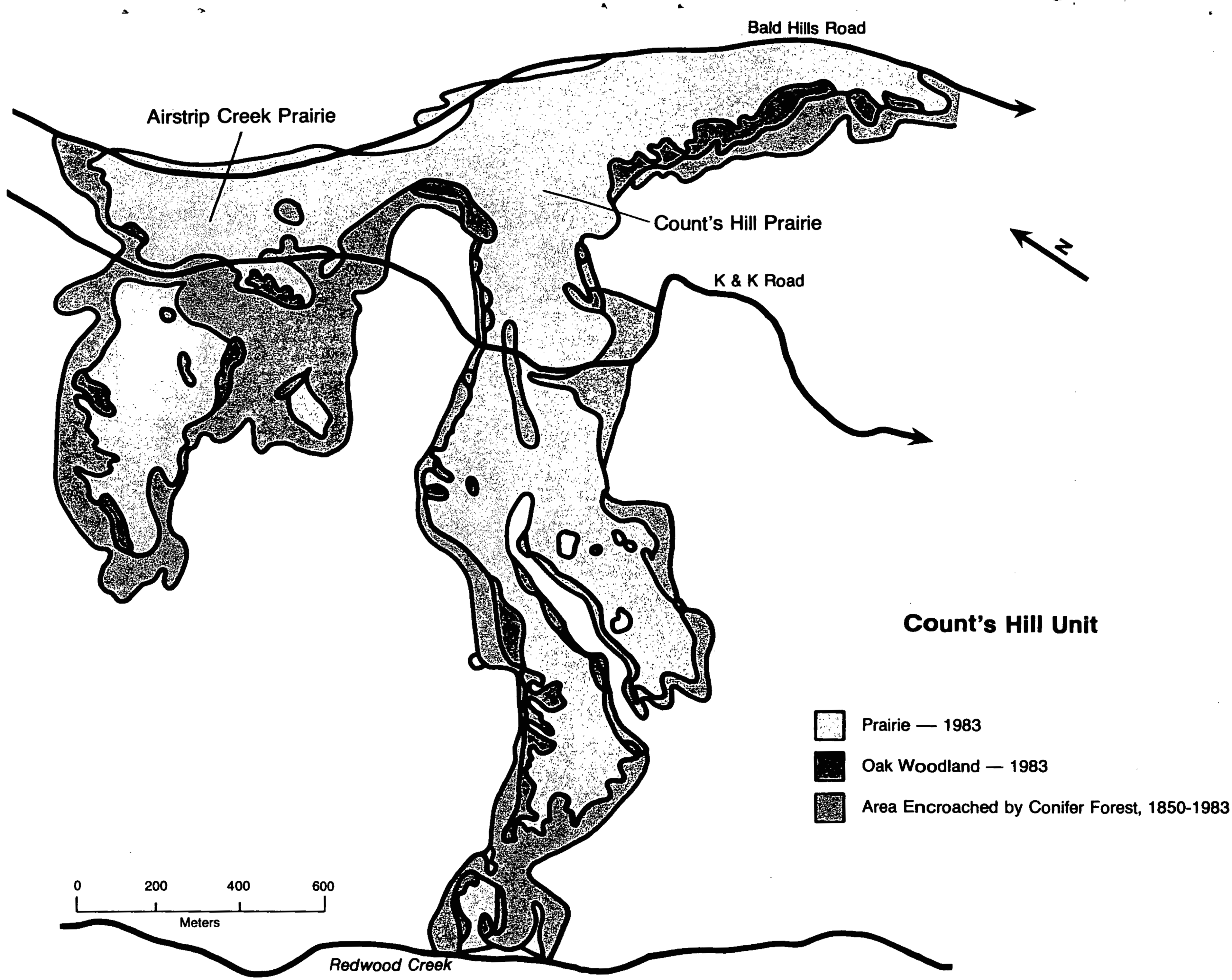
Oak Woodland — 1983

Area Encroached by Conifer Forest, 1850-1983

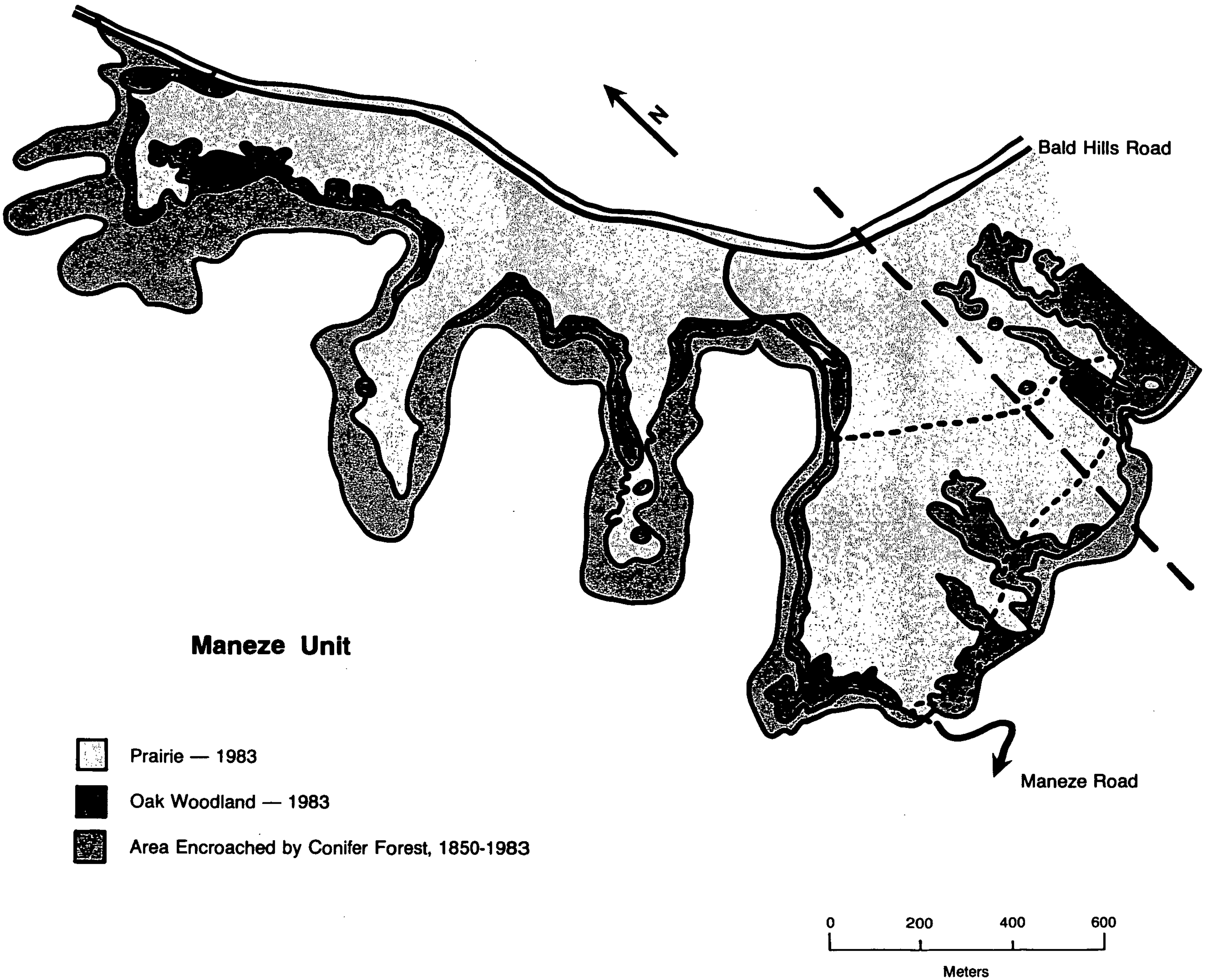

Bald Hills Road
K & K Road
N
W-Line Road
Bald Hills Road
Elk Camp Unit
Prairie — 1983
Oak Woodland — 1983
Area Encroached by Conifer Forest, 1850-1983
0
200
400
600
Meters

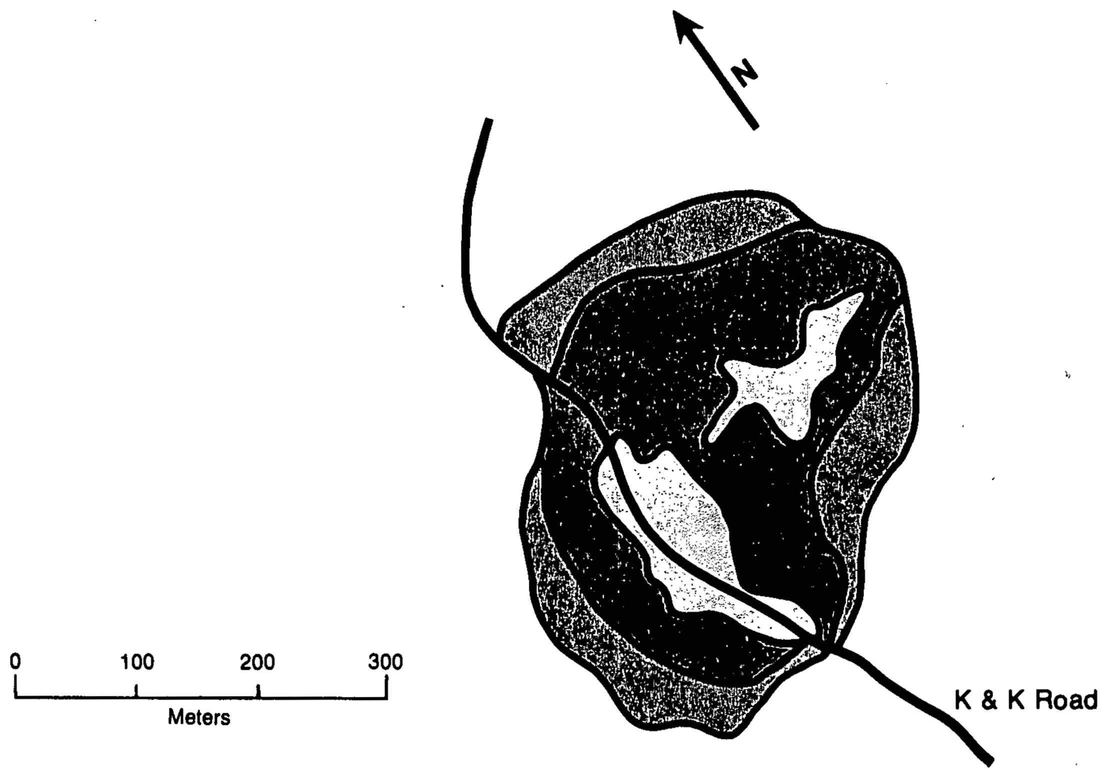


N
Bald Hills Road
K & K Road
0
200
400
600
Meters
Dolason Prairie
Dolason Unit
Prairie — 1983
Oak Woodland — 1983
Area Encroached by Conifer Forest, 1850-1983



Bald Hills Road
Airstrip Creek Prairie
Count's Hill Prairie
K & K Road
N
Count's Hill Unit
Prairie — 1983
Oak Woodland — 1983
Area Encroached by Conifer Forest, 1850-1983
0
200
400
600
Meters
Redwood Creek


N
Bald Hills Road
Maneze Road
Maneze Unit
Prairie — 1983
Oak Woodland — 1983
Area Encroached by Conifer Forest, 1850-1983
0
200
400
600
Meters

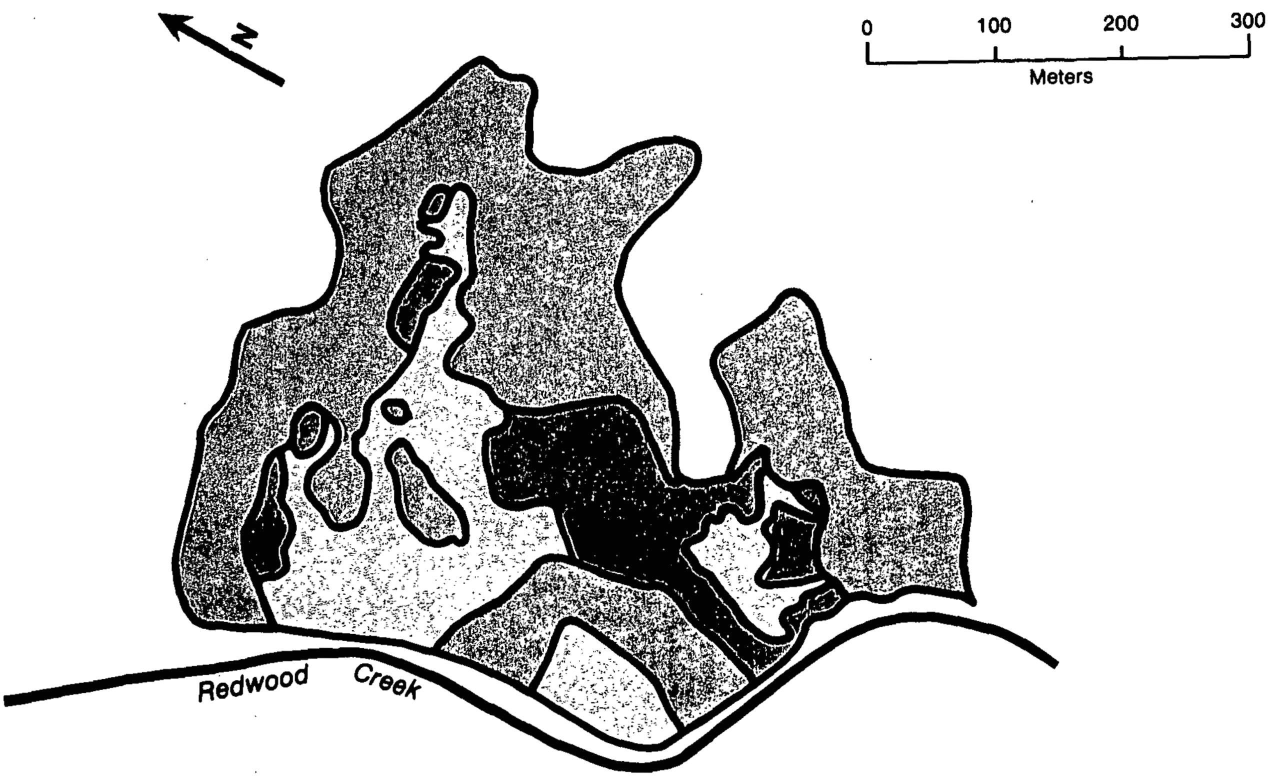


Tick Unit

Prairie — 1983

Oak Woodland — 1983

Area Encroached by Conifer Forest, 1850-1983



Pig Pen Unit

- Prairie — 1983
- Oak Woodland — 1983
- Area Encroached by Conifer Forest, 1850-1983

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