Long-Term Fire History from Sedimentary Charcoal Analysis: the Wildcat Lake and Glenmire Sites in Point Reyes National Seashore, California

Final Report

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December 2001

INTRODUCTION

The relationship between fire occurrence, climate change, vegetation composition and human impact has attracted considerable interest from a wide variety of professionals. As landscapes have become increasingly fragmented and modified by human activities, and regions of "natural vegetation" have become smaller and more rare, the importance of paleoecological research has increased for determining former vegetation patterns and fire regimes. Retrospective studies conducted by paleoecologists are becoming a critical resource for land managers in determination of appropriate strategies to restore "natural" vegetation to National Parks, and re-introduce natural processes such as fire into locations modified by recent human impacts and fire exclusion policies.

Retrospective studies take many forms, and provide data on several timescales. Historical records and ethnographic studies can document ecosystem change over the past decades to centuries (Treganza 1961; Duncan 1992). Analysis of fire-scarred living trees and stumps can extend the history of fire disturbance considerably, perhaps from hundreds of years to a millennium (Brown & Kaye 1998). Examination of charcoal and plant remains in stratigraphic sediments (found in small ponds, vernal pools and other moist places) can extend the record of vegetation history, fire disturbance and ecosystem effects to more ancient times - beyond the period provided by other proxy records (Whitlock & Anderson 2002). Burning of vegetation produces abundant charred particles, which are subsequently deposited in ponds, pools and wetlands through the action of air currents and water movements across the landscape. These charcoal particles are the direct evidence of former fires within the vicinity. Similarly, plants growing near the pools and wet places leave a fossil record in the form of their pollen, which is often specific to species and genera, and which in aggregate can characterize plant communities. Analysis of all kinds of proxy records assists in providing an integrated picture of ecosystem change.

The goal of sedimentary fire history studies in Point Reyes National Seashore is to document the long-term fire history of several vegetation types with enough spatial and temporal resolution to extend the reconstructions provided by historical records, ethnographic evidence and dendrochronological records (Brown & Kaye 1998). Such longer records allow an oppo1tunity to investigate the relationship between periods of differing climate in the past and potential changes in disturbance regime. Perceptions gained from this research are important in understanding the legacy of past fires in present ecosystems (Whitlock & Anderson 2002) as well as the role of fire disturbance in future climate changes (Overpeck et al. 1990; Price & Rind 1994; Bartlein et al. 1997; Brunelle-Daines & Anderson 2003).

Three paleoecological studies directed at the history of vegetation change have been conducted on the Point Reyes Peninsula, although only one of these included data on the history of fire. Rypins et al. (1989) examined three sites on the Peninsula, and the combined record provided evidence of vegetation change over the last ca. 12,300 radiocarbon years. Coastal exposures as well as a stratigraphic profile from Coast Trail Pond suggested that vegetation changed from a Douglas-fir (*Pseudotsuga menzeisii*)- Fir (*Abies*) forest to coastal sage scrub and grassland between ca. 10,300 and 9,400 radiocarbon years ago. Stratigraphic evidence suggested to Rypins et al that this Pleistocene- Holocene transition was characterized by more frequent high intensity storms.

Russell (1983) studied the pollen and charcoal from a sediment core from Wildcat Lake, on the Peninsula. Wildcat Lake is located near the southwest tip of Point Reyes National

Seashore, at ca. Although the core was not dated directly, identification of the core level with the first occurrence of pollen from introduced plant species, and downcore projection of sediment accumulation rates suggested that the core covered the last ca. 900 years. Russell (1983) used changes in the proportion of grass (Poaceae) and shrub pollen to determine that the importance of grassland and sage scrub vegetation alternated over the last millennium, even before the arrival of Europeans within the area. Charcoal particles identified from pollen slides showed less charcoal deposited above ca. 35 cm depth than below that. Estimate of the age of this depth were not provided.

Duncan's (1992) dissertation included pollen analysis of several sites in Marin County, including Mud Pond within Point Reyes National Seashore. Her research revolved primarily around the vegetation and ethnobotanical uses of plants by the Miwok at the time of European contact. The Mud Pond record records vegetation changes over the last ca. 1000 years.

The present study was initiated with fieldwork in the fall of 1998. We collected two sediment cores from the area. Wildcat Lake, a small landslide lake along the coast largely surrounded by coastal chaparral and scrub, yielded a nearly 11-meter sediment core that contains a ca. 3, 100-year record of vegetation and disturbance. The Glenmire site, more inland and located within the Douglas-fir (*Pseudotsuga menziesii*) - Redwood (*Sequoia sempervirens*) - Oak (*Quercus*) forest, yielded a nearly 4-meter core, containing a ca. 7,000-year record. Initial studies of these two cores showed that pollen preservation was very good and charcoal particles were abundant in both records. We did not attempt to determine the vegetation history in this part of the project. However, in terms of the fire history of the Peninsula, analysis of the charcoal particle stratigraphy has provided us with a unique opportunity to reconstruct the long-term fire history of two very different vegetation types within the Point Reyes National Seashore.

THE STUDY SITES

Wildcat Lake and Glenmire are both located near the southwest tip of Point Reyes National Seashore. While Wildcat Lake can easily be located on the USGS Double Point topographic Quadrangle, the location of Glenmire is a little obscure. Wildcat Lake occurs at ca. 62 m (200 ft) elevation, with latitude and longitude coordinates of 37°58' 10" and 122°47'05", respectively. The lake sits on a complex landslide deposit covering ca. 2.6 km^2 (Clague 1969). The overall characterization of the vegetation surrounding the pond is that of coastal scrub, dominated by California sagebrush (*Artemisia californica*), coyote brush (*Baccharis pilularis*) and California coffeeberry (*Rhamnus californica*). Only a few individuals of Douglas-fir were noted near the lake. The nearshore vegetation was dominated by bulrush (*Scirpus* sp.) and California laurel (*Umbellularia californica*). Table 1 contains an inventory of plants found during fieldwork on 31 October 1998. Terminology follows Hickman (1993).

Glenmire, an informal name, is a small wetland located immediately west of the Glen Campground. Elevation of Glenmire is ca. 167 m (540 ft), with latitude and longitude coordinates of 37°59'20" and 122°47'20", respectively. Glenmire occurs within closed canopy Douglas-fir forest with California !aural and mixed oak with hazelnut (*Corylus cornuta* var. *californica*) and California huckleberry (*Vaccinium ovatum*) in the understory. Bulrush and willows (*Salix* sp.) occur around the wetland. Plants occurring within the vicinity on 1 November 1998 are found in Table 1.

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Table 1. Plants collected near Wildcat Lake and Glenmire

		Wildcat Lake	Glenmire
Trees	*Eucalyptus* sp. [1]	X	X
	Pinus muricata [1]	X	
	Pseudotsuga menziesii	X	X
	Quercus agrifolia		X
	Umbellularia californica	X	X
Shrubs	*Alnus rubra*	X	
	Artemisia californica	X	
	Baccharis pilularis	X	X
	Ceanothus sp.		X
	Corylus cornuta var. *californica*		X
	Eriodictyon sp.		X
	Garrya sp.	X	
	Holodiscus discolor	X	X
	Lavatera arborea	X	
	Lonicera hispidula var. *vacillans*		X
	Lupinus arboreus	X	
	Mimulus guttatus	X	X
	Prunus sp.	X	
	Rhamnus californica var. *californica*	X	
	Rubus ursinus	X	X
	Salix sp.	X	X
	Sambucus mexicanus		X
	Sambucus racemosa var. *racemosa*	X	
	Toxicodendron diversilobum	X	X
	Vaccinum ovatum		X
	Vicia gigantea	X	
Herbs	*Adenocaulon bicolor*	X	
	Brassica rapa	X	
	Calystegia purpurata	X	
	Castelleja sp.	X	
	Chenopodium sp.	X	
	Cirsium vulgare	X	X
	Eschscholtzia californicum	X	
	Foeniculum vulgare [1,2]	X	X
	Fragaria vessa		X
	Geranium sp.	X	
	Marah fabaceous	X	X
	Oxalis rubra		X
	Plantago sp.	X	
	Poaceae species	X	
	Polystecum monetum	X	X
	Stachys sp.		X
	Urtica dioica	X	X
Wetlands	*Athyrium filix-femina*	X	X
	Conium maculatum	X	X

Wetlands (continued)	*Cyperus eragrostis*		X
	Equisetum arvense	X	
	Heracleum lanatum	X	X
	Juncus occidentalis		X
	Polygonum sp.	X	X
	Pteridium aquilinum	X	X
	Scirpus californicus	X	X

[1] Identified along trail to Wildcat Lake only
[2] Identified in meadow at Campground only

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METHODS

Sediment cores were extracted from both sites using a modified Livingstone sediment corer (Wright et al. 1984). We used a second corer with a plexiglass barrel (the short core) to retrieve the sediment-mudwater interface from Wildcat Lake. For coring at Wildcat Lake we used our coring platform - a 17-ft Cataraft outfitted with a plywood platform. For stability, the coring platform was anchored to the shore by guy lines. Two cores were taken in ca. 8.65 m of water on 30-31 October 1998. The Glenmire sediments were obtained on 1 November 1998 by standing on the mire surface that was covered with ca. 30 cm of water.

Methods for analyzing sedimentary charcoal have varied from study to study, despite efforts to standardize the study of sedimentary charcoal (Millspaugh & Whitlock 1995; Whitlock & Millspaugh 1996). Whitlock & Anderson (2002) reviewed the literature and made recommendations regarding the analysis of charcoal particles and the analysis of data. In this study we follow the methods of Whitlock & Anderson (2002).

Sediment samples of 5-cc were taken from individual levels in each of the cores studied. For the Glenmire core, we sampled each 1-cm level down to 250 cm in the core, producing 250 individual charcoal samples. We did not sample below this level because initial analysis of the sediments suggested minimal return for the effort. For the much longer Wildcat Lake core, our sampling strategy was different. Samples of 5-cc were taken from a composite of contiguous 3-cm sections of the core. In this manner we sampled the entire core, or approximately 350 individual samples. Each sediment sample was placed in a beaker, and 10 ml of sodium hexametaphosphate was added. Sodium hexametaphosphate is a dispersant, which breaks down the sediments and releases the charcoal particles and other large organic fragments. Subsequently, 100 ml of distilled water was added to each sample. The resulting sediment mixture was gently stirred, then allowed to disaggregate for 48 to 72 hours. The slurry was then sieved through 250-micron and 150-micron sieves. After washing with water, the sediments are scanned using a binocular dissecting microscope.

Each sieved sample was examined for its charcoal and plant macrofossil content, and the individual charcoal particles are tallied. Charcoal was identified by reference to particle color and texture - most charcoal particles are shiny black, and often retain cellular structure (Anderson et al. 1986). Charcoal concentration was calculated by dividing the number of charcoal particles counted per size category by the volume of sediment. The concentration of particles in the 125- and 250-micron categories were summed to produce a total charcoal concentration for each level analyzed.

We analyzed the 250-micron and larger fraction and the 150- to 250-micron fraction of charcoal particles because previous studies have shown that these two size fractions are probably indicative of local as well as extra-local and regional inputs of charcoal from fires (Whitlock & Anderson 2002). Two studies have shown that a greater proportion of charcoal particles > 125 microns are deposited close to a burn site (Whitlock & Millspaugh 1996; Gardner & Whitlock 2001). Therefore, distinct peaks in the charcoal especially of the larger size fraction could be interpreted as occurring primarily from a local fire. (This does not mean that other, smaller peaks in the 250-micron fraction are not local as well.)

Each of the cores was subjected to magnetic susceptibility analysis. Using a Sapphire II magnetic susceptibility meter, we measured the ability of the sediments to accept an induced magnetic charge. In essence, sediments that have a higher inorganic content will have a higher magnetic susceptibility. This is because inorganic sediment often contains magnetic particles, such as magnetite, which readily accept a magnetic charge. These measurements are often used as a proxy for erosion within the watershed. In the case of lakes, high magnetic susceptibility from landscape erosion is most often a result of local disturbance, such as from a fire or human-caused land clearance, or from a climatic event.

The core chronology was determined by radiocarbon dating of specific levels within the cores. We subcontracted with Beta Analytic, Inc. of Miami, Florida, to analyze the radiocarbon chronology. Radiocarbon dates were converted to calendar years before present using Stuiver & Reimer (1993).

RESULTS

Sediment Chronology

Six radiocarbon dates were obtained for the two records (Table 2). The lower date on each of the profiles contained enough carbon to return a whole-sediment standard radiocarbon date. Because of very low organic content in the other four samples, Accelerator Mass Spectrometry (AMS) dates were necessary. Beta-157440 consisted of organic sediment with Douglas-fir needles; Beta-157441 was entirely Douglas-fir needles; while Beta-157442 and Beta-155421 both consisted of wood fragments.

Construction of a sediment chronology was a simple procedure for the Wildcat Lake core, since both radiocarbon date increased in age with increasing depth (Table 2). I also assigned an approximate age of ca. 1900 AD for the depth of 58.5 cm. Above this depth charcoal concentrations are virtually nil, probably corresponding to the period of fire exclusion as determined by nearby tree-ring fire-scar records (Brown & Kaye 1998).

The sediment chronology was more complex for Glenmire because of an age reversal in the sediment record (Beta-157441 & Beta-157442; Table 2). Because the standard deviations on these two dates overlapped in time I took a non-standard approach to assign ages to sediment depths for this section of the core. I assumed that the entire interval between 156 and 183 cm encompassed the period between 1600 yr BP (1,650 minus 50 yr BP at 156 cm) and 1750 yr BP (1,710 plus 40 yr BP at 183 cm). The other radiocarbon dates were in sequential order and did not necessitate recalculation. In addition, I assigned an age of 1900 AD for the 103 cm depth, again based upon the period of fire exclusion (Brown & Kaye 1998).

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Table 2. Radiocarbon dates for Glenmire and Wildcat Lake.

Site Name	Laboratory #	Depth (cm)	^{14}C Age (yr BP)	Calendar Age (AD/BC & BP)	Data Type
Glenmire (core 3)	Beta-157440	127-128	1,240 ± 40	Cal AD 780 (Cal BP 1170)	AMS
	Beta-157441	156	1,710 ± 40	Cal AD 350 (Cal BP 1600)	AMS
	Beta-157442	183	1,650 ± 50	Cal AD 410 (Cal BP 1540)	AMS
	Beta-125978	240-250	5,410 ± 110	Cal BC 4350 to 4065 (Cal BP 6300 to 6015)	Standard Bulk
Wildcat Lake (core 1)	Beta-155421	417	2,000 ± 40	Cal AD 10 (Cal BP 1940)	AMS
	Beta-125979	1074-1080	3,110 ± 60	Cal BC 1395 (Cal BP 3345)	Standard Bulk

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Magnetic Susceptibility

The magnetic susceptibility (MS) of each of the cores varies considerably with depth. Magnetic susceptibility is measure in Electromagnetic Units (emu) per cc, with typical values in the range of $X = 10^{-7}$. The Glenmire record (Figure 1) shows very high MS in the top 100 cm of the core. Magnetic susceptibility is very low from ca. 100 cm to ca. 185 cm depth, increasing to ca. 250 cm depth, and remaining high to the bottom of the core. Of particular interest is the high MS in the top meter of the core. This corresponds to minimum values of charcoal concentration (see below) and may represent high erosion rates associated with watershed disturbance and fire exclusion during the historic period. The MS for the Wildcat Lake core (Figure 2) documents very low values in the top ca. 270 cm. MS is variable to ca. 770 cm depth, but increases to maximum values below this. Again, these may correspond to individual erosion and/or disturbance events within the watershed.

Charcoal Analysis

Glenmire: Although Glenmire Core 3 was nearly 400 cm long, the organic content below about 250 cm was very low. Consequently we obtained a date of 5,410 +/- 110 yr BP (ca. 6,170 calendar years ago) at ca. 245 cm depth. We then concentrated our analyses on the core above 250 cm depth. Figure 3 shows the charcoal concentration for the Glenmire record. The data are graphed as number of particles for each size fraction, as well as the total number of charcoal particles. The chronology is in calendar years.

Five zones of charcoal deposition are recognized. Charcoal Zone I-Gm represents the top 100 cm of the core, and charcoal concentrations are extremely low. I believe that this zone corresponds to the period of fire exclusion over the last ca. 100 years. Charcoal Zone II-Gm is

Figure 1. Magnetic susceptibility for the Glenmire core, Point Reyes National Seashore, California.

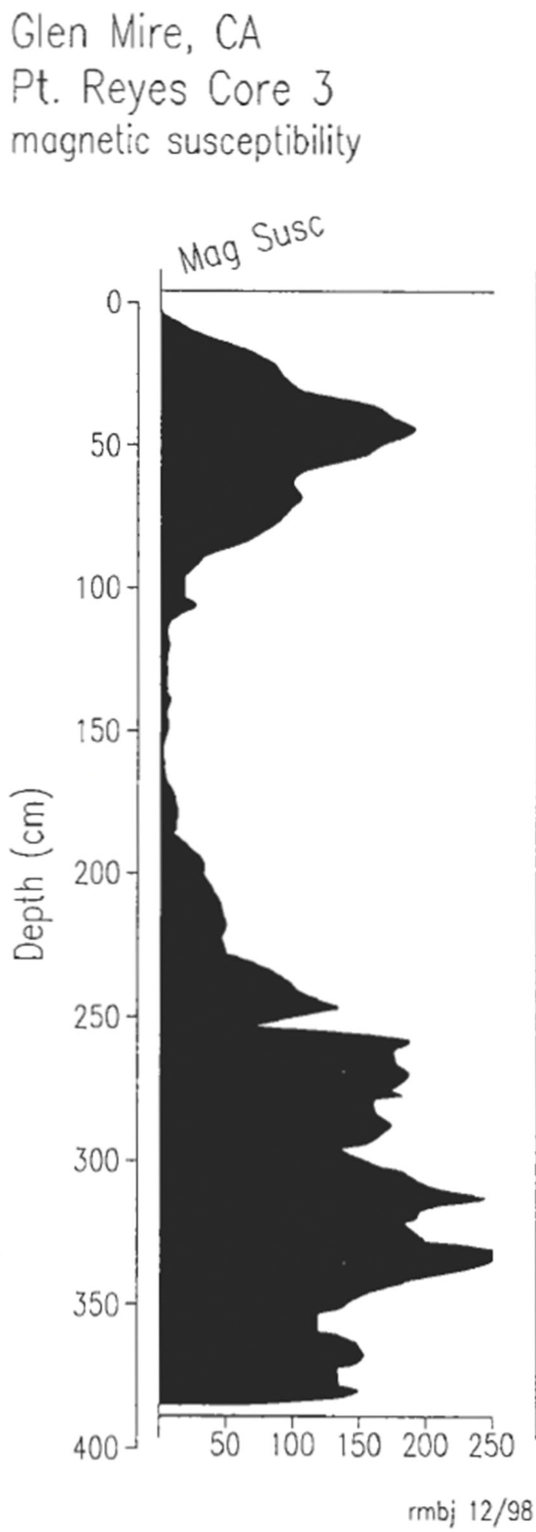


Figure 2. Magnetic susceptibility for the Wildcat Lake core, Point Reyes National Seashore, California.

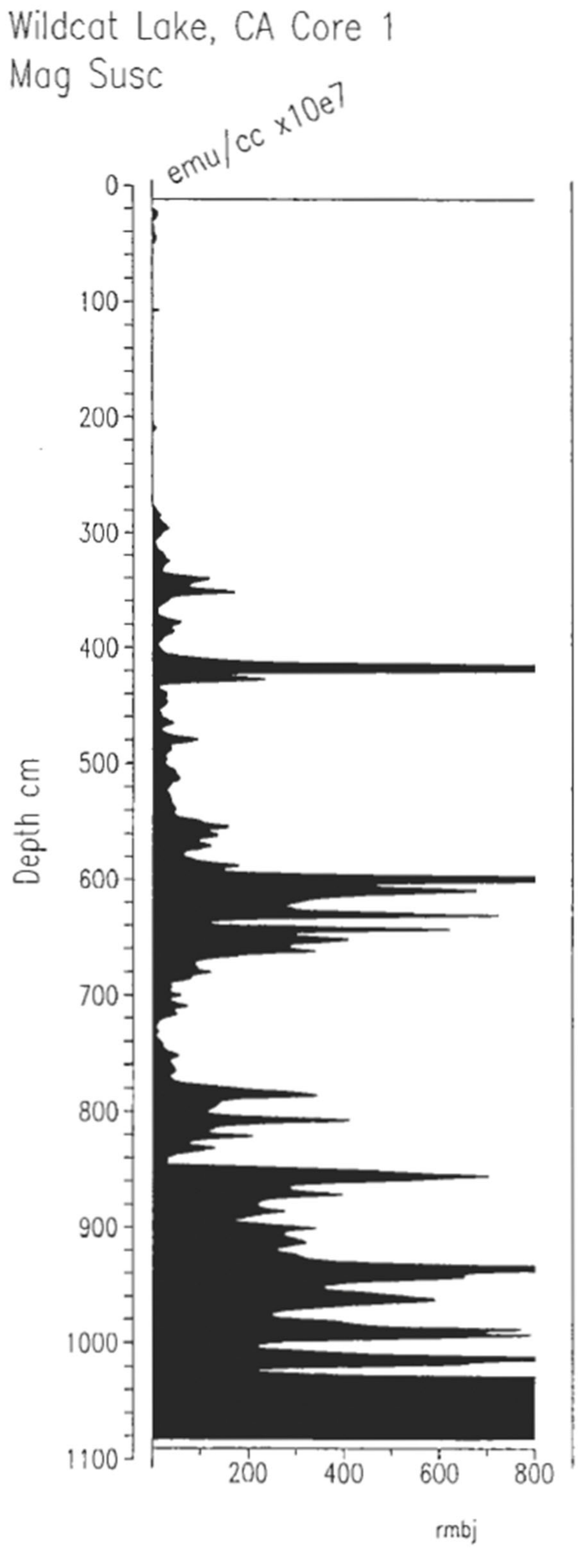
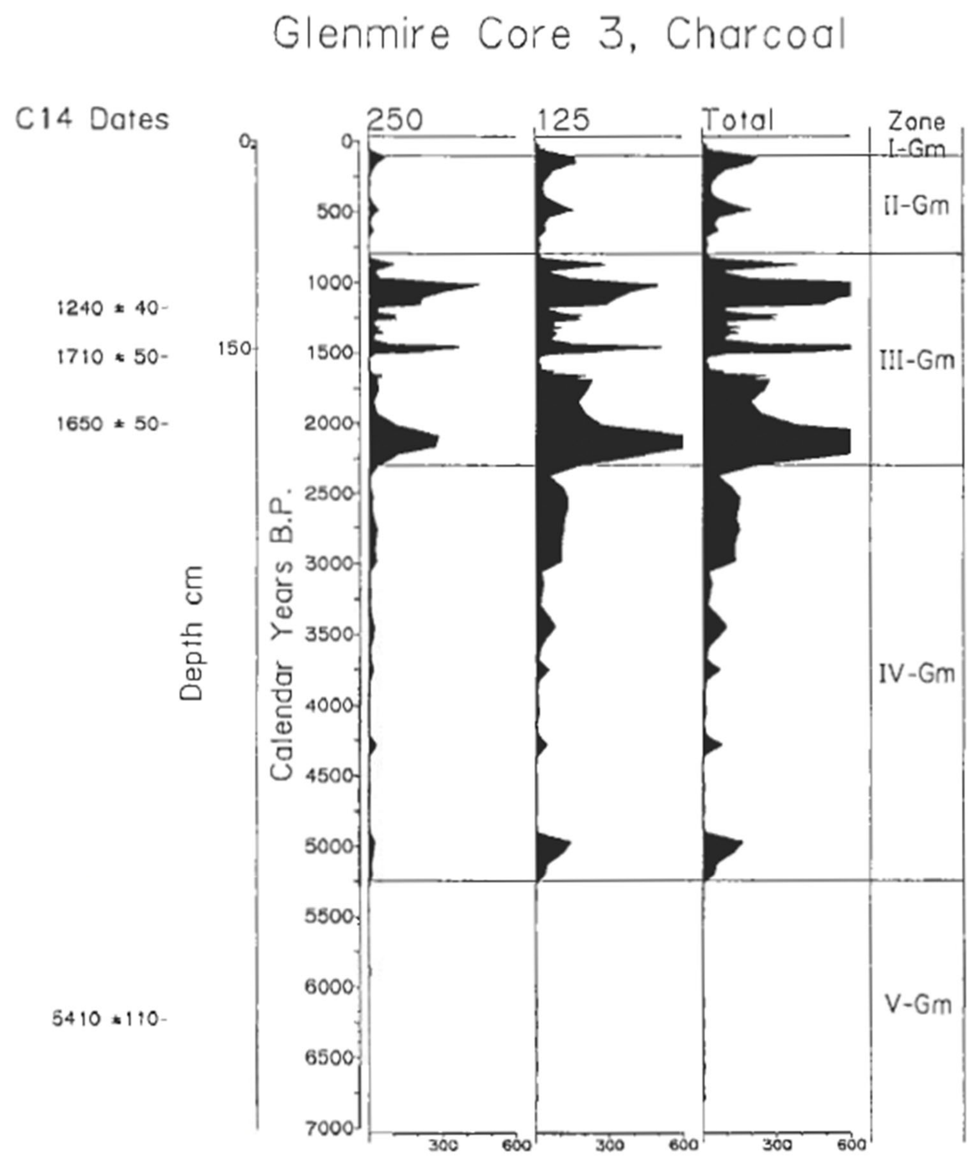


Figure 3. Charcoal stratigraphy for the Glenmire core, Point Reyes National Seashore, California.



from ca. 100 cal yr BP to 800 cal yr BP. Charcoal is found in each level, and at least two charcoal peaks are recorded, centered around ca. 125 and 500 cal yr BP. Charcoal Zone II-Gm occurs from ca. 800 cal yr BP to ca. 2300 cal yr BP. It is distinguished by the highest charcoal concentrations of the record, as well as the largest individual charcoal peaks. Only one short period during Zone III-Gm has very low levels of charcoal deposition - ca. 1500 to 1600 cal yr BP. Charcoal Zone IV-Gm spans the period of ca. 2300 cal yr BP to ca. 5250 cal yr BP. The pattern of charcoal deposition in this zone is much like that in Zone I-Gm, with individual, but low, peaks in charcoal perhaps corresponding to individual fires near the wetland. These peaks are centered between ca. 2300 and 3000 cal yr BP, and around 3450, 3750, 4250 and 5000 cal yr BP. Charcoal Zone V-Gm represents the period ca. 5250 to 6750 cal yr BP. Very little charcoal was recovered from this time interval. Samples below this in the core were not analyzed.

Wildcat Lake: The Wildcat Lake core is more than 2.5 times longer than Glenmire, but is only 3,110 ± 60 yr BP (radiocarbon years) or ca. 3,395 calendar years old. Figure 4 shows the charcoal concentration for the Wildcat Lake record (data are only available for the top ca. 3,400 years). As with Figure 3, the data are graphed as number of particles for each size fraction, as well as the total number of charcoal particles, and the chronology is in calendar years.

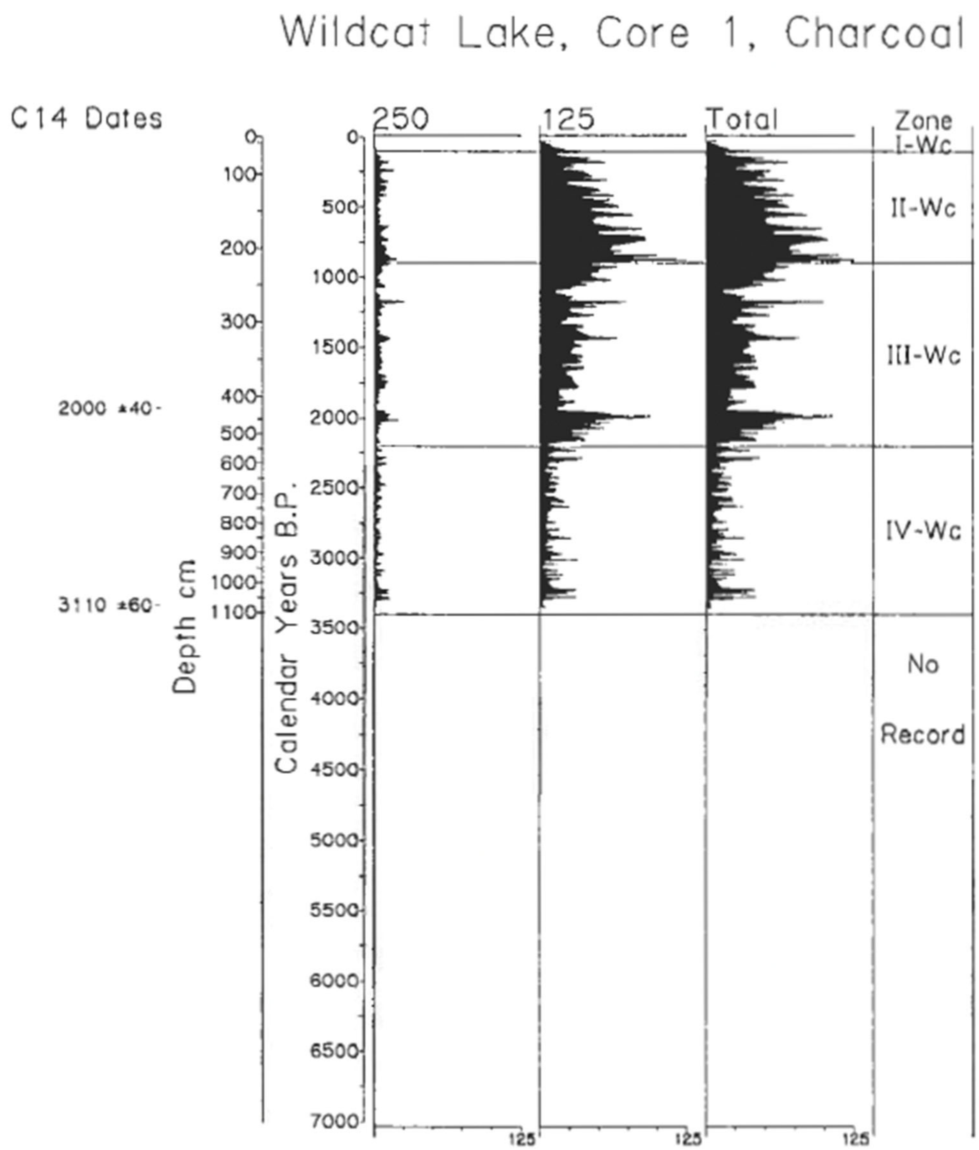
Four zones of charcoal deposition are recognized (Figure 4). Charcoal Zone I-Wc is characterized by very low charcoal concentrations. This is the top ca. 58.5 cm of the record, and probably corresponds to the fire exclusion period since ca. 1900 AD. Charcoal Zone II-Wc is characterized by the highest charcoal concentrations of the record, with values averaging over 75 particles per cc. Charcoal was consistently recovered from each of the levels studied. Although the lower portion of this Zone is not well constrained, I place the age of this Zone from ca. 100 cal yr BP to ca. 900 cal yr BP; a maximum deposition of charcoal occurs at ca. 875 cal yr BP. Charcoal Zone III-Wc shows lesser, but still consistent, concentrations of charcoal. Age dating places this zone from ca. 900 cal yr BP to ca. 2200 cal yr BP. Major peaks occur at ca. 1175, 1450 and 2000 cal years ago. Charcoal concentrations in Charcoal Zone IV-Wc, dating from ca. 2200 to ca. 3400 cal yr BP, are the least of any period prior to Euro-American settlement. Our core was not able to penetrate further into the sediment, and it is entirely possible that we reached the bottom of the deposit.

DISCUSSION & CONCLUSIONS

Sedimentary charcoal has become increasingly important for understanding the long-term history of fire disturbance in forested ecosystems of the Sierra Nevada (Anderson & Smith 1997; Brunelle-Daines & Anderson 2003), the Cascades and Klamath ranges (Long et al. 1998; Mohr et al. 2000), the Rocky Mountains (Millspaugh & Whitlock 1995; Whitlock & Millspaugh 1996), Minnesota (Clark 1990), boreal Canada (MacDonald et al. 1991 Hallett & Walker 2000), as well as in Europe and elsewhere (see also other references in Clark et al. 1997). However, such studies are rarely undertaken in non-forested areas. In this regard, the study of long-term fire history from Wildcat Lake, surrounded by coastal sage scrub in Point Reyes National Seashore is a unique endeavor. Coupling this record with that of the nearby Glenmire site, situated in coastal Douglas-fir forest, allows us to make comparisons that inform the relative rates of occurrence and importance of fire in two adjacent, but physiognomically very different, plant communities.

Our understanding of the chronology of the Wildcat Lake and Glenmire sediment cores is critical to interpretation of both records. While the chronology is based upon several

Figure 4. Charcoal stratigraphy for the Wildcat Lake core, Point Reyes National Seashore, California.



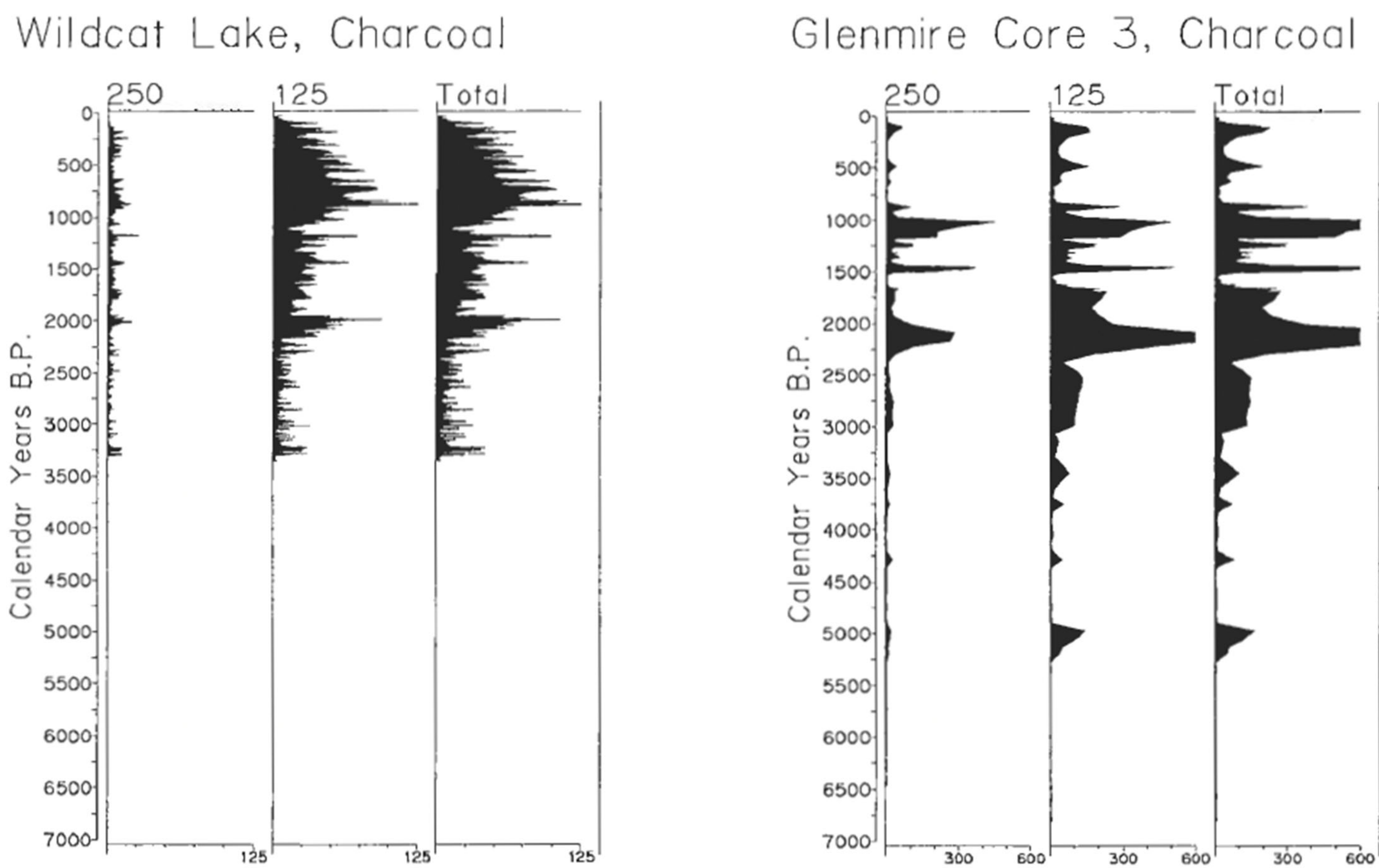
radiocarbon ages, none of the dates provided a definitive chronology for the most recent 1000 years. Therefore, events during that critical time period are interpreted by interpolation between the uppermost radiocarbon date and the core surface. In addition, the depth corresponding to the most recent 100 years is not precisely known, but was assigned for both records based upon the decline in charcoal amounts in the uppermost sediments (see below; Figures 3 & 4), as well as very high magnetic susceptibility levels in the Glenmire core (Figure I). Additional dating will be very important in establishing the exact chronology for these time periods. For the most recent 1000 years, this would entail additional radiocarbon dates. For the most recent 100 years pollen or additional historical data would be helpful to assign a calendar age to the time of regional and local settlement by Euro-Americans. Settlement and initiation of cattle ranching within coastal California occurred by the late 1700's AD (Mensing 1993; Mensing & Byrne 1998). This event is registered in other sediments of mainland coastal California, and in the offshore sediments of the Santa Barbara basin, by the first occurrence of pollen of weedy plants, including red filaree (*Erodium cicutarium*), which is most often associated with cattle operations. Russell (1983) used this technique in her initial examination of a short core from Wildcat Lake. The first occurrence of pollen of other introduced species (i.e., dock [*Rumex* sp.], plantain [*Plantago lanceolata*], gum [*Eucalyptus* sp.]) can also be used (Mudie & Byrne 1980) in some areas. In addition, ^{210}Pb dating measures the ^{210}Pb activity in the sediments, which decreases with increasing age of the sediments. The activity of this radioisotope of lead peaked in 1963-64 at the height of atmospheric atomic testing. Because of the half-life of this isotope (ca. 22 years) the technique is a very accurate way to measure the last 150 years (Benoit & Rozan 2001).

As integral to our understanding of the sediment chronology is the tree-ring fire-scar research of Brown & Kaye (1998). Brown & Kaye sampled trees from three forest types at four sites in Point Reyes National Seashore. One forest type, the Bishop pine (*Pinus muricata*) forest, was generally too young to produce long fire-scar records. However, two stands dominated by Douglas-fir and one dominated by coast redwood did allow for a fire chronology backwards into the early to mid-1800's AD. Fire ceased to be a factor of disturbance in the Douglas-fir dominated forests after 1905 AD (Five Brooks site) or 1918 AD (Limatour Road site). Fire exclusion did not commence in the coast redwood site (Pine Gulch Redwoods) until ca. 1945 AD. These data fix the age of recent sediment where charcoal values are at a minimum, as discussed above.

Figure 5 presents a side-by-side comparison of the Wildcat Lake and Glenmire records. The timing of change in charcoal deposition and fire regime is remarkable similar between the two sites, even though the direction of change is not always the same. The effect of fire suppression on the drainages surrounding both Wildcat Lake and Glenmire is clear in the sedimentary charcoal record. Charcoal particles were either not deposited or were very rare in the most recent sediments - those above 103 cm depth in the Glenmire core and above 58.5 cm depth in the Wildcat Lake record. Based upon the data of Brown & Kaye (1998) a conservative age estimate of ca. 1900 AD was assigned to these depths. (A more accurate age estimate could be calculated from using pollen or ^{210}Pb activity data, but these techniques were not part of the present analysis.) Charcoal deposition zones from lower levels in the cores are nearly contemporaneous at both sites. Zone II lower boundaries are ca. 800 and 900 calendar years ago at Glenmire and Wildcat Lake, respectively, while Zone III lower boundaries are ca. 2300 calendar years ago at Glenmire and ca. 2200 calendar years ago at Wildcat Lake. Both records document reduced amounts of charcoal during Zone IV.

However, the two records differ in three important ways. First, maximum amounts of charcoal in the Wildcat Lake record occur during Zone II, while maximum amounts in the

Figure 5. Comparison of the charcoal stratigraphies for the Glenmire and Wildcat Lake records.



Glenmire record occur in Zone III. The reason for this is unclear, but may be related to either climate changes or the effect of coastal Native American groups. Local climate changes related to sea-level rise can probably be ruled out since sea levels approached their near-modern extent by ca. 6000 yr BP (Atwater et al. 1977; Moratto 1984). Existing paleobotanical data suggest that the late Holocene may have been fairly complacent to climate change as no major change in the pollen stratigraphy of Coast Trail Pond sediments is discerned (Rypins et al. 1989). However, the sampling interval at this location may have been too coarse to reveal climatic fluctuations, such as the Medieval Warm Interval and Little Ice Age, noted for the latest Holocene elsewhere in California (e.g., Graumlich 1993; Swetnam 1993; Stine 1994). Numerous archaeological investigations on and near Point Reyes have confirmed that Native Americans heavily utilized the coastal environment of the area for at least the last 3000 years (Moratto 1984, p. 275; Duncan 1992), and the role that these original inhabitants of the region played in management of plant communities may have been substantial.

Second, charcoal deposition is more continuous in the Wildcat Lake record, with less between-sample variability, while deposition in the Glenmire record occurs at more discreet intervals. This can result either from ecological or sedimentological processes. One ecological explanation for this pattern could lie in a greater fire frequency for the sage scrub site, with more episodic fire occurrence surrounding the coastal forest site. However, the difference could simply be due to the mode of deposition of charcoal in lakes versus wetlands. Deposition is more continuous in lakes, and potentially more episodic in wetlands, which can dry out during periods of low ground water recharge (Anderson & Smith 1997; Whitlock & Anderson 2002).

Third, the absolute abundance of charcoal varies between the Glenmire and Wildcat Lake records. The number of charcoal particles in the sage scrub record never exceeds 125 particles per cc, where the average is about half that. At the forested site, however, the number of charcoal particles often exceeds 300 / cc with more than 600 / cc for several periods. This is probably related to the physiognomy of the vegetation at the two sites. Coastal sage scrub vegetation is dominated by shrubs and sub-trees. This vegetation type consists of abundant fine fuels from small leaves and twigs that would be available for consumption and charcoal production during fire. On the other hand, the biomass is greater in coastal forest, dominated more by trees, and wood charcoal would be expected to comprise a greater percentage of the total charcoal. This observation is reinforced by comparison of the amounts of the 250 micron fraction alone; the number of the largest size particles is always relatively small in the coastal sage scrub record, where trees are not abundant.

For both cores the MS values and charcoal concentrations are mirror images of each other (Figures 1 to 4). This suggests that erosion after fire may not be the most significant cause of higher MS values. Instead, some other process probably controls changes in inorganic input into the sediments. At the present time the explanation for this relationship remains unclear, but additional paleobotanical analyses may provide an explanation for events that have occurred in the watershed in the past.

Interpretation of the fire history record would be improved considerably by analysis of the pollen and plant macrofossil record of the Glenmire and Wildcat Lake records. Pollen analysis would allow for the reconstruction of the vegetation, and perhaps climate, history of the sites. Though different vegetation histories would be expected from the two records owing to elevational and other differences between the two sites, understanding the vegetation and climate changes that have occurred during the late Holocene could assist in clarifying the disparate fire history records. In this regard, the extremely high sedimentation rate of the Wildcat Lake core could provide an unparalleled opportunity to analyze vegetation change with very high resolution.

ACKNOWLEDGEMENTS

Many individuals have contributed to the success of this research project. I especially thank Peter Brown, Rocky Mountain Tree-Ring Laboratory, for suggesting the project, for serving as liaison with the National Park Service, and for field assistance and helpful discussions. I am grateful to Dan Buckley and Barbara Moritsch, National Park Service, for financial and logistical support; to Mitch Power and Mark Daniels for help with coring Wildcat Lake and Glenmire and for plant identifications; to Renata Brunner Jass, Amy Kelly, Bridgette Watson, and Allison Bair for assistance with laboratory studies; and to Susie Smith, who provided the plots of the charcoal data.

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