# DOCUMENTATION OF PREHISTORIC VEGETATION FOR A SMALL COASTAL PRAIRIE IN THE NORTH COAST RANGE, HUMBOLDT COUNTY, CALIFORNIA, USING OPAL PHYTOLITH ANALYSIS AND REPEAT PHOTOGRAPHY

by

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DOCUMENTATION OF PREHISTORIC VEGETATION FOR A SMALL COASTAL PRAIRIE IN THE NORTH COAST RANGE, HUMBOLDT COUNTY, CALIFORNIA, USING OPAL PHYTOLITH ANALYSIS AND REPEAT PHOTOGRAPHY

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ABSTRACT

Documentation of Prehistoric Vegetation for a Small Coastal Prairie in the North Coast Range, Humboldt County, California, Using Opal Phytoliths Analysis and Repeat Photography

Karen L. Youngblood

This study documented the prehistoric vegetation of a small coastal prairie in the northern Coast Range, Humboldt County, California. Two primary methods were used, repeat photography and opal phytolith analysis. Tree core analysis also provided information on historic vegetation conditions of the study site. A historic orthophoto, 1942, was overlain with a recent orthophoto, 2000, which determined conifer encroachment had occurred over the last 58 years, but was not uniform spatially. Intersection of the1942 prairie polygon and 2000 prairie polygon created four vegetation zones used for opal phytolith sampling. Zone GG was grass-dominated in 1942 and remains grass-dominated today. Zone GT was grass-dominated in 1942 and is now tree-dominated. Zone TG was tree-dominated in 1942 and is now grass-dominated. Zone TT was tree-dominated in 1942 and remains tree-dominated today.

Opal phytolith concentrations were categorized for each vegetation zone by morphological shape indicating festucoid-type and panicoid-type grasses. Average opal concentrations for each morphological type were statistically significantly different between vegetation zones using a nonparametric Kruskal-Wallis test. High variability between sample points within and between vegetation zones indicates a dynamic vegetation history for the study site. Vegetation boundaries created from aerial photographs do not designate prehistoric vegetation boundaries.

Low concentrations of dumbbell opals found in all vegetation zones indicate that panicoid grasses did not dominate this site prehistorically. However, the presence of dumbbell phytoliths in all zones show that native grasses have occurred at the site at some time in the past. It is likely that *Danthonia californica*, a dumbbell-producing native currently very sparse at the study site, was more widespread prehistorically and also present in the current forest zones. My first hypothesis, that the study site is being encroached by forest vegetation is supported by repeat aerial photography and opal phytolith analysis. My second hypothesis, that the study site was prehistorically part of a larger prairie is not supported by opal phytolith analysis. Prairie vegetation occurred at the site but was not homogenous and probably not stable over the long term. Rather, it appears that the study site was prehistorically a temporal and spatial vegetation mosaic.

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# INTRODUCTION

The extent and the composition of California grasslands, including coastal prairies, are not well recorded (Heady et al. 1988). Several scientists have speculated on the extent of native California grassland. Burcham estimated that the native California grassland, before European settlement, might have covered more than 8 million hectares (Stromberg et al. 2001). Beetle (1947) stated that due to the present distribution of numerous perennial grass species, the pristine grassland was extensive and corresponded roughly with the extent of the present day annual grassland, including that portion now cultivated. Clements (1934) concluded that widely scattered patches of perennial bunchgrass were relicts of a vast perennial grassland. Actual prehistoric grassland conditions in California will probably never be known precisely, however, many studies have been conducted in attempts to supplement preexisting knowledge of prehistoric grassland conditions, size and composition.

Currently, an area of about 7 million hectares (25% of the total area of California) is oak savanna, and is now dominated by exotic grass species primarily of Mediterranean origin delineated as grassland in California. Most of this area was formerly native grassland (Huenneke 1989). Consequently, native perennial grasslands in California are among the most endangered ecosystems in the United States (Peters and Noss 1995). Of the 7 million hectares of current California grassland, 355,614 hectares are coastal prairie, the type of grassland examined in this study. Humboldt County has 162,214 hectares of coastal prairie, which comprise 18% of the county's vegetation cover and 2.4 % of the state's grassland (Huenneke 1989).

The coastal prairie is discontinuous and occurs along the California coast from Santa Cruz northward below 1000 m in elevation and seldom more than 100 km from the coast. The coastal prairie favors a cool, wet climate (Heady et al. 1988). The boundary between coastal prairie and valley grassland is unclear, but it probably lies near the inland side of the coastal redwood zone. Typically coastal prairies occur on ridges and south-facing slopes, or alternate with forest and scrub in the valleys and on north-facing slopes. Coastal prairies also commonly are earth flows, occurring on poorly drained soils, often clays derived from serpentine outcrops (Heady et al. 1988).

In the northern coastal region, small and scattered coastal prairies are characteristically dominated by native perennials *Danthonia californica*, *Festuca idahoensis* (Heady et al. 1988), and *Stipa spp.* (Bartolome and Klukkert 1986). Several important introduced perennials occur in these stands, including *Anthoxanthum odoratum*, *Danthonia pilosa*, *Holcus lanatus* and *Plantago lanceolata* (Heady et al. 1988, Hektner and Foin 1977). Heady et al. (1988) suggested that the presence of introduced perennials along the coast, but not inland, lends support to the theory that in the pristine state the coastal areas supported few annuals.

The regional disturbance regime, such as fire and grazing, is significant when determining the prehistoric extent of coastal prairies. The use of fire, for various objectives, has been documented for almost every California Indian group, including those that inhabited the coastal prairie. Native Americans burned prairies regularly to maintain acorn crops and other desirable flora and fauna (Lewis 1993). According to Greenlee and Langenheim (1990), presettlement fires in coastal grasslands were frequent, with 2 to10 year return intervals.

Regular burning set back ecological succession, and prevented conifer encroachment into prairies. In the past, managed burning maintained and enlarged the extent of prairies. Since European settlement in the area, managed burns of coastal prairies in the north coast region essentially stopped, allowing forest vegetation to progressively encroach upon larger prairies. In Redwood National Park, over 830 acres (336 hectares) of prairies and oak woodlands have converted to Douglas-fir dominated forest during the last 130-140 years (Sugihara and Reed 1987). It may be that coastal prairie species have evolved under an intense fire-frequency regime (Heady et al. 1988).

Livestock grazing in coastal prairies has occurred for a relatively short time, since the mid-1800s with European settlement, compared with managed burning in coastal prairies. However, the combination of fire suppression by European settlers and the year-long heavy grazing by cattle and sheep transformed coastal grasslands into almost pure stands of non-natives including: *Holcus lanatus*, *Anthoxanthum*, *Bromus hordeaceus*, *Lolium perenne*, *Avena fatua*, and *Hordeum* spp. Forbs, largely unpalatable to cattle, also spread rapidly in the absence of fire: *Silybum marianum*, *Cynara scolymus*, and *Hypericum perforatum* became dominant on much of the former coastal grasslands (Barbour and Major 1988). Additionally, it is important to consider that some of California's current grassland (estimated 7 million hectares) may not have formerly been perennial grassland but have been created from other vegetation types- such as oak woodland, chaparral, or coastal scrub -due to grazing (Hamilton 1997).

Shrubs (McBride and Heady 1968) or trees (Callaway and Davis 1993) invade coastal grasslands when fire and grazing are excluded. McBride and Heady (1968) studied the vegetation dynamics of a *Baccharis* brushland in Contra Costa County, California and concluded that not only did northern coastal scrub invade coastal prairie, but also it in turn was invaded by mixed evergreen forest. Transition from scrub to forest at the Contra Costa site was estimated to take about 50 years in the absence of disturbance. Callaway and Davis (1993) used aerial photographs spanning 42 years to show substantial conversion of unburned vegetation from prairie to coastal sage scrub, coastal sage scrub to chaparral, and chaparral to oak woodland. These transition rates indicated that vegetation patterns in the study area are dynamic, and may reflect a "shifting mosaic" landscape even in the absence of large-scale disturbance.

In summary, considerable research has been done to characterize the present-day coastal prairie as described. We know what plant associations will most likely occur in coastal prairies and those that will occur in more inland grasslands. We know how disturbance will affect both directions of succession of a coastal prairie community. We know how other plant species interact, compete and invade the coastal prairie community. We know that the pristine coastal prairie is endangered due to invasion by non-native perennials mostly introduced from the Mediterranean. What we do not know is how coastal prairies were distributed prehistorically. It is thought by some that coastal prairies may have been patchy on a finer scale. Kuchler labeled mapped units as "coastal prairie-scrub mosaic" (Barbour and Major 1988). It is possible that coastal prairies existed in a temporal and spatial mosaic of vegetation types including shrub and forest communities.

The objective of this study was to describe the prehistoric vegetation of a small coastal prairie in order to better understand historical dynamics of the prairie/forest community. My first hypothesis was that forest vegetation had encroached upon the study site, which will eventually become a closed forest in the absence of disturbance and significant environmental change. My second hypothesis was that the study site was prehistorically part of a more extensive coastal prairie.

# SITE LOCATION AND DESCRIPTION

## Location

The study site was 4.7 hectares and located in the northwestern corner of Humboldt State University's L.W. Schatz Demonstration Tree Farm (Figure 1), approximately 26 km due east of the coast and several km east of the redwood forest zone. The tree farm, 148 ha, is a mixed conifer forest in the Mad River watershed of northern Humboldt County, California, Maple Creek USGS topographic quadrangle, T5N, R3E, S32. The forested tree farm was adjacent to larger areas of coastal prairie also referred to as "bald hills" some of which were being grazed at the time of the study. Davis Creek, which flows along the northern boundary of the study site, is a tributary to Maple Creek, which flows into the Mad River. A tributary of Davis Creek flows along the southern boundary of the study site.

## Land Use History

Historically, the Whilkut Indians inhabited this area of the Mad River watershed, now known as Butler Valley (Kroeber 1972, Heizner 1974, Mead 1971). The Whilkut, strongly related linguistically to the Hupa Indians living just northeast of the Whilkut territory. Their population was estimated to be about 500 in 1770 (Kroeber 1972). Several villages are known to have existed in and near Butler Valley suggesting that the valley was suitable for human habitation (Kohl 1972). The Whilkuts most likely turned to the northern oak woodland covering the ridges around Butler Valley for their sources

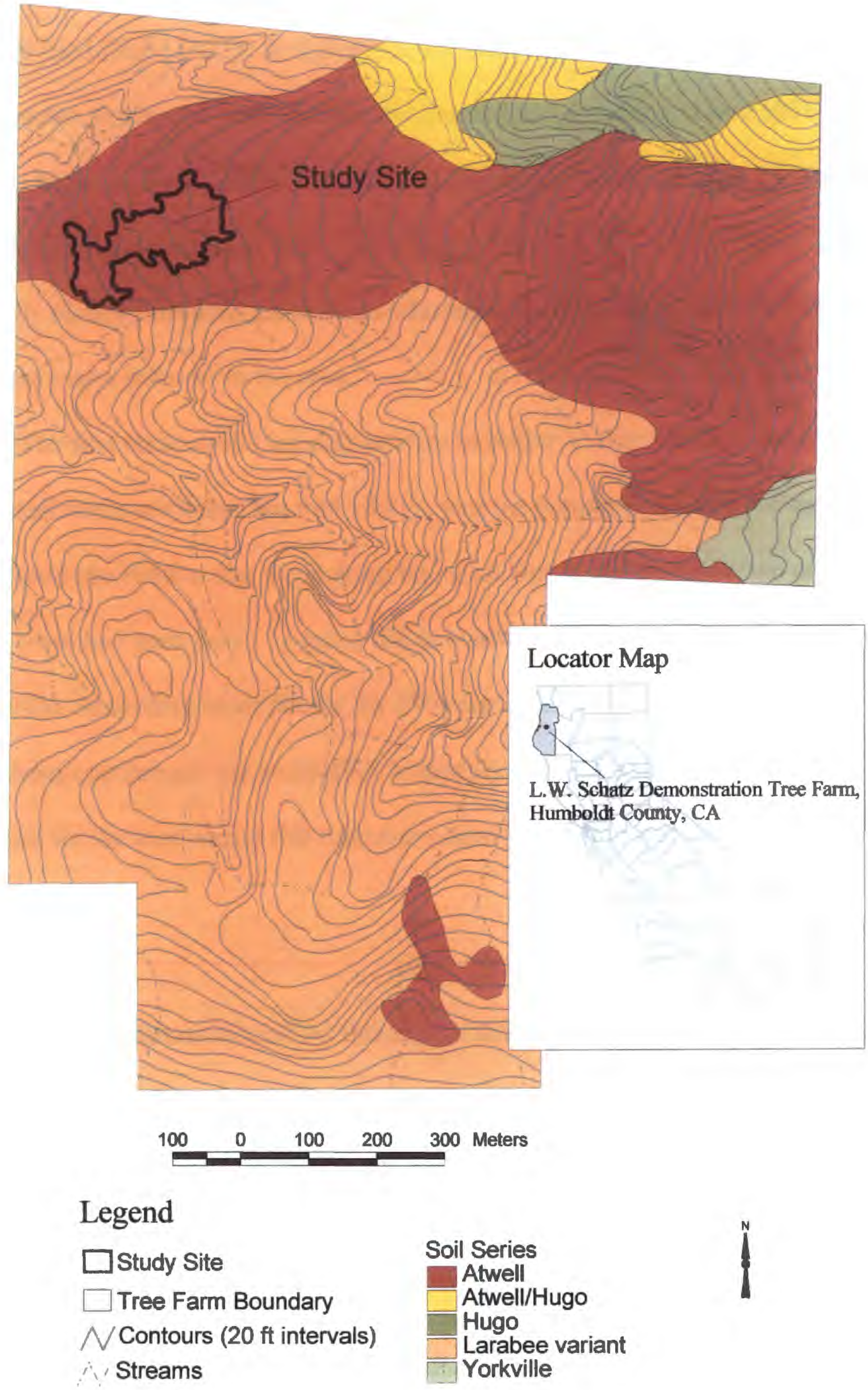


Figure 1. Study site location. Shown within L.W. Schatz Demonstration Tree Farm property boundary with soil series, streams and topography. Scale shown is 1:10,000.

of winter food (Kohl 1972). It is possible that the Whilkuts were regularly burning certain areas, to maintain open prairies for hunting and gathering (Loud 1918). Violent conflicts between the Whilkuts, neighboring tribes and European settlers in this region began in 1858 and continued until 1864 (Kohl 1972). By the 1880's, Butler Valley was settled by mostly European immigrants who made their livelihood by stock raising which is still the major industry in the area.

The first commercial logging activity in Butler Valley, which started with some of the earliest white settlers in the mid 1800's, was the cutting of tan-oak for tan bark. It wasn't until the 1940's, that the logging boom hit Butler Valley when two mills in a nearby town had been built. Logging did not occur at the study site until sometime soon after 1948. According to air photos, by 1954 through 1975, several roads were built near and at least one through the study site. It appears from the photos that the silvicultural treatment for the area during this time was a heavy selection cut.

## Climate

Average annual rainfall for this region is about 1650 mm (Ranty 1972). Most of the rainfall occurs between November and May (Kohl 1972). Summer brings coastal fog into the area at night. Temperatures are warm in the summer but rarely exceed 20° C. Winters are cool and wet.

## Geology and Soils

The study site, located in the north Coast Range of California, is underlain by the central belt of the Franciscan formation (McLaughlin et al. 2000). The broad outline of topography is controlled by a series of longitudinal folds and faults, and is dominated by an irregular, knobby earthflow topography common to the Franciscan formation. The study site appeared to be part of a slow moving earthflow, showing signs of movement such as cracks, hummocky topography, and leaning trees.

The soil type at the study site was classified in the Atwell series: a fine, mixed, isomesic Mollic Hapludalf. It is described as a very deep, moderately well or somewhat poorly drained soil that formed in material from sheared sedimentary rocks (Natural Resource Conservation Service 1993).

## Physiography

The aspect of the study site was SSW. Position was the middle 1/3 portion of a convex slope and slope ranged from 5 to 20%. The elevation of the study site ranged from 700 to 800 m.

## Vegetation

The study site was mainly comprised of native and non-native grasses and shrubs, which resembled a mosaic of Heady et al.'s (1988) description of coastal prairie and coastal scrub communities. Few trees grow within the grass-dominated area, predominantly *Fraxinus latifolia* and *Acer macrophyllum*. *Abies grandis* and *Pseudotsuga menziesii* seedlings (less than 3 cm diameter), comprise less than 1% cover, and also grow within the grass/shrub vegetation zone. The dominant shrubs include: *Rosa spp.*, *Rhus diversiloba*, *Lupinus spp.* and *Baccharis pilularis*. The dominant introduced grasses include: *Holcus lanatus*, *Dactylis glomerata*, and *Anthoxanthum* *odoratum*. The dominant native grasses include: *Bromus carinatus* and *Elymus glaucus*. The surrounding forested area was dominated by *Umbellularia californica, Alnus rubra, Pseudotsuga menziesii*, and *Abies grandis*. (See Appendix A for a species list of the study site).

Several large Douglas-fir and one grand fir (114 to 152 cm dbh) with especially large, low, live, long branches were present at the study site. These branches are a clear indication that the conifers developed in the open for an extended period. The presence of the open-grown Douglas-fir and grand fir now surrounded by forest vegetation was an indicator of previous prairie conditions and was an important consideration used to select the study site.

Remnant oak woodlands bordered the nearby bald hills, approximately 1.2 km east and 1.0 km north of the study site. The dominant tree species of these oak woodlands were *Quercus garryana* and *Q. kelloggii*.

# METHODS

Several different methods can be used to study vegetation dynamics: permanent plot monitoring, collecting data from the same site over a long period of time; development of a chronosequence, selecting several similar plots with factors other than age held relatively constant; repeat photography, analysis of change through photographs of the same site; and paleobotanical methods. Paleobotanical methods include dendrochronology, pollen analysis, and opal phytolith analysis. Dendrochronology uses tree rings and scars to interpret past conditions. Pollen analysis uses pollen preserved in sediments to determine vegetation history and requires environmental conditions that will prevent decomposition of fragile pollen. Such conditions are found in the constantly wet sediments of ponds, lakes or marshes. Opal phytolith analysis uses plant microfossils from soil to determine past vegetation and is appropriate when prairie vegetation is part of the site history. Due to the availability of historic and current aerial photographs and the presence of at least 58 years of prairie vegetation, the two primary methods used for this study were repeat aerial photography and opal phytolith analysis. Tree core analysis was also used to support results from the two primary methods.

## Repeat Aerial Photography

An initial review of aerial photographs from 1942 and 2000 suggested that the prairie/forest boundary of the study site had changed. Repeat aerial photography does not produce photographs whose features correspond exactly when overlain because of errors introduced by terrain displacement compounded by changes in tree height overtime. Also, due to the study site's small area and even smaller areas of vegetation change over 58 years, orthorectification (a form of georectification which corrects for terrain displacement) of the aerial photographs was required. According to Manzer (1996) scan sample rate (expressed in dpi at photo scale), rectification procedures, selection of control points and DEM data density are all important in controlling the image quality of the digital orthophoto. In order to assure image quality and a high level of precision the following procedures were used.

To start the orthorectification process, standard 9 X 9 format panchromatic aerial photographs were scanned for 1942 and 2000 at 1200 dpi. A March II GPS (global positioning system) unit was used to obtain five to ten ground control points of identifiable features surrounding the study site taking advantage of road intersections. The number of ground control points was limited by the number of features identifiable in both the oldest (1942), and the most recent (2000) photo. There were very few roads and structures in 1942, so the number of ground control points for the rectification of the old photograph was only five. At each chosen ground control point in the field, five hundred to 1000 fixes (the number of positions (x, y, and z) recorded in the GPS unit), were obtained. Since post-processing averages the final position based on each fix acquired with the GPS unit, generally the more positions acquired for each ground control point the more precise the final position. However, due to the quality and sensitivity of the March II GPS unit, some positions required up to two hours reaching only 500 fixes. The resulting difference of position after post-processing 500 fixes compared to 1000 fixes was determined to be insignificant. Consequently, 500 fixes was more commonly the maximum number of fixes acquired for each position. The coordinate system Universal Transverse Mercator (UTM) and North American Datum (NAD) 1983 were used.

The ground control point coordinates were real-time differentially corrected and post-processed using the March II post-processing software (PCGPS) developed by Corvallis Microtechnology. Post-processing allows the transferring of the original ground-obtained GPS data into a computer for correction of errors that might be caused by selective availability of satellites (pre-2000) or atmospheric interference. Post-processing also enables the translation of GPS data for an appropriate format to be used in a Geographic Information System (GIS) software package. Real-time differential correction uses the readings of a stationary GPS receiver at a base station with a precisely determined position (often by using other GPS base stations). The base station's data is used to correct the field GPS data resulting in a more precise field position. The general precision of the March II unit with post-processing is 1 to 5 meters on the ground. For this study, the highest level of precision obtainable is necessary to ensure that errors in geographic placement of each sampling zone are minimal.

The differentially corrected ground control points, a 10 x 10m USGS digital elevation model, the camera calibration information, and the scanned images, were used in the orthorectification module of ERDAS Imagine to resample each image using cubic convolution. Resampling is the process of extrapolating data values for the pixels on the new image from the values of the source pixels (ERDAS 1997), which results in the digital orthophoto. Cubic convolution uses the data file values of sixteen pixels in a 4 x 4 window to calculate an output value with a cubic function. Although more computationally intensive than using nearest neighbor interpolation (using the value of the closest pixel to assign the output pixel value), cubic convolution results in a more accurate orthophoto (Foley 1996). Once images were orthorectified, horizontal error between images was calculated by measuring the distance between identical points along roads between images.

Orthophotos were then overlain to observe vegetation boundary changes over time. Vector polygon layers were created in ArcView by delineating the boundaries of the prairie vegetation in the 1942 orthophoto and the 2000 orthophoto. The prairie/forest boundaries were digitized on screen. In most cases, shadows were assumed to obscure grass vegetation, so shadowed areas were included in the prairie polygons. Large conifers within the prairie were delineated and excluded from the prairie polygons. Difficult to discern small trees and shrubs were included in the prairie polygon. The two prairie polygons, historic (1942) and recent (2000) were intersected using Arc Info. Four vegetation zones were identified as a result of the intersection of the 1942 prairie boundary and the 2000 prairie boundary. One vegetation zone was grass-dominated in 1942 and was still grass-dominated in 2000 (GG); another was grass-dominated in 1942 and was tree-dominated in 2000 (GT); the third was tree-dominated in 1942 and was grass-dominated in 2000 (TG); the fourth zone was tree-dominated in 1942 and was still tree-dominated in 2000 (TT). The recognition of the four zones initiated the next phase of this project, opal phytolith analysis.

## Opal Phytolith Analysis

Opal phytoliths are inorganic biogenetic plant particles composed of hydrated silicon dioxide (($SiO_2 \cdot nH_2O$). They are formed in plants through the passive uptake of monosilicic acid by way of the transpiration stream from soil solution (Jones and

Handreck 1967). As the plant uses water, silica is precipitated out in and around cells in mostly the leaf portion of the plant. Opal phytoliths are added to the soil when the plant leaves die and decompose. The phytoliths remain in the surface soils because they are silt-sized, most ranging from 2 to 50 microns, which are larger than the underlying dominant clays. They are resistant to erosion because they are composed of silica and can persist in the surface soils for long periods of time. Wilding (1967) fractionated and purified a 60 g sample of opal phytoliths from 45 kg of Ohio brunizem soil for carbon dating. The 60 g sample contained 1.3% carbon, which had a carbon date of 13,300 +/- 450 years.

In the Poaceae, phytolith morphology is diagnostic at the subfamily and tribal levels. Twiss et al. (1969) were able to clearly differentiate three distinct morphological types of opal phytoliths: panicoid grasses which were dumbbell shaped, festucoid grasses which were short-cell shaped, and chloridoid grasses which were saddle shaped.

Others have identified grass and tree opals that differ strikingly in morphology and mass, making them useful as indicators of prehistoric prairie/forest boundaries and evidence of past prairie presence (Witty and Knox 1964, Rovner 1971, Wilding and Drees 1971, Bartolome and Klukkert 1986, Fisher and Jenkins 1987, Kalisz and Boettcher 1990, Knoepp et al. 1998). The solid polyhedral, silt-sized, grass phytoliths are easy to identify in contrast to tree phytoliths which are irregularly-shaped and clay-sized, generally less than 5 microns. Diagnostically-shaped opals for most trees have not been found. Prairie soils have much higher quantities of opal phytoliths, commonly 10 to 20 times more than forest soils (Rovner 1971).

The presence and abundance of dumbbell or panicoid opal, is most diagnostic in determining the presence of prehistoric prairie vegetation in California. The native perennials assumed to have dominated prehistoric California coastal prairies are *Stipa* spp. and *Danthonia californica,* both of which contain significant amounts of dumbbell-shaped (panicoid) opal phytoliths (Bartolome and Klukkert 1986). Currently, only one known native California grass (*Danthonia californica)* at my study site produces dumbbell opal phytoliths.

Soil Sampling and Laboratory Methods

Soil sampling design for opal phytolith analysis was based on results of air photo analysis, which determined four different vegetation zones. Thirty-six sample locations were stratified, based on the four vegetation zones, with equal allocation. Three approximately equal area plots were selected for each zone so that there were 12 plots. Three sample points were placed in each plot. Sample points were placed at least 9.6 m (maximum ground positional error calculated from orthorectification) within the boundary of each polygon to lie below image maximum error limits. However, because zone TG polygons were small, sometimes less than 19.2 m across, six of nine sample points were less than 9.6 m from the boundary. The sample points were evenly dispersed towards the center of each polygon, however the actual placement of the sample points was somewhat arbitrary. When in the field, present day vegetation and key features, such as the road and very large individual conifers, identified in photos confirmed the locations of the sample points within each polygon.

A clean trowel (washed with distilled water to avoid cross contamination) was used to collect soil from the A horizon between 0 and 10 cm depth (Bicknell et al. 1988, 1990, 1991, 1993a, 1993b, 1993c, Kalisz and Boettcher 1990) at each sampling point. Collected soil was treated in the laboratory at Humboldt State University. Opal phytolith analysis techniques have been described in Bicknell et al. (1988, 1990, 1991, 1993a, 1993b, 1993c), Bartolome and Klukkert (1986), and Piperno (1988). Laboratory methods used, as specifically adapted to this study are as follows.

Surface soil samples were air dried in loosely covered paper containers. A spoonful of each dried sample was sieved through 2-mm sieves to remove rocks, roots, leaves, and other material larger than 2 mm. The remaining soil was weighed, and then crushed with a glass mortar and pestle. The crushed sample was then sieved through a 150 micron wire mesh sieve. The soil fraction that passed the sieve was weighed, and then digested in 30% hydrogen peroxide ($H_2O_2$) on a hot plate (Pyromultimagnistir). Hydrogen peroxide was used because it digests organics without destroying silica particles. At the beginning of this phase of organic digestion, four capsules with 40,050 microscopic glass beads (microspheres) that were similar in size (15 to 20 microns) and specific gravity (2.5) to opal phytoliths, were added to each weighed soil sample. The digest was allowed to settle for at least one hour, and the supernatant was decanted and discarded. The sediment was diluted with 40 ml of 5% sodium hexametaphosphate, and dispersed by immersion in an ultrasonic water bath for 5 minutes. This suspension was wet sieved through a 106-micron wire mesh sieve, and the suspension passing the sieve was diluted to 200 ml with room temperature distilled water.

Suspended samples were then processed through two timed sedimentations in which the particles less than 10 microns and greater than 50 microns were discarded. The remaining suspension was allowed to settle for at least one hour, the supernatant was decanted, and sediment was retained. Sediment was washed into centrifuge tubes with 15 ml distilled water, and centrifuged two minutes and decanted. Tertiary butanol alcohol (TBA) was then added to the sediment to dry it in preparation for suspending it in oil. The sediment and TBA were transferred to storage vials, centrifuged, and the TBA was decanted. Immersion oil (150 c.s) was added to the storage vials to adequately dilute sample volume. Permanent microscope slides were prepared by covering the oil suspended sediment with a cover slide and sealing it with clear finger-nail polish.

Microscope slides were examined at 400x on a Leica light transmitting, phase contrast microscope. Traverses were made of each slide, and opal phytoliths were counted in distinct observable categories: dumbbells, short cells, and rods (see Appendix B for laboratory data). Microspheres were counted simultaneously. The counting continued on each sample until 30 microspheres were observed. The addition of a known quantity of glass beads to a known sample weight allowed the determination of the number of opal bits per gram of soil (Bicknell et al., 1993a). Consistent with Bicknell's studies, dumbbells represent panicoid-type grasses and both short cells and rods represent the festucoid-type grasses at the study site. The opal assemblages from each sample were compared with the reference opal collection of the Paleobotany Laboratory, College of Natural Resources and Sciences, Humboldt State University, and with published references (Twiss et al. 1969).

## Tree Core Analysis

Tree ages of the five largest open grown trees were determined to provide additional historic vegetation information of the study site. The morphological characteristics of the trees (large low lateral branches) support the hypothesis that the study site was an open environment and most likely grass-dominated historically.

A standard 16-inch (40.6 cm) or a standard 36-inch (91.4 cm) increment borer was used to extract tree cores from four Douglas-fir and one grand fir. Cores were mounted on a wooden platform, lightly sanded to enhance ring clarity, and studied for age and growing conditions.

The following steps were used to extrapolate ages for the four cores that did not reach tree pith:

1. Core length including the bark thickness was measured.
2. Core length (1) was subtracted from half the dbh.
3. Number of years growth in the last inch of the core was counted.
4. Number of rings per inch (3) were multiplied by the core length difference from half dbh (2).
5. Number resulting from step 4 was added to the total number of rings counted on core.

# RESULTS

## Repeat Aerial Photography

Orthorectification of the oldest (1942) and most recent (2000) aerial photographs allowed the comparison of the study site's prairie shape and area over 58 years. The prairie area in 1942 was 2.4 hectares, which had decreased by 33 percent to 1.6 hectares in 2000 (Figure 2, 3). Although, conifer encroachment in some areas changed the prairie/forest boundary reducing the size of the prairie, logging changed the prairie/forest boundary location in other areas enlarging the size of the prairie. Consequently, the overall change in prairie area was minimal.

When 1942 and 2000 prairie polygons were intersected, four main vegetation zones used for opal phytolith sampling resulted (Table 1). The change in major vegetation cover in zone GT was caused by conifer encroachment. The change in vegetation cover in zone TG was most likely caused by logging. The four vegetation zones and the soil sampling points for opal phytolith analysis are shown in Figure 4. When the GPS-obtained ground control points used for orthorectification were post-processed, positional error for each ground control point was calculated. The positional root-mean-square (RMS) error for the ten ground control points ranged from 1.3 to 7.3 m on the ground (Table 2). National map accuracy standards, for 1:24,000 scale topographic maps, require well-defined horizontal features to be within 7.2 m on the ground of their correct position at the 68 percent level of confidence (Welch and Remillard 1999). All points except ground control point #13 fell within the national standard acceptable level.

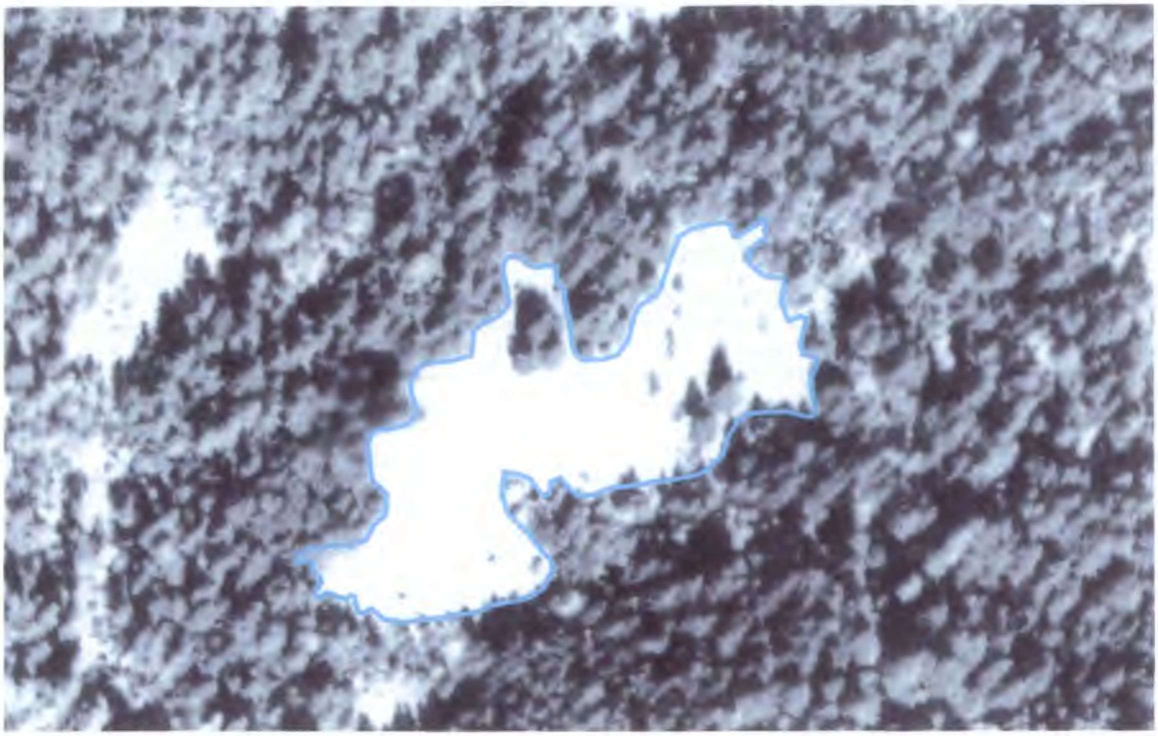

Figure 2. Prairie in 1942 with boundary shown in blue. Photo scale is 1:4000.

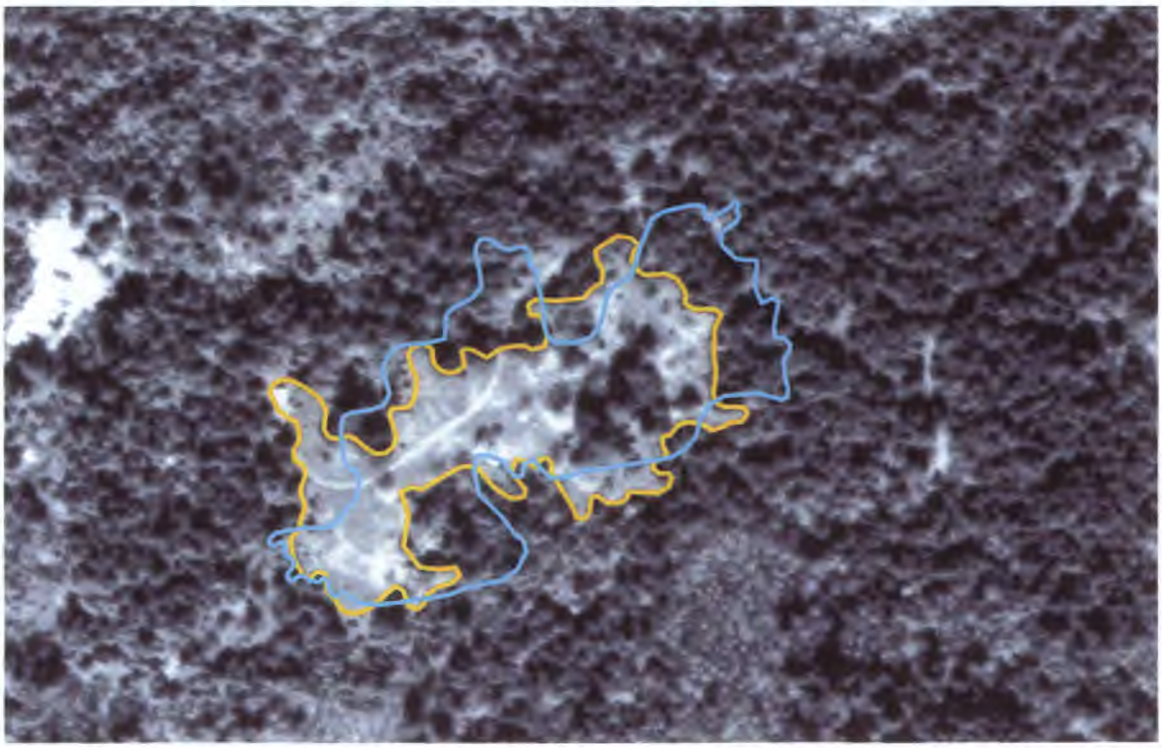

Figure 3. Prairie in 2000. Boundary shown in yellow and overlapping boundary from 1942 shown in blue. Photo scale is 1:4000.

Table 1. Summary of four vegetation zones determined from aerial photographs for opal phytolith sampling.

| Zone | Past Dominant Vegetation (1942) | Present Dominant Vegetation (2000) | Area (hectare) |
|---|---|---|---|
| GG | Grass | Grass | 1.2 |
| GT | Grass | Trees | 1.2 |
| TG | Trees | Grass | 0.4 |
| TT | Trees | Trees | 1.9 |

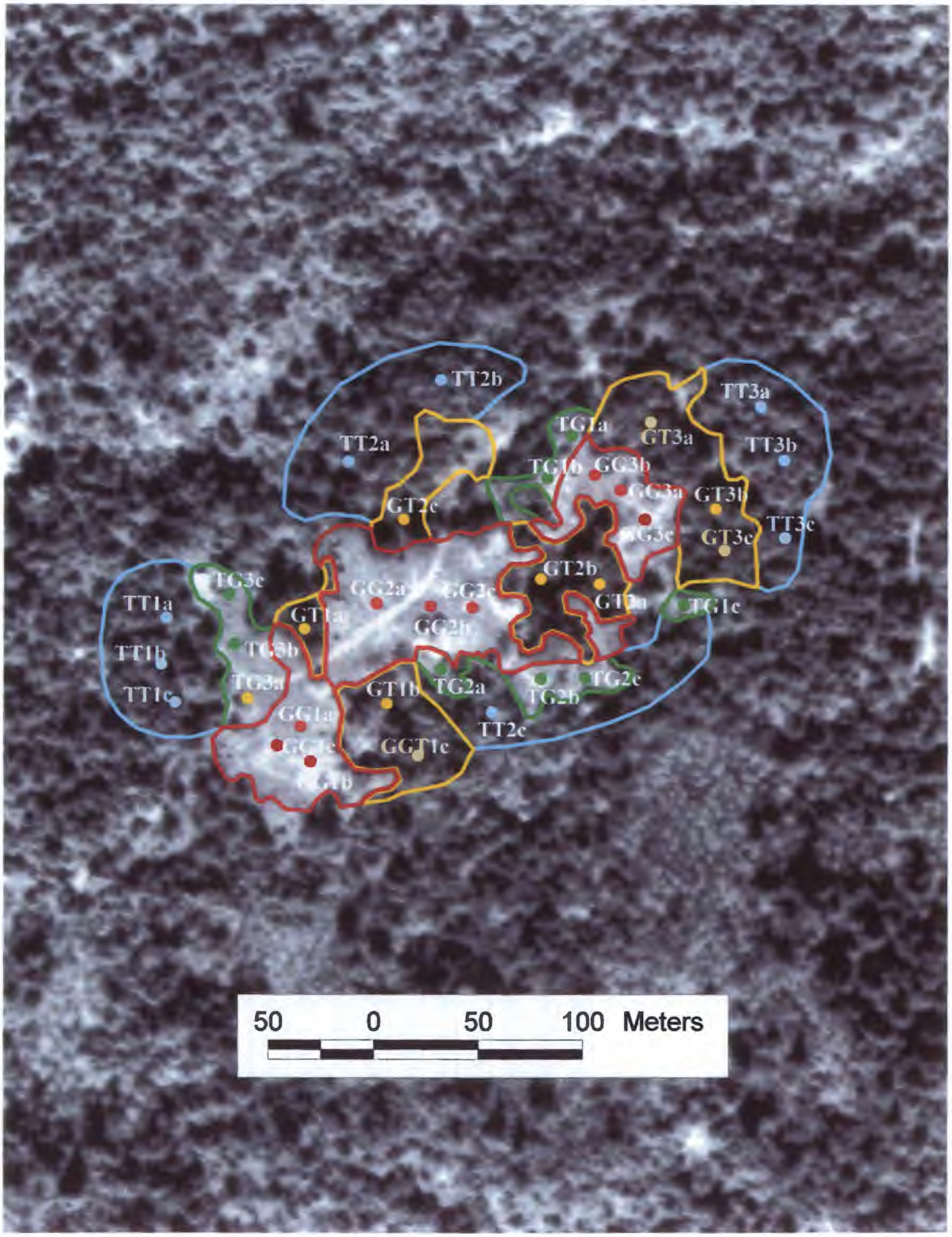


Figure 4. Vegetation zones and sample point location. Zone GG, grass in 1942 and 2000, is shown in red. Zone GT, grass in 1942 and forest in 2000, is shown in yellow. Zone TG, forest in 1942 and grass in 2000, is shown in green. Zone TT, forest in 1942 and 2000, is shown in blue. Scale of photo is 1:3000.

Table 2. Ground control point post-processing summary.

| GCP # | Location | Northing | Easting | Horizontal 2DRMS Error (m) | # Nodes Used | Total Nodes | % Nodes Used |
|---|---|---|---|---|---|---|---|
| 1 | Haul Rd/Priv. Prop Rd | 4513321.1928 | 426270.7812 | 4.51 | 77 | 500 | 15.4 |
| 2 | Haul Rd/Maple Crk. Rd | 4513364.0027 | 426079.6857 | 1.50 | 203 | 500 | 40.6 |
| 4 | Bridge on County Rd | 4514846.5995 | 425906.9721 | 2.27 | 105 | 1000 | 10.5 |
| 8 | Haul Rd/Station Rd | 4513372.1331 | 426447.9260 | 1.41 | 130 | 1000 | 13 |
| 9 | Haul Rd/Davis Rd | 4513594.2407 | 426963.3270 | 2.98 | 479 | 1000 | 47.9 |
| 10 | Carlson Rd near cattle guard | 4513555.7473 | 427515.1179 | 1.92 | 77 | 500 | 15.4 |
| 11 | Carlson Rd, corral | 4513627.1542 | 427626.5057 | 1.26 | 309 | 1000 | 30.9 |
| 12 | Davis Rd/Pumphouse Rd | 4514493.9776 | 426884.6783 | 6.64 | 80 | 500 | 16 |
| 13 | Davis Rd woodgate | 4514651.3877 | 426997.3109 | 7.31 | 96 | 500 | 19.2 |
| 15 | Red Barn on County Rd | 4513980.7883 | 426015.9009 | 2.38 | 150 | 500 | 30 |

The orthorectification process created RMS errors for each orthophoto. Errors were calculated from the input coordinates of ground control points and the corresponding ground control point location manually placed on each digital photo. The overall RMS error for the 1942 photo was 0.0163 mm and for the 2000 photo was 0.0105 mm. This error is the difference of the initial ground control point location on digitized images and the ground control point location on images after transformation.

The orthophoto RMS error caused an average 3.8 m ground distance error between the 1942 and 2000 orthophotos. Error for twenty-two tested points ranged from 0.1 to 9.6 m. As expected, the largest error occurred at the edge of the photo. Considering the age, scale, and quality difference of the oldest and most recent photos the overall resulting RMS errors were reasonable for the purpose of this study.

The orthophoto RMS error was especially important when determining the location of the soil sampling points within the smallest polygons. The smallest polygons delineated were for zone TG, tree-dominated in 1942 and grass-dominated in 2000. Sample point positional errors were larger than the distance to polygon edges for six of the nine sampling points in zone TG: TG1a, TG1b, TG1c, TG2a, TG2b, and TG2c. Consequently, I could not be certain that these six soil samples were actually collected from the zone desired.

## Opal Phytolith Analysis

Opal concentration per gram soil for different morphological types, (dumbbell, short cell, rods, and dumbbell ratio, in the 0 to 10 cm depth of soil) were calculated for the four vegetation zones (Table 3). Photographs of the three main opal phytolith types, dumbbells, short cells and rods, which were found in the soil samples are shown in Figure 5-8.

Opal concentrations for the 36 samples were compared using nonparametric Kruskal-Wallis test by morphological type and vegetation zone. There was statistically significant differences for the four vegetation zones, GG, GT, TG, and TT, at the 0.05 level of significance for all opal concentrations, dumbbell, short cells, rods, total, and dumbbell ratio (Table 4). When the 6 samples in zone TG, that had positional error greater than the distance to the vegetation zone boundary, were excluded from statistical analysis, all four vegetation zones remained statistically significantly different for all morphological types and dumbbell ratio (Table 5).

The Kruskal-Wallis Multiple-Comparison Z-Value Test was used to determine which vegetation zones were significantly different (Table 6). Dumbbell concentrations were similar for vegetation zones GG and TG and significantly different from zone TT. For short cells, zone GG and TG were statistically significantly different from zone GT. For rods and total opal concentrations, zone GG and TG were similar and significantly different from zone GT and TT. The dumbbell ratio values were similar for zones GG, GT, TG and significantly different from zone TT. Generally, the trends were that opal concentrations in zones GG and TG were similar and greater than concentrations in zones

Table 3. Average opal phytolith concentrations by vegetation zone with first standard deviation (in parenthesis) and range within group.

| Zone | Number of Samples | Dumbbells (bits/gram soil) | Range: Dumbbells | Short Cells (bits/gram soil) | Range: Short Cells | Rods (bits/gram soil) | Range: Rods | Total (bits/gram soil) | Range: Total | Dumbbell Ratio | Range: Dumbbell Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GG | 9 | 3053 (1946) | 488 to 6071 | 28632 (33956) | 1951 to 114986 | 117217 (53120) | 11216 (206064) | 148902 (82753) | 13655 to 325604 | 0.023 (0.012) | 0.0065 to 0.038 |
| GT | 9 | 1359 (1555) | 0 to 4655 | 6286 (5460) | 1315 to 17291 | 52271 (41569) | 22886 (133011) | 59916 (47899) | 26042 to 154958 | 0.024 ( 0.024) | 0 to 0.071 |
| TG | 9 | 2532 (1713) | 464 to 4625 | 35006 (29529) | 6086 to 89749 | 127047 (71006) | 29674 (227611) | 164585 (97229) | 37092 to 321061 | 0.023 (0.024) | 0.0034 to 0.067 |
| TT | 9 | 377 (548) | 0 to 1510 | 15196 (16673) | 670 to 49073 | 43442 (42864) | 4018 (121716) | 59015 (59286) | 4687 to 158634 | 0.005 (0.008) | 0 to 0.022 |

Note: Dumbbell ratio is the amount of dumbbell opal divided by total opal.

Figure 5. Dumbbell phytolith from soil sample GT3a. Bar equals 5 microns.

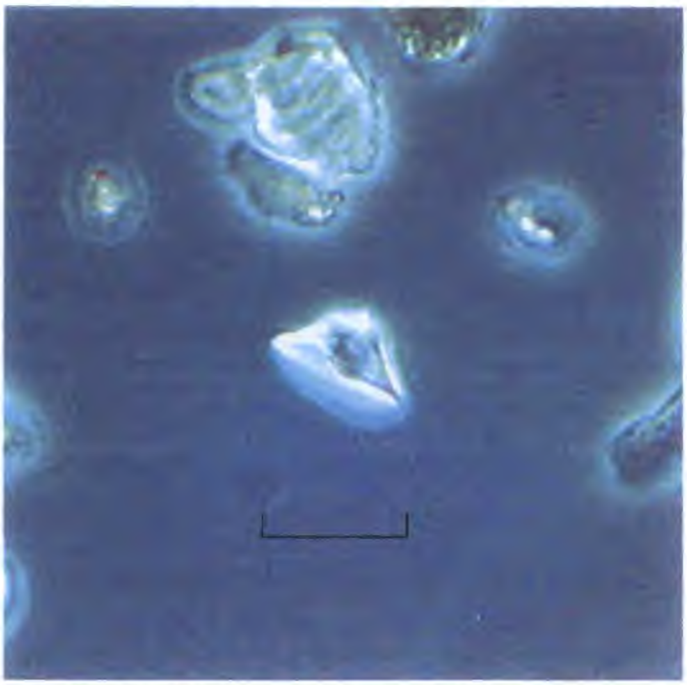

Figure 6. Short cell phytolith from soil sample TG1c. Bar equals 5 microns.

Table 4. Summary statistics for 36 samples using a non-parametric Kruskal Wallis test. Medians are significantly different if probability level < 0.05.

| Morphological Type | Chi-Square (H) | Probability Level |
|---|---|---|
| Dumbbell Concentration | 13.256 | 0.004 |
| Short Cell Concentration | 11.052 | 0.011 |
| Rod Concentration | 12.770 | 0.005 |
| Total Concentration | 11.917 | 0.008 |
| Dumbbell Ratio | 9.039 | 0.029 |

Table 5. Summary statistics for 30 samples, excluding samples not conclusively within correct vegetation zone, using a non-parametric Kruskal Wallis test. Medians are significantly different if probability level < 0.05.

| Morphological Type | Chi-Square (H) | Probability Level |
|---|---|---|
| Dumbbell Concentration | 11.402 | 0.010 |
| Short Cell Concentration | 10.789 | 0.013 |
| Rod Concentration | 11.188 | 0.011 |
| Total Concentration | 10.044 | 0.018 |
| Dumbbell Ratio | 9.166 | 0.027 |

Table 6. Kruskal-Wallis Multiple-Comparison Z-Value Test for different opal phytolith types and dumbbell ratio. Medians are significantly different if z-value > 1.9600.

| Dumbbell | GG | GT | TG | TT |
|---|---|---|---|---|
| GG | 0.0000 | | | |
| GT | 1.8860 | 0.0000 | | |
| TG | 0.4491 | 1.4370 | 0.0000 | |
| TT | 3.2781 | 1.3921 | 2.8291 | 0.0000 |
| | | | | |
| Short Cell | GG | GT | TG | TT |
| GG | 0.0000 | | | |
| GT | 2.4833 | 0.0000 | | |
| TG | 0.5593 | 3.0426 | 0.0000 | |
| TT | 1.2528 | 1.2305 | 1.8121 | 0.0000 |
| | | | | |
| Rods | GG | GT | TG | TT |
| GG | 0.0000 | | | |
| GT | 2.0358 | 0.0000 | | |
| TG | 0.3132 | 2.3490 | 0.0000 | |
| TT | 2.6175 | 0.5817 | 2.9307 | 0.0000 |
| | | | | |
| Total | GG | GT | TG | TT |
| GG | 0.0000 | | | |
| GT | 2.0806 | 0.0000 | | |
| TG | 0.4251 | 2.5056 | 0.0000 | |
| TT | 2.3267 | 0.2461 | 2.7517 | 0.0000 |
| | | | | |
| Dumbbell Ratio | GG | GT | TG | TT |
| GG | 0.0000 | | | |
| GT | 0.7634 | 0.0000 | | |
| TG | 0.7409 | 0.0225 | 0.0000 | |
| TT | 2.8515 | 2.0881 | 2.1106 | 0.0000 |

GT and TT (Figure 9, 10). Dumbell ratio values indicate that zone GG, GT, and TG were similar and significantly different than zone TT.

"Low," "moderate," "relatively high" and "very high" characterization of phytolith quantities were developed by Godar (1995) using cluster analysis on 287 soil samples from four of Bicknell's study sites: Mount Tamalpais, Fort Ross, Salt Point, and Sinkyone. High range values from each vegetation zone in this study were used in Godar's characterization model, to identify a quantity descriptor for each morphological type (Table 7). High range values are chosen because standard deviations within each group are very high so independent sample values may be more indicative of prehistoric vegetation than the averages for each zone. "Low" amounts of panicoid opals (dumbbell type) were found in all zones GG, GT, TG and TT. Likewise, "low" dumbbell ratio values occurred for each vegetation zone. "Low" amounts of total opal (which includes short, rod, and dumbbell concentrations) were found in zone GT and TT; however, "moderate" amounts of total opal were found in zones GG and GT.

## Tree Core Analysis

Five trees at the study site, four Douglas-firs and one grand fir, were aged by counting annual rings from the bark to the pith. All cored conifers showed significant annual growth for most of their lives possibly due to limited competition. The trees also have morphological features of being open grown (large, low, live branches). Consequently, the ages of the trees suggest the minimum length of time the area in which they were growing was an open environment (Table 8). The number of years added due to extrapolation for the

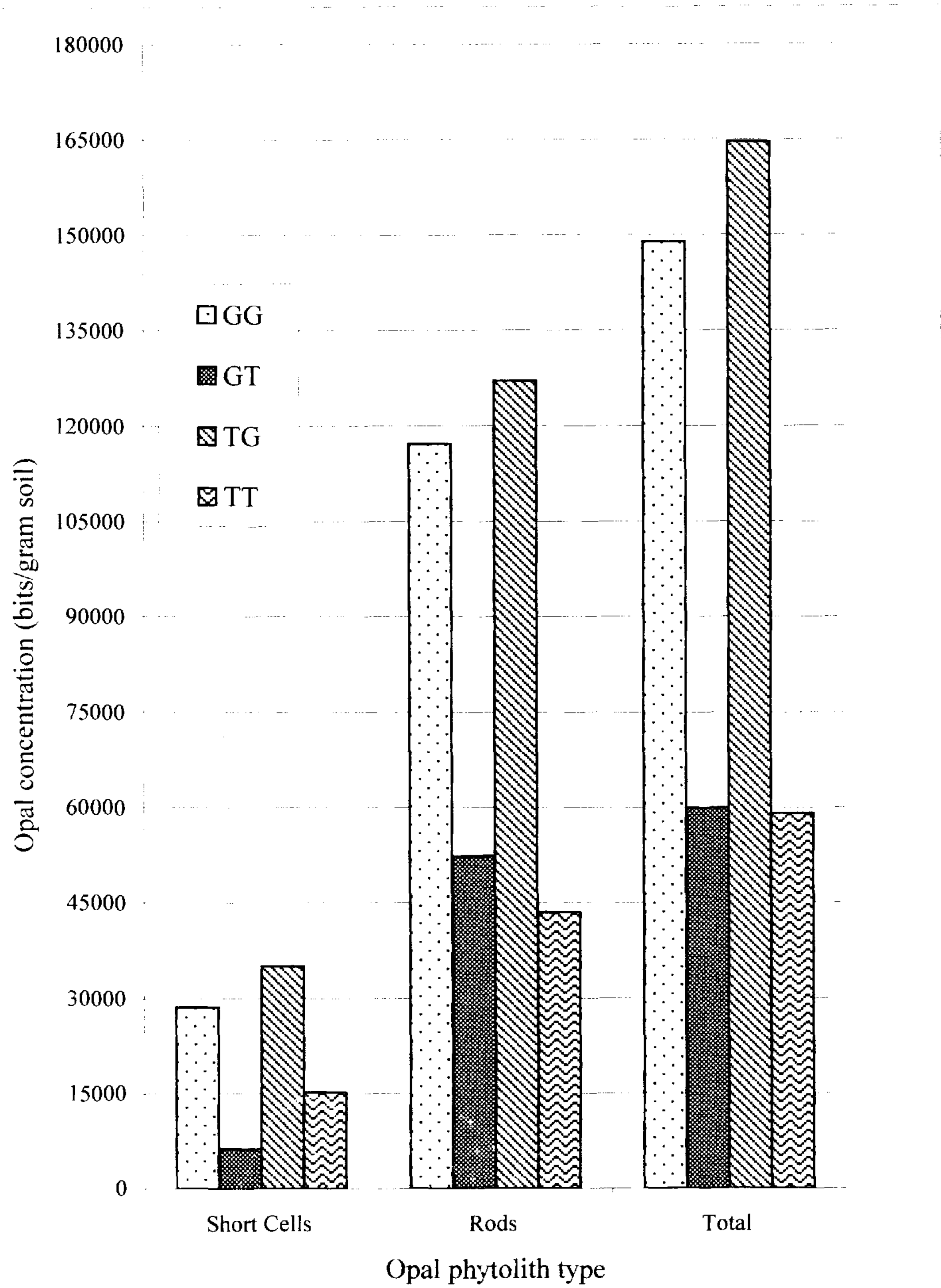


Figure 9. Opal phytolith concentrations by type for each vegetation zone.

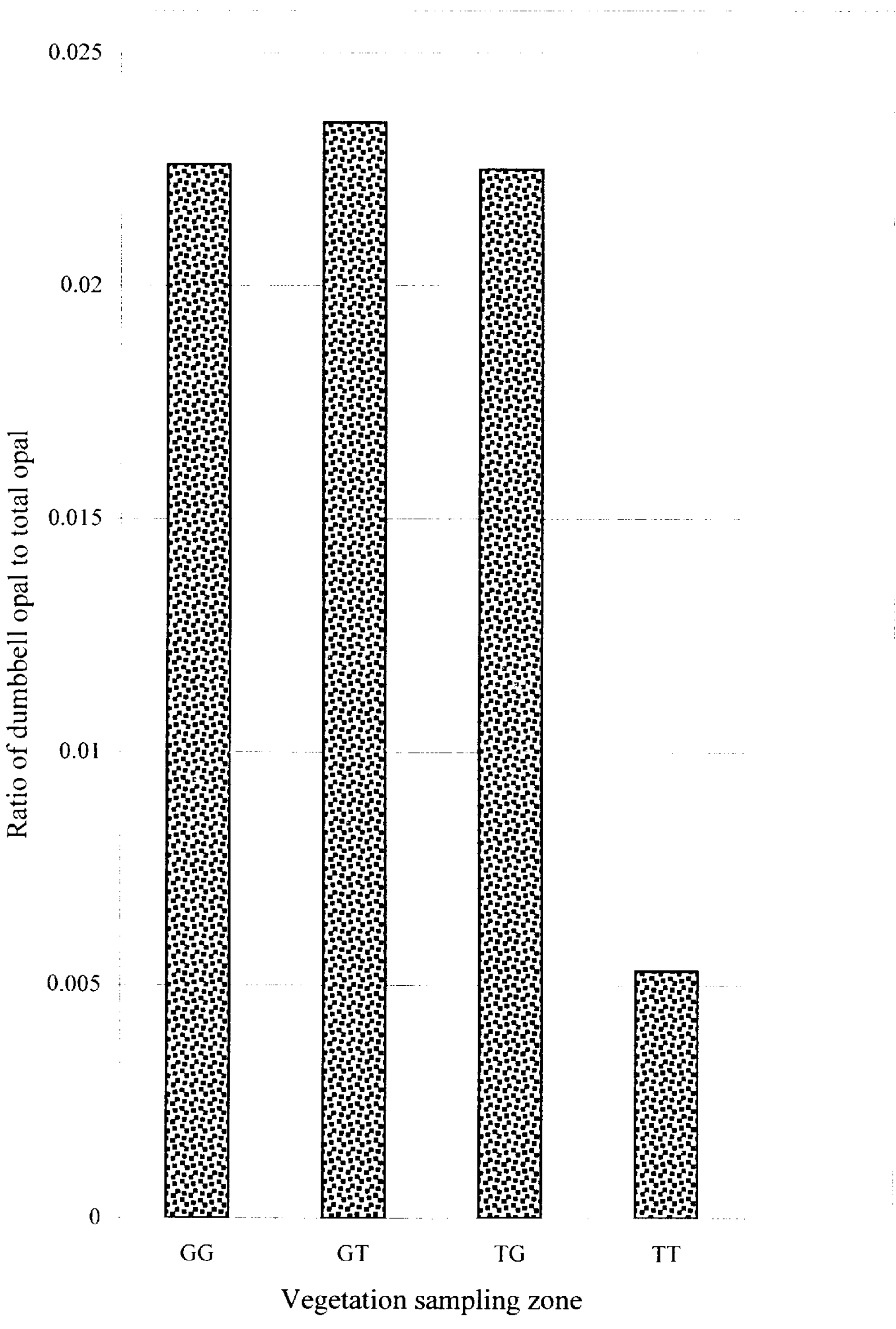


Figure 10. Dumbbell ratio for all four vegetation zones.

Table 7. Opal value characterization by site using high range value.

| Zone | Dumbbells (bits/gram soil) | Total (bits/gram soil) | Dumbbell Ratio |
|---|---|---|---|
| GG | low < 30900 | moderate > 286,500 and < 420,700 | low < 0.091 |
| GT | low < 30900 | low < 286,500 | low < 0.091 |
| TG | low < 30900 | moderate > 286,500 and < 420,700 | low < 0.091 |
| TT | low < 30900 | low < 286,500 | low < 0.091 |

Note: Value characterization created by using cluster statistics on data from 287 soil samples (Godar 1995).

Table 8. Summary of five tree cores from study site.

| Tree ID | Zone | Diameter (cm) | Height to core (cm) | Species | Core length (cm) | Age | Estimated average annual growth in first twenty years (cm/year) | Estimated average annual growth for life of tree (cm/year) | Estimated year started growing |
|---|---|---|---|---|---|---|---|---|---|
| 1 | GT | 115.6 | 86.4 | Douglas-fir | 38.1 | 45 | 1.0 | 0.8 | 1957 |
| 2 | GT | 101.6 | 114.3 | Douglas-fir | 33.0 | 50 | 1.0 | 0.7 | 1952 |
| 3 | TT | 92.7 | 129.5 | grand fir | 34.3 | 64 | 0.6 | 0.6 | 1938 |
| 4 | TT | 123.2 | 116.8 | Douglas-fir | 47.0 | 84 | 1.1 | 0.6 | 1918 |
| 5 | TT | 152.4 | 137.2 | Douglas-fir | 53.3 | 102 | 1.0 | 0.6 | 1900 |

five cores, ranged from four to ten. The oldest tree, a Douglas-fir, was 102 years old and had a 53.3 cm dbh. The youngest Douglas-fir, 45 years old, had a 38.1 cm dbh. When cored, tree 1, 2, and 4 were growing in relatively open areas, however, tree 3 and 4 were growing in a closed forest.

# DISCUSSION AND CONCLUSIONS

My first hypothesis, forest vegetation had encroached upon the study site, which will eventually become a closed forest in the absence of disturbance and significant environmental change, was supported. The results from repeat aerial photography and opal phytolith analysis showed that conifer encroachment had occurred at the study site. Orthorectified aerial photographs showed that the 2000 prairie was 0.8 hectares (33%) smaller than the 1942 prairie. Repeat aerial photography documented forest encroachment in zone GT, which had grass vegetation in 1942 and forest vegetation in 2000. Although conifer encroachment occurred at the prairie, it was not uniform spatially. Logging may have prevented a more continuous pattern of conifer encroachment. The intersection of the two polygons created the vegetation zones sampled including zone GT, grass-dominated in 1942 and tree-dominated in 2000. This vegetation zone encompassed the extent of observable conifer encroachment in the aerial photographs.

Opal phytolith analysis documented forest encroachment in zone TT, which is entirely forest vegetation now, but had dumbbell opals for some sample points. It is likely forest encroachment will continue into zone GG and TG, areas currently dominated by grass vegetation. Conifer encroachment has occurred at the site, yet interrupted by disturbances. Conifer encroachment will most likely continue to occur at the site. The grass-dominated areas in the study site, occupied by grasses, shrubs, tree seedlings and saplings, will most likely become a closed forest in the absence of significant disturbance.

My second hypothesis, the study site was prehistorically part of a more extensive coastal prairie, was not supported. Opal phytolith sample point concentrations for all morphological types and dumbbell ratio were low except in zone GG and TG, which had sample points with moderate levels of total opal. Opal phytolith concentrations for all morphological types within and between vegetation zones were highly variable indicating a dynamic vegetation history for the study site. Although statistical analysis showed an overall trend in which opal concentrations for zone GG and TG (currently grass-dominated) were similar and higher than GT and TT (currently tree-dominated), opal concentrations for grass sites are not 10 to 20 times greater than forest sites as suggested by Rovner (1971).

Opal phytolith results were not as expected. In order to support my second hypothesis, all four vegetation zones would show similar and very high total opal concentrations. Significant differences in opal concentration between vegetation zones are difficult to interpret and may have occurred for several reasons. First, there may have been positional error in sample location, which would cause erroneous opal concentrations for vegetation zone TG. Polygons for vegetation zone TG, tree-dominated in 1942 and grass-dominated in 2000, were a result of logging that occurred between 1942 and 2000. These polygons were the smallest and it was most difficult to determine correct soil sample position without error in placement. It is possible that average opal concentrations for zone TG were similar to GG because six soil samples collected for zone TG were erroneously collected from zone GG.

Second, opal movement in the soil could have caused uncontrollable and random error in opal phytolith concentrations. Human disturbance, erosion of surface soils, animal digging and burrowing, and earthflow are several ways in which resident opal can be moved from site of deposition. At the study site, logging, animal activity, and earthflow may have contributed to some opal phytolith translocation.

Finally, unexpected statistical differences in opal phytolith results may have been influenced by a dynamic vegetation history at the site. There was high variability in opal concentrations for all opal types in all vegetation zones shown as "range" in Table 3. Consequently, the prehistoric vegetation within each zone was not homogenous and so not statistically comparable. Current vegetation boundaries developed from repeat aerial photography do not indicate prehistoric vegetation boundaries.

Both natural and human caused disturbances have occurred at the site, which have influenced the dynamics of vegetation change over time. The most prevalent observable natural disturbance at the study site is earthflow. Disturbance caused by earthflow at the study site has most likely interrupted ecological succession and affected the rate of conifer encroachment. However, sparse Douglas-fir and grand fir seedlings and saplings are currently growing throughout the grass-dominated areas indicating the progression of conifer encroachment. Interactions among biology, disturbance, and the physical environment suggest that some patches in the vegetation mosaic change rapidly, while other patches which appear identical in species composition, may remain in place for long periods of time due to edaphic factors (Callaway and Davis 1993).

Human caused disturbances to this site may have included grazing, homesteading, and fires and has included logging. The study site is in a region that was inhabitated by the Whilkut Indians and it is likely that they burned and managed the landscape to maintain grassland habitat. Variable and low opal phytolith concentrations at the study site suggest prehistoric vegetation was a mosaic of vegetation types, which means that if the Whilkut Indians burned at the site, it was probably infrequent. Logging has interrupted vegetation succession at the site and as a result may have slowed the rate of conifer encroachment on the site.

Opal phytolith results from the study site, are more clearly interpreted when compared to seven other California north coast, opal phytolith studies (Bicknell et al. 1988, 1990, 1991, 1993a, 1993b, 1993c, Evett 2002 personal communication). However, opal phytolith results from other study sites can only be used as a general guideline because opal phytoliths produced over time can be influenced by many environmental and vegetative factors. Phytolith formation and deposition rates vary depending on soil factors, climate, and geomorphology as well as vegetation composition, production, and preservation. Jones and Beavers (1964) found higher opal concentrations in moderately well and poorly drained soils regardless of present vegetation. Also, silica rich parent material contributes to a higher phytolith production based on the amount of silica available in soil solution that can be used by plants at the site (Drees et al. 1975).

Opal concentrations for this study, labeled Schatz Tree Farm, are first compared with opal phytolith results from Bicknell's six study sites in northern coastal California (Table 9). Six to eighteen samples were analyzed for each prairie location and each forest location. Average opal concentration from zone GG and TG at Schatz Tree Farm, currently grass-dominated vegetation, was compared to the other present day grass-dominated sites. Average concentration for 18 samples from zone GT and TT at Schatz Tree Farm, currently forest vegetation, was compared with the other present day forest sites. Prehistoric vegetation types for these sites were not determined in this table.

Table 9. Opal phytolith concentrations from Schatz Tree Farm study site compared with other prairie and forest sites in northern coastal California.

| Current Vegetation | Location | # of Samples | Dumbbells (bits/gram soil) | Short Cells (bits/gram soil) | Rods (bits/gram soil) | Total (bits/gram soil) | Dumbbell Ratio |
|---|---|---|---|---|---|---|---|
| Grass | Sinkyone | 12 | 94991 | 80657 | 54059 | 229708 | 0.423 |
| Grass | Fort Ross | 6 | 62915 | 109236 | 34211 | 206363 | 0.275 |
| Grass | Jughandle | 6 | 60151 | 94846 | 40660 | 195656 | 0.332 |
| Grass | Montano De Oro | 6 | 11147 | 70716 | 61663 | 143526 | 0.067 |
| Grass | Patrick's Point | 6 | 0 | 42867 | 23082 | 65950 | 0.000 |
| Grass | Lake Earl | 6 | 4371 | 26912 | 17048 | 48331 | 0.088 |
| **Grass** | **Schatz Tree Farm** | **18** | **2793** | **31819** | **122132** | **156744** | **0.023** |
| Forest | Jughandle | 6 | 25127 | 77381 | 23922 | 126430 | 0.161 |
| Forest | Sinkyone | 12 | 0 | 24185 | 35345 | 59531 | 0.000 |
| Forest | Fort Ross | 6 | 15304 | 32335 | 8334 | 55974 | 0.136 |
| Forest | Patrick's Point | 6 | 1487 | 23716 | 15047 | 40250 | 0.067 |
| Forest | Lake Earl | 6 | 0 | 2451 | 2074 | 4525 | 0.000 |
| Forest | Montano De Oro | 6 | 0 | 1386 | 1369 | 2755 | 0.000 |
| **Forest** | **Schatz Tree Farm** | **18** | **868** | **10741** | **47856** | **59466** | **0.014** |

Comparing the present day prairie sites, dumbbell and short cell concentration at Schatz Tree Farm, were very low and most similar to the opal concentrations at Lake Earl. Schatz Tree Farm rod and total concentrations were relatively high and most closely related to Montano De Oro rod and total concentrations. Schatz Tree Farm has the lowest dumbbell ratio, of sites with some dumbbells present and closely related to Montano De Oro and Lake Earl.

Comparing the present day forest vegetation sites, very low dumbbell and short cell concentrations at Schatz Tree Farm compared most closely with Patrick's Point. Schatz Tree Farm forest rod and total concentrations were again relatively high and compared most closely with Sinkyone. Finally, the dumbbell ratio value at Schatz Tree Farm forest site was lowest for all sites that had some dumbbell opal present, and most closely related to Patrick's Point.

According to this comparative analysis, average opal concentrations for vegetation zone GG and TG (currently grass-dominated) at Schatz Tree Farm, with the exception of rod and total concentration, were overall most similar to grass sites at Lake Earl. Rod and total concentrations were most similar to those found at Montana De Oro. Lake Earl opal concentrations between samples were quite variable as were concentrations between samples at Schatz Tree Farm. Bicknell et al. (1991) concluded that Lake Earl had only small areas of prehistoric grass cover. It was suggested that the sparse and small grass sites at Montano De Oro were prehistorically grass-dominated (Bicknell 1990).

Opal concentrations for vegetation zone GT and TT (currently tree-dominated) at Schatz Tree Farm, again with the exception of the rod and total opal concentration, were overall most similar to forest sites at Patrick's Point. Rod and total concentrations were most similar to forest sites at Sinkyone. According to Bicknell et al.'s (1988) prehistoric vegetation analysis of Patrick's Point, the current forest vegetation had not changed from prehistoric conditions. Low opal concentrations found at Sinkyone's current forest sites indicated they were also prehistorically dominated by forest vegetation.

Evett (2002 personal communication) found opal phytoliths concentrations as high as 3,000,000 bits per gram soil at Sea Ranch in Sonoma County, California. Evett concluded that this very high concentration indicated long-term stability of coastal prairie. By comparing my results to Bicknell's findings at six different sites, and to Evett's results, it is clear that my overall opal concentrations for all four vegetation zones are very low.

The relatively high rod concentrations found in all vegetation zones at the study site were unexpected and may have been influenced by vegetation other than grasses. Rods are common and not morphologically distinct for any family or tribe of grasses. It appears that some types, such as plain rods and discs, are ubiquitous to the point of no value (Rovner 1971). In fact, many dicots and even shrubby species currently present at the site may contribute rod phytoliths to the pool. According to the phytolith library at Humboldt State University, *Pteridum, Fragaria, Juncus, Carex*, and *Lupinus* all deposit rods in small amounts and all occur presently at the study site (Table 10). Even *Pseudotsuga menziesii, Tsuga heterophylla, Abies grandis* contribute rods in relatively low amounts. According to a study in Oregon Douglas-fir forest, Douglas-fir produces rods that are indiscernible from monocot rods (Norgren 1973). Rod production and deposition of dicots and shrubby species is much lower than in monocots.

Table 10. Phytolith morphological types observed for different grass, shrub, and tree species. (Humboldt State University Phytolith Library)

| Species | Dumbbell | Rod | Short | Amorphous | Currently present at site |
|---|---|---|---|---|---|
| *Agrostis stolonifera* | | X | | | yes |
| *Aira caryopylla* | | | | X | yes |
| *Anthoxanthum odoratum* | | X | | | yes |
| *Baccharis pilularis* | | | X | | yes |
| *Bromus carinatus* | | X | | | yes |
| *Carex obnuta* | | X | X | | yes |
| *Cynosurus echinatus* | | X | | | yes |
| *Dactylis glomerata* | | X | X | | yes |
| *Danthonia californica* | X | X | | | yes |
| *Descampsia ceaspitosa* | | X | X | | no |
| *Elymus glaucus* | | X | X | | yes |
| *Equisetum arvense* | | X | | | yes |
| *Festuca rubra* | | X | | | no |
| *Fragaria virginiana* | | X | | | yes |
| *Holcus lanatus* | | X | | | yes |
| *Juncus sp.* | | X | | | yes |
| *Lolium sp.* | | | X | | yes |
| *Lupinus arboreous* | | X | | X | yes |
| *Pseudotsuga menziesii* | | X | X | | yes |
| *Pteridum aquilinum* | | X | X | | yes |
| *Stipa pulchra* | X | X | | | no |
| *Tsuga heterophylla* | | X | | | no |

Dicotyledonous plants generally contain levels of silica between 5 and 10% of those found in Poaceae (Jones and Handreck 1967), so even though these species exist at the site, it is not likely that they are the only or even main contributors of the very high rod concentrations. If dicot, shrub and tree species contributed to rod concentrations, which in turn would have inflated the total opal concentrations at Schatz Tree Farm, grass opal concentrations would be even lower than calculated. Consequently, dumbbell and short cell concentrations may be more indicative of prehistoric prairie conditions than rods.

Tree core analysis provided little additional information about historic vegetation conditions at the study site. Of the five cored trees in the study site, three were older than the oldest aerial photo (64, 84, and 102 years) but younger than European settlement and so could not provide additional information about prehistoric vegetation conditions. However, the significant annual growth for the duration of the trees' lives, in addition to the trees' morphological characteristics, substantiates that they had grown in an open environment. This evidence supports the idea that portions of the study site were occupied by grass vegetation, at least as long as 102 years ago (the oldest tree cored).

The very low concentration of dumbbell opals, in all four vegetation zones, indicated that panicoid grasses although present, did not dominate this site historically. The presence of dumbbell phytoliths in all zones indicated that some dumbbell producing grasses have probably occurred at the site in higher abundance than today. Currently, *Danthonia californica*, is the only dumbbell producing grass at the study site and is very sparse. It is likely that *Danthonia californica*, a common grass in native coastal prairies, was more widespread historically at the study site and sparsely present in the current forest zones.

Although, presence of dumbbell opal and tree core analysis indicates that grass vegetation occurred in portions of the study site historically, average opal concentrations for all morphological types were low. The determination that opal phytolith concentrations were low was supported by both regional study comparison and Godar's (1995) characterization of phytolith quantities. Furthermore, the disturbance regime has created a dynamic vegetation history for the site. These factors suggest that even though grasses have occupied the site, they were probably not the long-term stable vegetation of the site. It is likely that the prehistoric vegetation at the site was not exclusively, or even predominantly, coastal prairie but a mosaic of forest, shrub, and prairie vegetation.

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## PERSONAL COMMUNICATION


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Appendix A. Study site species list.

| Species | Common Name | Family |
|---|---|---|
| ***Forbs and Grasses*** | | |
| *Achillea millefolium* | yarrow | Asteraceae |
| *Adenocaulon bicolor* | trailplant | Asteraceae |
| *Agrostis stonlonifera* | creeping bent grass | Poaceae |
| *Aira caryopyllea* | silver hairgrass | Poaceae |
| *Anthoxanthum odoratum* | sweet vernal grass | Poaceae |
| *Asarum caudatum* | wild ginger | Aristolochiaceae |
| *Aster spp.* | aster | Asteraceae |
| *Bromus carinatus* | California brome | Poaceae |
| *Bromus hordeaceous* | brome | Poaceae |
| *Carex spp.* | sedge | Cyperaceae |
| *Cirsium arvense* | Canada thistle | Asteraceae |
| *Cirsium vulgare* | bull thistle | Asteraceae |
| *Cynoglossum grande* | hound's tongue | Boraganaceae |
| *Cynosurus chinatus* | hedgehog dogtail | Poaceae |
| *Dactylis glomerata* | orchard grass | Poaceae |
| *Danthonia californica* | California oatgrass | Poaceae |
| *Dipsacus sativus* | wild teasel | Dipsacaceae |
| *Elymus glaucus* | blue wildrye | Poaceae |
| *Equisetum arvense* | common horsetail | Equisetaceae |
| *Erythronium oregonum* | fawn lily | Liliaceae |
| *Frageria virginiana* | wild strawberry | Rosaceae |
| *Galium spp.* | bedstraw | Rubiaceae |
| *Geranium spp.* | geranium | Geraniaceae |
| *Glyceria striata* | manna grass | Poaceae |
| *Hierochloe occidentalis* | sweetgrass | Poaceae |
| *Holcus lanatus* | velvet grass | Poaceae |
| *Iris spp.* | Iris | Iridacae |
| *Juncus spp.* | rush | Juncaceae |
| *Lolium multiflorum* | Italian ryegrass | Poaceae |
| *Mentha spp.* | mint | Lamiaceae |
| *Ophioglossum pusillum* | northern adder's tongue | Ophioglossaceae |
| *Oxalis oregana* | redwood sorrel | Oxalidaceae |
| *Phleum pratense* | cultivated Timothy | Poaceae |
| *Pink* | pink | Caryopyllaceae |
| *Plantago lanceolata* | English plantain | Plantaganaceae |
| *Polystichum munitum* | sword fern | Dryopteridaceae |
| *Pteridum aquilinum* | brachen fern | Dennstaedtiaceae |
| *Sanicula spp.* | sanicula | Apiaceae |
| *Satureja douglasii* | yerba buena | Lamiaceae |
| *Thalictrum occidentale* | meadowrue | Ranunculaceae |
| *Trillium ovatum* | coast trillium | Liliaceae |
| *Urtica dioica ssp. gracilis* | stinging nettle | Urticaceae |

Appendix A. Study site species list (continued).

| | | |
|---|---|---|
| *Vicia spp.* | vetch | Fabaceae |
| *Smilacina racemosa* | false solomon's seal | Liliaceae |
| *Trientalis latifolia* | western starflower | Primulaceae |
| ***Shrubs*** | | |
| *Baccharis pilularis* | coyote brush | Asteraceae |
| *Berberis nervosa* | Oregon grape | Berberidaceae |
| *Ceanothus thyrsiflorus* | blueblossom | Rhamnaceae |
| *Hedera helix* | English Ivy | Araliaceae |
| *Lonicera hispidula var. vacillans* | climbing honeysuckle | Caprifoliaceae |
| *Lupinus spp.* | purple lupine | Fabaceae |
| *Oemleria cerasiformis* | oso berry | Rosaceae |
| *Rhus diversiloba* | poisen oak | Anacardiaceae |
| *Ribes californicum* | California gooseberry | Grossulariaceae |
| *Ribes sanguinium* | red flowering currant | Grossulariaceae |
| *Ribes uva-crispa* | gooseberry | Grossulariaceae |
| *Rosa gymnocarpa* | wild rose | Rosaceae |
| *Rubus ursinus* | California blackberry | Rosaceae |
| *Salix spp.* | willow | Salicaceae |
| *Symphoricarpos albus* | snowberry | Caprifoliaceae |
| *Vaccinium ovatum* | evergreen huckleberry | Ericaceae |
| *Vinca major* | periwinkle | Apocynaceae |
| ***Trees*** | | |
| *Abies grandis* | grand fir | Pinaceae |
| *Acer macrophyllum* | big leaf maple | Aceraceae |
| *Alnus rubra* | red alder | Betulaceae |
| *Arbutus menziesii* | pacific madrone | Oleaceae |
| *Corylus cornuta var. californica* | hazelnut | Betulaceae |
| *Fraxinus latifolia* | Oregon ash | Oleaceae |
| *Lithocarpus densiflorus* | tan oak | Fagaceae |
| *Pseudotsuga menziesii* | Douglas fir | Pinaceae |
| *Rhamnus purshiana* | cascara buckthorn | Rhamnaceae |
| *Sequoia sempervirens* | coast redwood | Taxaceae |
| *Tsuga heterophylla* | western hemlock | Pinaceae |
| *Umbellullaria californica* | California bay | Lauraceae |

Appendix B. Laboratory data and phytolith concentration calculations.

| Sample # | **Tot Rods** | **Tot Short** | **Tot Dumb** | Grams of soil sampled | Fraction of soil < 150 mm (used to total) | Dumbbell (bits/gram soil) | Short cells (bits/gram soil) | Rods (bits/gram soil) | Total (bits/gram soil) | Dumbbell ratio (dumbbell/ total) |
|---|---|---|---|---|---|---|---|---|---|---|
| GG1a | **399** | **124** | **12** | 28.45 | 0.62 | 3649 | 37705 | 121324 | 162678 | 0.022 |
| GG1b | **543** | **303** | **12** | 19.70 | 0.71 | 4554 | 114986 | 206064 | 325604 | 0.014 |
| GG1c | **450** | **78** | **5** | 19.30 | 0.81 | 1715 | 26761 | 154390 | 182866 | 0.009 |
| GG2a | **134** | **16** | **6** | 19.00 | 0.28 | 6071 | 16189 | 135580 | 157839 | 0.038 |
| GG2b | **46** | **8** | **2** | 21.90 | 1.00 | 488 | 1951 | 11216 | 13655 | 0.036 |
| GG2c | **122** | **30** | **1** | 20.90 | 0.37 | 690 | 20696 | 84162 | 105548 | 0.007 |
| GG3a | **147** | **20** | **4** | 13.20 | 0.51 | 3155 | 15777 | 115963 | 134896 | 0.023 |
| GG3b | **134** | **12** | **3** | 17.50 | 0.43 | 2151 | 8605 | 96089 | 106846 | 0.020 |
| GG3c | **156** | **18** | **6** | 14.40 | 0.44 | 5006 | 15019 | 130163 | 150188 | 0.033 |
| | | | | | | | | | | |
| GT1a | **200** | **26** | **7** | 13.65 | 0.59 | 4655 | 17291 | 133011 | 154958 | 0.030 |
| GT1b | **255** | **31** | **3** | 16.70 | 0.71 | 1343 | 13878 | 114154 | 129375 | 0.010 |
| GT1c | **85** | **15** | **1** | 17.55 | 0.95 | 319 | 4792 | 27156 | 32268 | 0.010 |
| GT2a | **77** | **15** | **0** | 15.55 | 1.00 | 0 | 5151 | 26442 | 31594 | 0.000 |
| GT2b | **134** | **11** | **0** | 18.30 | 0.91 | 0 | 3531 | 43012 | 46543 | 0.000 |
| GT2c | **154** | **11** | **9** | 16.95 | 1.00 | 2835 | 3465 | 48517 | 54818 | 0.052 |
| GT3a | **87** | **5** | **7** | 20.30 | 1.00 | 1841 | 1315 | 22886 | 26042 | 0.071 |
| GT3b | **88** | **14** | **1** | 17.10 | 1.00 | 312 | 4372 | 27481 | 32165 | 0.010 |
| GT3c | **90** | **9** | **3** | 17.30 | 1.00 | 926 | 2778 | 27780 | 31484 | 0.029 |

Note: [1]A total of 160200 beads was added to each soil sample and 30 beads were counted for each sample. These numbers were constant for all samples tested.

[2]Laboratory samples are labeled by vegetation zones A, B, C, D which correspond to GG, GT, TG, and TT respectively.

Appendix B. Laboratory data and phytolith concentration calculations (continued).

| Sample # | Tot Rods | Tot Short | Tot Dumb | Grams of soil sampled | Fraction of soil < 150 mm (used to total) | Dumbbell (bits/gram soil) | Short cells (bits/gram soil) | Rods (bits/gram soil) | Total (bits/gram soil) | Dumbbell ratio (dumbbell/ total) |
|---|---|---|---|---|---|---|---|---|---|---|
| TG1a | **135** | **17** | **11** | 12.70 | 1.00 | 4625 | 7148 | 56764 | 68537 | 0.067 |
| TG1b | **64** | **15** | **1** | 16.70 | 0.69 | 464 | 6955 | 29674 | 37092 | 0.013 |
| TG1c | **111** | **12** | **8** | 17.90 | 0.59 | 4057 | 6086 | 56294 | 66437 | 0.061 |
| TG2a | **249** | **24** | **5** | 20.45 | 0.35 | 3721 | 17861 | 185307 | 206889 | 0.018 |
| TG2b | **184** | **67** | **4** | 21.80 | 0.28 | 3527 | 59083 | 162258 | 224868 | 0.016 |
| TG2c | **147** | **50** | **1** | 19.40 | 0.30 | 908 | 45418 | 133528 | 179853 | 0.005 |
| TG3a | **246** | **97** | **4** | 10.10 | 0.57 | 3701 | 89749 | 227611 | 321061 | 0.012 |
| TG3b | **224** | **65** | **1** | 14.20 | 0.43 | 884 | 57443 | 197956 | 256282 | 0.003 |
| TG3c | **104** | **28** | **1** | 18.90 | 0.31 | 904 | 25316 | 94029 | 120249 | 0.008 |
| | | | | | | | | | | |
| TT1a | **31** | **14** | **1** | 16.25 | 1.00 | 329 | 4601 | 10187 | 15116 | 0.022 |
| TT1b | **123** | **36** | **2** | 13.60 | 0.80 | 982 | 17669 | 60369 | 79020 | 0.012 |
| TT1c | **211** | **63** | **1** | 16.20 | 0.57 | 577 | 36342 | 121716 | 158634 | 0.004 |
| TT2a | **111** | **32** | **0** | 16.60 | 1.00 | 0 | 10294 | 35707 | 46001 | 0.000 |
| TT2b | **27** | **15** | **0** | 12.90 | 0.65 | 0 | 9624 | 17324 | 26948 | 0.000 |
| TT2c | **137** | **65** | **2** | 14.50 | 0.49 | 1510 | 49073 | 103430 | 154013 | 0.010 |
| TT3a | **6** | **1** | **0** | 15.95 | 0.50 | 0 | 670 | 4018 | 4687 | 0.000 |
| TT3b | **45** | **10** | **0** | 17.65 | 0.52 | 0 | 5824 | 26208 | 32032 | 0.000 |
| TT3c | **18** | **4** | **0** | 15.40 | 0.52 | 0 | 2670 | 12015 | 14685 | 0.000 |

Note: [1]A total of 160200 beads was added to each soil sample and 30 beads were counted for each sample. These numbers were constant for all samples tested.

[2]Laboratory samples are labeled by vegetation zones A, B, C, D which correspond to GG, GT, TG, and TT respectively.