PALEOENVIRONMENT OF ELKHORN SLOUGH AND SURROUNDING WETLAND HABITATS: A GEOLOGICAL STUDY USING AN ECOLOGICAL APPROACH.

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By
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ABSTRACT

Elkhorn Slough is a tidally influenced coastal embayment located in northern Monterey County, in the central region of Monterey Bay. While various studies in the Slough have described the longterm geological history and very recent ecological conditions, this paper is an attempt to bridge the gap between geological and ecological studies, using data from deep and shallow sediment cores, recorded human history and by comparing older fossilized communities to those found in existing coastal wetlands. Shell fragments, microfossils, organic debris, and sediment grain size are each indicative of a particular type of environment and were used to describe the environmental changes. These data indicate that the modern Elkhorn Slough was formed about 10 thousand years ago (kya) when rising sea level invaded the Elkhorn River Channel. From 6 kya to present, sedimentation rates exceeded sea level rise and salt marshes colonized mudflats. The native oyster, *Ostrea lurida*, dominated benthic communities at the slough mouth from 10-4 kya when shallow open water habitats were most widespread. Clam communities were also common at the mouth from 7 kya to present. A unique gastropod community occurred throughout the slough around 3.5 kya, after the decline of oyster communities. Salt water did not regularly invade the northeastern region of Elkhorn Slough, allowing freshwater communities to develop 4 kya and persist to the present. Salt water periodically influenced the eastern region of Moro Cojo Slough creating brackish water conditions from 5-1 kya. Neither the temporal occurrences or rate of occurrence of communuties displayed a particular pattern associated with ecological succession, suggesting that the colonization of the shoreline by a rising sea created a variable pattern of community distribution.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the members of my committee who made this project possible: The chairman of my committee, Mike Ledbetter, for providing the necessary scientific guidance throughout the course of this project; John Oliver for suggesting the topic and initiating discussions with an interesting point of view; and Dave Schwartz, for offering his field expertise and geological knowledge of Elkhorn Slough.

Several people were responsible for helping me identify the seeds and pollen found in my cores, including David Adam of the U.S. Geological Survey and David Bruck of San Jose State University. I gratefully acknowledge their time, assistance and efforts.

I would like to thank the California Division of Transportation (CALTRANS) and the consulting firm of Dames and Moore for allowing me to sub-sample a series of cores collected along Highway 1. They opened their laboratory to me and provided me with an abundance of material that would have otherwise been difficult to obtain.

Field work was an important aspect in the collection of data and I was fortunate enough to have field assistants with a healthy curiosity of what lies beneath the slough. Special thanks are extended to Mark Silberstein, Tom Okey, Hunter Lenihan, Kim Kiest, Peter Slattery, Dave Schwartz and John Oliver for often putting up with less than desirable conditions in the murky mudbanks of Elkhorn Slough. Because of their support and efforts, I was able to complete this project in a timely fashion.

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INTRODUCTION

California coastal wetlands are dynamic ecosystems which were created during the last rise in sea level, about 10 thousand years ago (kya). These estuarine environments have held the interest of both geologists and ecologists alike; geologists studying the systems on a scale of tens of thousands of years, and ecologists investigating a period of perhaps tens of years. Geological investigations of various wetland systems throughout the world have focused primarily on the sedimentary record (Frost, 1988; Wanless et al., 1988; Reed, 1989; Wood et al., 1989; and Flethcer et al., 1990), lithologic and fossil record (Lohmar et al., 1980: Schwartz et al., 1986), and rise in sea level (Atwater et al., 1979; Ellison, 1989). These studies cover time spans of up to 18 kya and focus on the geologic events which created the estuarine environments that we see today.

Examples of long term ecological research, or "successional" studies of estuarine environments are few and usually cover a period of only a few years (e.g., Redfield, 1971; Zedler, 1977), with the most being a period of perhaps a decade (Macginite, 1935). These relatively short term investigations focus predominantly on ecological conditions which exist today, leaving a gap between the long term geological studies and the short term ecological research. Bridging the gap may be a useful step towards developing a historical model with important application for future wetland restoration and enhancement. With information based on where a system has been in the past, informed management decisions can be made.

The few studies that have attempted to bridge the gap between geology and ecology have focused on biological (Redfield, 1971), geological (Huntley and Prentice, 1988), or chemical (Ford, 1990) aspects of estuarine development. One example of a study that attempts to bridge this gap was conducted in a terrestrial environment in Indiana (Jackson, Futyma and Wilcox, 1988), far removed from any marine influences of the open coast.

Elkhorn Slough is an ideal setting to study how certain geologic events (i.e., rise in sea level) created, changed and affected ecological communities. Elkhorn Slough is one of the largest estuaries in California, and is located in northern Monterey County, just landward of central Monterey Bay (Figure 1). The recent geologic history of the slough (10 kya) has been well described (Schwartz et al. 1986), and outlines the general development of the slough, including gross changes in slough hydrology, relative ages of extant sedimentary habitats, sedimentologic features, and microfossils assemblages. Although this work includes a broad historical description of the area, there is little information on the development of ecological communities as the rise in sea level influenced Elkhorn Slough and the surrounding wetland habitats. Schwartz et al. (1986) showed that Elkhorn Slough contained extensive salt marsh habitats during the last 4 kya. This study extends the earlier geologic coring work of Schwartz by coring the tributaries of the slough's main channel and around the upper edge of the system where freshwater habitats appear to have played a major role in determining the community development.

The major objective of this project is to describe the paleoenvironment of the Elkhorn Slough system, focusing on the ecological changes that have occurred since sea level invaded the system about 10 kya. Particular attention to patterns and trends associated with the colonization of a shoreline by a rising sea were also noted. These goals were accomplished by describing the major ecological communities that lived throughout the slough, mapping their extent through time, and documenting their changes from 10 kya to present.

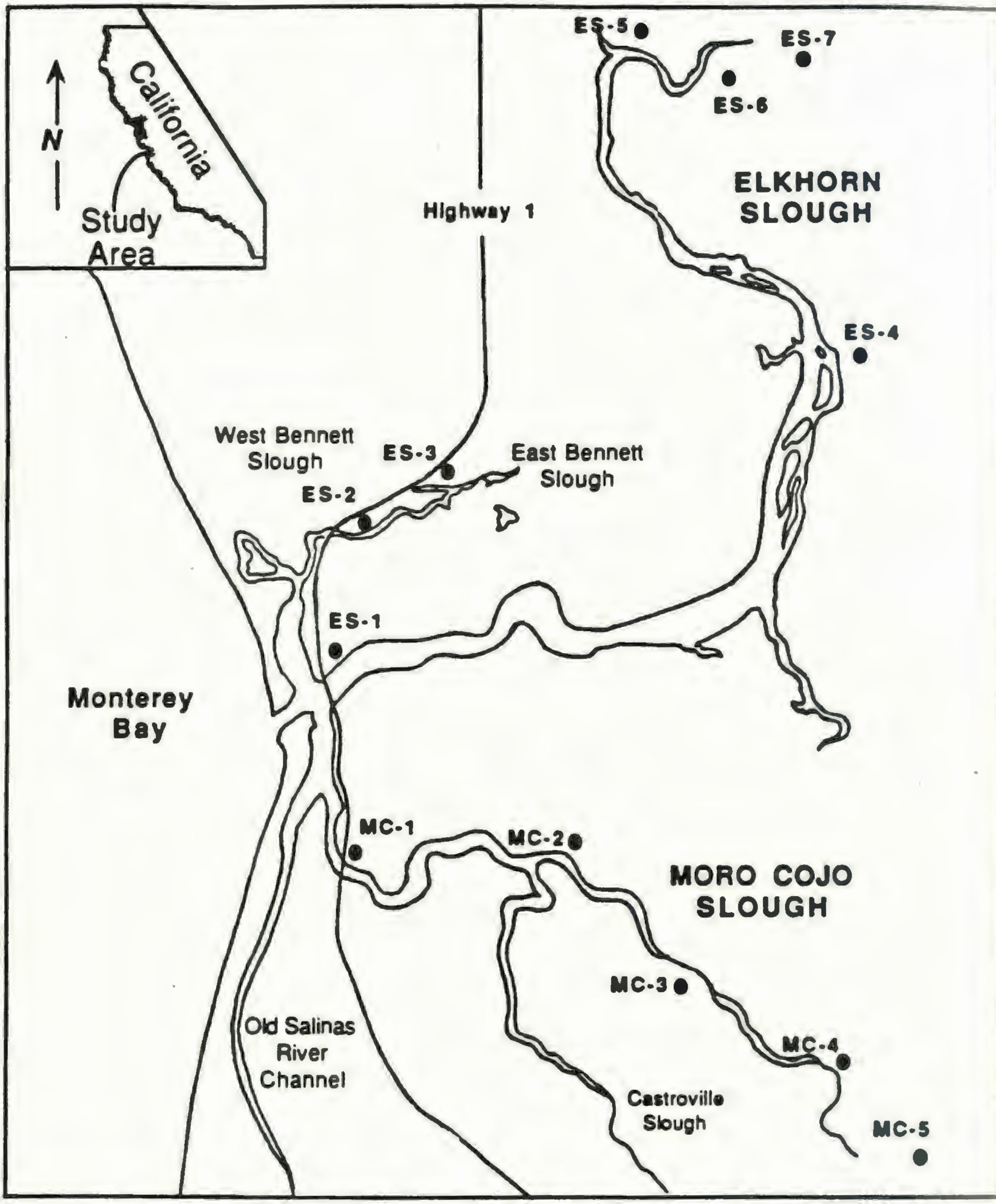


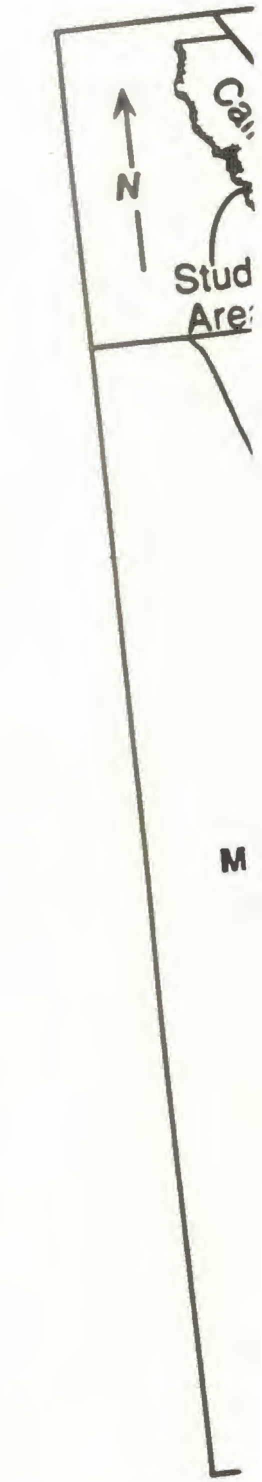
Figure 1: Location of coring stations in Elkhorn Slough and Moro Cojo Slough.

MATERIALS AND METHODS

During 1989, a series of deep and shallow sediment cores wa Slough and Moro Cojo Slough (Fig. 1). Sample sites were chosen tc middle and back of each slough. In order to determine the more recen conditions, a hand-auger 3 cm in diameter and 7 meters long was usec sediment cores. During the summer of 1989, California Transportatior conducted a Highway 1 improvement study which required collecting c ($\leq$40 m) along specific sites near the highway. Sub-samples were obtai cores at approximately every meter. A commercial drill rig was hired in complete the series of deep cores in Elkhorn Slough and Moro Cojo Slou were sub-sampled at half-meter intervals.

Samples were split into 10 gram sub-samples, dried at 50 °C and p solution (0.5g/l) to defloculate the clay particles. After soaking for 24 hou was washed through a 63 µ sieve. In accordance with common micropaleo standards, the >63µ fraction was dried and split into approximately 300 gr samples, where numbers of microfossils, macrofossils, organic debris and fc remains were counted and recorded. Marine indicators such as foraminifera a are often associated with marine clay, and indicate low energy environments (1983). Larger shell fragments from mollusks, specifically oysters (*Ostrea luri* (*Protothеca staminea, Tresus nuttalli,* and *Macoma* spp.) and small gastropods *californica*) were identified using an illustrated key (Keen and Coan, 1974; and al., 1981); root material and other fossilized plant remains were identified to the possible taxanomic order.

Radiometric age determination (^{14}C) of selected shell fragments and pea was carried out by Krueger Enterprises in Cambridge, Massachusetts. Samples



were pretreated using an ultrasonic cleaner and leached thoroughly with dilute HCl to assure that only fresh carbonate material was used in the analysis. Age assignments assume that shells were deposited locally and are not allocthonous material.

Vertical distribution of ecological communities and habitats of both Elkhorn Slough and Moro Cojo Slough was based on core data and ^{14}C ages. Schematic diagrams show an estimated areal extent of a particular community or habitat and were based on the same information. These estimated boundaries assume that the communities relied upon the same environmental parameters as today.

OCCURRENCE OF PALEOENVIRONMENTAL INDICATORS

The paleoenvironmental indicators used to determine the ecological conditions during the last 10 kya include sediment grain size and type, microfossils, macrofossils, gastropods and fresh water peat deposits. The fining upward sequence of sediment grain size is one characteristic of a rising sea and the fine marine sediment that overlies the coarser non-marine sand defines an environmental boundary between non-marine/marine conditions. Microfossils (i.e. foraminifera and ostracods) and gastropods (*Assiminea*) were found in marine clay deposits and are characteristic of a low energy, brackish water condition. The occurrence of macrofossils (oysters and clams) suggests shallow to sub-tidal, open water conditions. Fresh water peat deposits suggest that the site was isolated from direct marine influence, collecting water from adjacent fresh water streams.

Elkhorn Slough

Paleoenvironmental Indicators in Sedimentary Cores

Mouth: The upper meter from the core collected near the present day main channel (Fig. 1, core ES-1) consisted of landfill deposits and fresh organic detritus, followed by a well sorted marine sand, and is underlain by a poorly sorted non-marine gravelly sand at the base (37 m). Although large shell fragments were found throughout the core, two noticeable occurrences of *Ostrea lurida* shell fragments were found at depths of 25 and 18 meters (Fig. 2).

The upper meter of sediment collected from the second core near the mouth of the system (Fig. 1, core ES-2) consisted of a fine marine clay that was underlain by a well sorted fine-grained marine sand. The marine sand deposit is interrupted by a lens of marine clay which contained an abundance of marine indicators including, *Ostrea lurdia* fragments and microfossils from 14 to 17 meters (Fig. 2). *Ostrea lurida* was the common

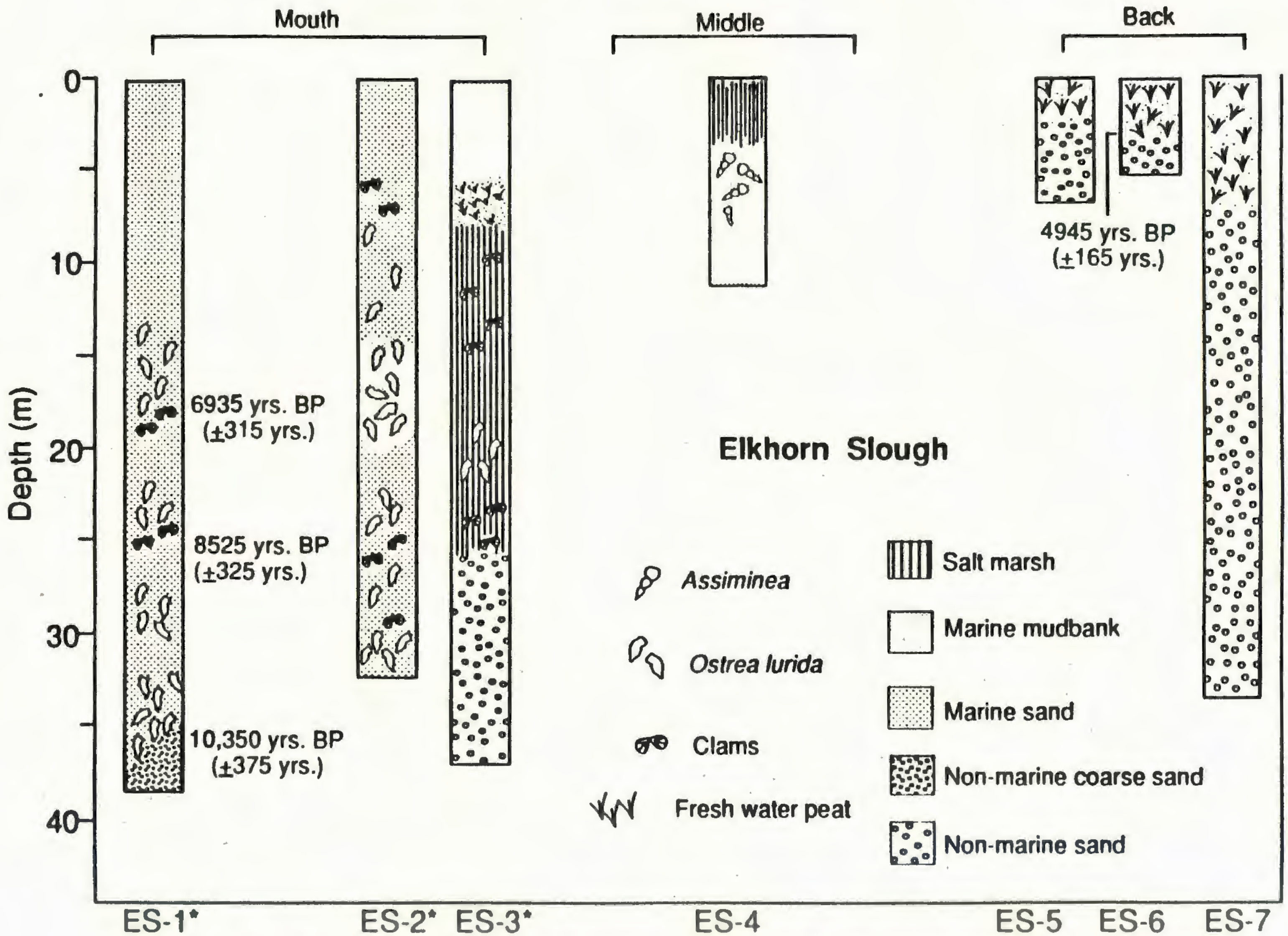


Figure 2: Vertical distribution of major ecological communities and habitats identified in cores from Elkhorn Slough. Core ES-7 collected and analyzed by D. Schwartz in 1984. (* indicates cores recovered by CALTRANS). Table 1 lists standard error for C^{14} dates.

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macrofossil throughout the core, but two deposits of clams were found at 5 m and 27 m in the core (Fig. 2).

The upper 6 m of core ES-3 consisted of a marine clay deposit underlain by a horizon of fresh water peat near 7 m (Fig. 2). A salt marsh deposit lies below the peat and continues to a depth of about 25 m where it is underlain by a non-marine sand. Clam deposits, including *Protothaca* and *Macoma*, were common in this core and were found at depths ranging from 25 to 10 meters, *Ostrea lurida* fragments however only occurred at 23 meters.

Middle: Core ES-4 reached a depth of 11 m with the top 4 m consisting of a salt marsh deposit underlain by marine clay and microfossils. Small gastropods identified as *Assiminea* were found at depths of 5 m, but other shell fragments were not present in this core (Fig. 2).

Back: The three cores that were recovered in the northeastern edge of Elkhorn Slough, showed similar sequences with a non-marine peat deposit underlain by a poorly sorted non-marine sand (Fig. 2, cores ES-5, 6 and 7). There were no microfossils or macrofossil deposits found in these cores.

Sediment Grain Size and Type: Most deep cores revealed a general fining upward sequence of sediments ranging from the poorly sorted non-marine gravelly sands found at 37 m at the mouth of Elkhorn Slough, to the fine-grained silty marine clay common throughout the system. These grain- size distributions are similar to the quantitative grain-size analysis of cores analyzed by Schwartz (1983) and define the boundaries which distinguish the non-marine environment from the marine environment.

The most dramatic evidence of paleoenvironmental change is the boundary of non-marine fluvial deposits and the marine sedimentary sequence that is seen in five of the cores in Elkhorn Slough. The first such boundary occurs at the mouth of the slough (Fig. 2, core ES-1). This abrupt change from non-marine gravelly sand, characteristic of a graded stream deposit, to a poorly sorted marine sand occurs near the base of the core. A finer grain, well-sorted non-marine sand overlain by a brackish water deposit of salt marsh determines the second distinct environmental boundary at 25 m in Elkhorn Slough (Fig. 2, core ES-3). Finally, a poorly sorted, non-marine sand lies at the base of the cores taken from the back of the slough (Fig. 2, ES-5 at 3.5 m, ES-6 at 4 m and ES-7 at 7.5 m), and all are overlain by a fresh water peat horizon.

Microfossils: Sediment deposition in estuarine environments can occur by two mechanisms: deposition caused by fluvial deposits and erosional run-off, and by a steady rise in sea level. Because of the presence of marine indicators overlying the non-marine sand deposits, the fining upward sequence found in Elkhorn Slough clearly shows that the rise in sea level is the predominant factor in sediment deposition.

Microfossils, such as various species of foraminifera and ostracods, are the primary marine indicators found in the clay deposits which overlie the coarser marine sand. The marine clay deposits are usually deposited during conditions of low tidal energy and are more prevalent in cores ES-2, ES-3 and ES-4 (Fig. 2). Two occurrences of these deposits are found in core ES-2, first at a depth from 18-15 m, and again in the top meter of sediment.

Relative abundances of foraminifera and organic debris found in sub-samples taken from Elkhorn Slough are described in Figure 3 and show how the abundances of both microfossils and salt marsh plants increase with decreasing tidal energy. The presence of foraminifera and ostracods in the core recovered from the middle of Elkhorn Slough (Fig. 1, core ES-4) indicate that this was probably a low energy environment as sea level was rising. Nearly 70% of the sub-sample extracted from the core consisted of foraminifera, and almost 20% of the sub-sample consisted of marine organic debris (Fig. 3).

Macrofossils: Oysters and clams make up the distinct ecological communities which existed in Elkhorn Slough over the last 10 kya. The oyster *Ostrea lurida* is the most abundant macrofossil present in the cores, occurring predominantly at the mouth of the system, but is found to exist as far back as Bennett Slough (Fig. 1 and 2). The large abundances of shell fragments throughout core ES-1 suggests the open water subtidal conditions near the ocean were the prime habitat for this oyster (Appendix 1). The first shell horizon appearing in ES-1 occurs at 36 m and has a ^{14}C age of 10.35 kya, $\pm$375 (Fig 2, Table 1). The oysters appear to be the dominant community in the cores until about 6 kya, when the channels began to fill in with sediment resulting in a more narrow distribution pattern in the restricted channel.

Scattered occurrences of *Ostrea lurida* were found in the relatively low energy environment of Bennett Slough (Fig. 2, cores ES-2 and ES-3). A horizon of oysters found at 20 m in core ES-3 was the last occurrence of oysters in the cores recovered from Elkhorn Slough, and suggests that the channel began to fill in at Bennett Slough at approximately 7 kya.

Various types of clams are the second most abundant macrofossil present throughout Elkhorn Slough, ranging from as deep as 30 m to as shallow as 5 m, and covering a time span in the cores from about 8-4 kya. Two occurrences of clams (*Macoma* and *Tresus*) were found at 25m and 18 m (Fig. 2, core ES-1). Clam communities become

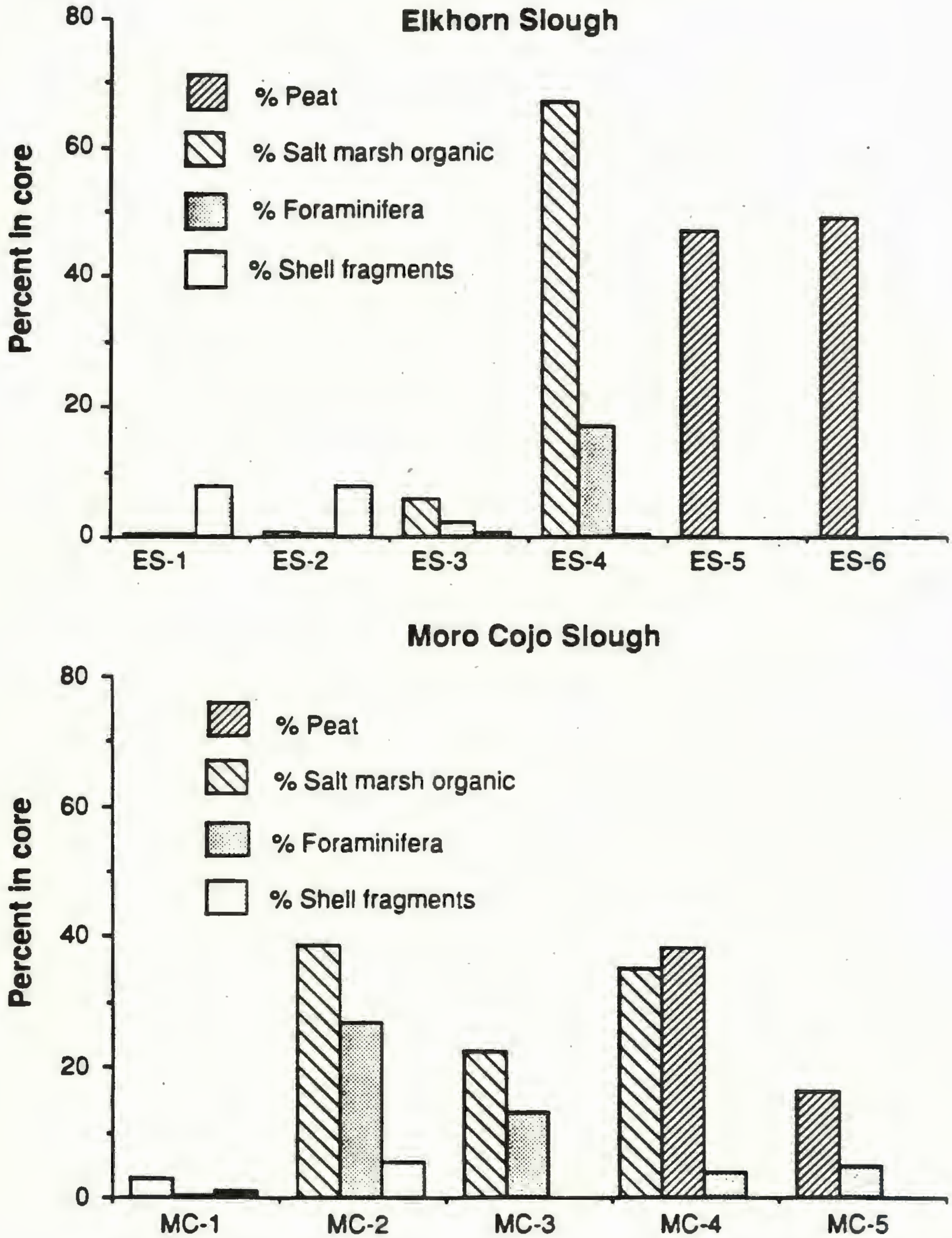

Figure 3: Percent of organic debris, foraminifera and shell fragments in sub-samples for each core.

Sample	Depth (m)	^{14}C Date	Sediment accumulation rate
ELKHORN SLOUGH:			
ES-1	36.0	10,350, ± 375	6.0 mm/yr.
ES-1	25.0	8525, ± 325	4.4 mm/yr.
ES-1	18.3	6935, ± 315	2.6 mm/yr.
ES-6*	3.3	4945, ± 165	0.67 mm/yr.
MORO COJO SLOUGH:			
MC-1	22.3	7410, ± 290	5.3 mm/yr.
MC-1	10.6	5235, ± 265	2.0 mm/yr.
MC-2	5.0	3460, ± 850	1.4 mm/yr.
MC-5*	3.5	3780, ± 145	0.93 mm/yr.

Table 1: Absolute ages and sediment accumulation rates based on ^{14}C analysis of shell fragments and peat deposits (* indicates peat sample). See Figure 1 for sample locations.

more abundant in cores ES-2 and ES-3, occurring near the base of core ES-2, and near the non-marine/marine boundary in core ES-3 (Fig. 2). Their disappearance from the cores at 4 kya indicates that like the oysters, the clam's distribution was limited to the width of the channel.

A small community of gastropods identified as the brackish water snail *Assiminea* , was found in the middle of the system at a depth of about 3-4 m (Fig. 2, core ES-4). The presence of *Assiminea* suggests that this part of the slough was probably a salt marsh at about 4 kya.

Fresh Water Peat Deposits: Evidence of fresh water communities first appear in the fossil record about 5 kya and are primarily found in the outer edges near the northeastern slough (Fig. 2, cores ES-5, ES-6 and ES-7). The fresh water peat, named because of the absence of marine indicators, overlies the non-marine sand deposited by an ancient river bed. ^{14}C dating of a peat layer in core ES-6 suggests that this boundary lies at approximately 5 kya (Table 1), when fresh water influx, combined with high rates of sedimentation, created a fresh water marsh that existed until historical times (Oliver et al., 1990).

A fresh water peat horizon from 7-5 m indicates that a fresh water spring invaded an area in Bennett Slough about 4 kya for a brief period in geologic time (Fig. 2, core ES-3). Historical accounts of fresh water springs in Elkhorn Slough suggest that fresh water probably occurred sporadically throughout the slough during the last several thousand years.

Moro Cojo Slough

Paleoenvironmental Indicators in Sedimentary Cores

Mouth: The upper 4 m of core MC-1 was marine clay underlain by a well-sorted to poorly sorted marine sand (Fig. 4). Macrofossil deposits were found throughout the core and included a small muscle deposit at 9m, an oyster deposit between 10-16 m and a clam deposit at 23 meters. Because of the absence of any marine indicators below 23 m, the base of the core is probably a non-marine sand.

Middle: The upper 3 m of core MC-2 contained predominantly salt marsh organic deposits underlain by marine clay to a depth of 13 meters (Fig. 4). Gastropod shells were found in a thin horizon at 5 m (Fig. 4, core MC-2) and co-occurred with a deposit of salt marsh seeds identified as *Ruppia maritima* (D. Adam, U.S. Geological Survey 1989, pers. comm.). Oyster shells were found in a marine clay deposit at 10-14 m and were underlain by a poorly sorted non-marine sand at the base of the core (Fig. 4).

The second core recovered from the middle of the slough was similar to MC-2, with the upper 2 m consisting of salt marsh organic deposits underlain by marine clay (Fig. 3, core MC-3). Although the bore-hole collapsed before a distinct sand layer was found, the base of the core became sandy, indicating that the same poorly sorted non-marine sand horizon found in core MC-2 was probably near the base of core MC-3. The gastropod *Assiminea* and *Ruppia* seeds were found at the 5 m horizon (Fig. 4).

Back: The upper 5 m of core MC-4 consisted primarily of a fresh-water peat deposit, with a thin horizon of marine clay deposited at 1.5 meters (Fig. 4). The base of MC-4 reached a depth of 7 m, and consisted mostly of salt marsh organic debris with some occurrences of ostracods.

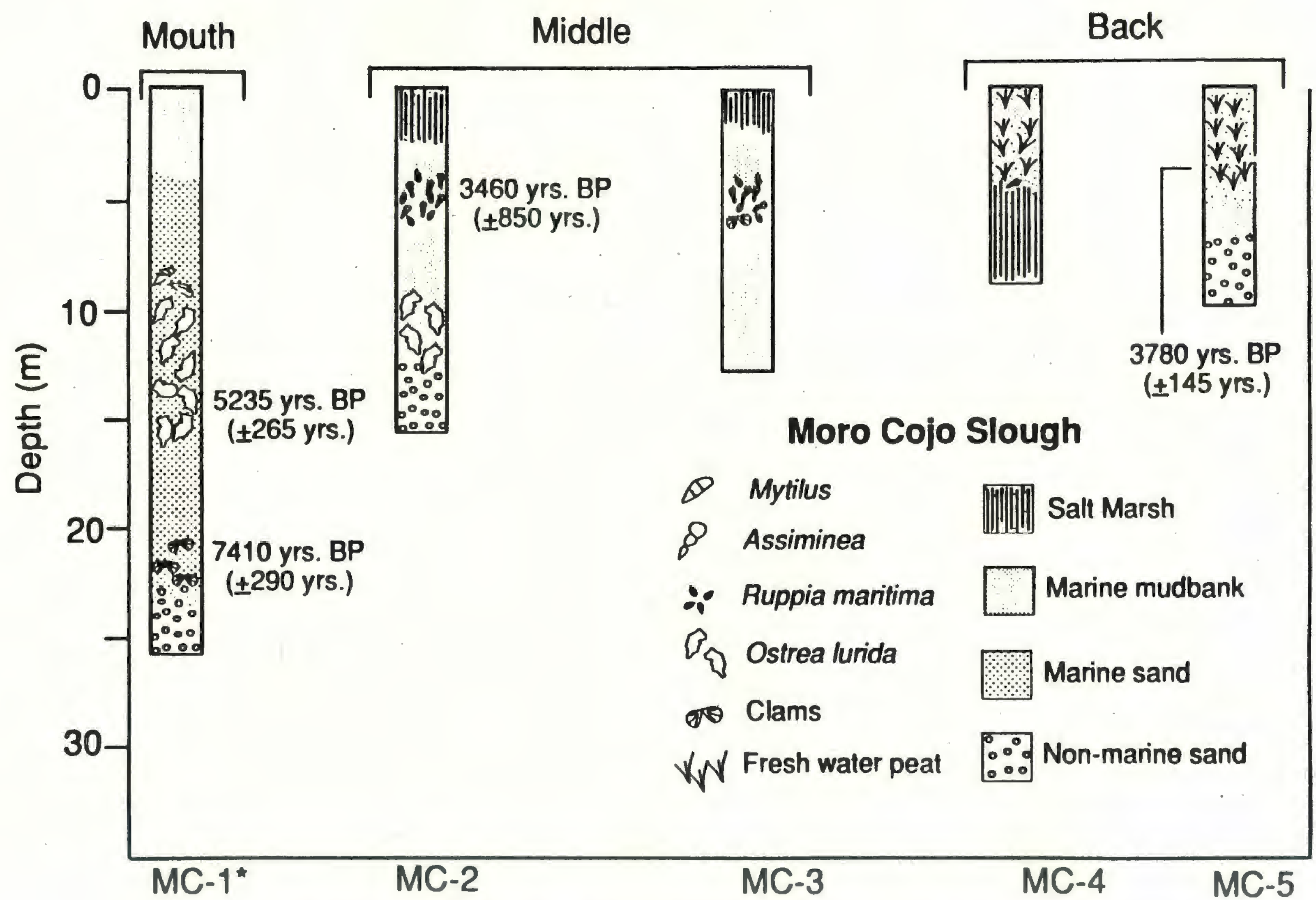

Figure 4: Vertical distribution of major ecological communities and habitats in cores from Moro Cojo Slough. (* Indicates cores recovered by CALTRANS). Table 1 lists standard error for C^{14} dates.

The core collected in the eastern most region of the slough (Fig. 4, core MC-5), reached a depth of 9 m. The upper 6 m consisted of a fresh-water peat deposit underlain by a 1 m horizon of marine clay. The base of this core contained a poorly sorted non-marine sand deposit.

<u>Sediment Grain Size and Type</u>: The sedimentary deposits found in Moro Cojo Slough showed a general fining upward sequence of grain size, from a non-marine fluvial environment to a marine environment, similar to cores collected from Elkhorn Slough. The transition of non-marine environments to marine environments was found in three of the five cores recovered from Moro Cojo, ranging from depths as deep as 23 m and as shallow as 7 m (Fig. 4).

The base of the core collected near the mouth of Moro Cojo Slough (Fig. 1) consisted of a poorly sorted non-marine sand, grading upward into a finer-grained marine sand (Fig. 4, core MC-1) consistent with the known rise in sea level during the past 10 kya. The age of a shell layer near the base of the non-marine/marine interface in MC-1 is about 7.41 kya, suggesting that marine water did not invade this part of the system until after it had reached Elkhorn Slough. While the coarse non-marine gravelly sands found at the base of the mouth of Elkhorn Slough appear to be absent in Moro Cojo, they may actually lie at a deeper depth.

A poorly sorted weathered sand, probably from the Aromas Formation in the surrounding hillsides, defines the non-marine/marine boundary near the base of core MC-2 (Fig. 4) and is overlain by the fine marine clays indicative of a low energy, estuarine environment.

Microfossils: Various species of foraminifera and ostracods are abundant in the clay deposits of Moro Cojo Slough and occur from the mouth of the system to the eastern most edges of the slough. Marine clay deposits are usually deposited during conditions of low tidal energy and brackish water. They are more prevalent in cores MC-2, MC-3 and MC-5 with a thin horizon in MC-4 (Fig. 4). Most of the marine clays are overlain by salt marsh organic debris, deposited when sedimentation rates exceeded rising sea level rates.

The presence of microfossils in the cores recovered from the eastern region of Moro Cojo Slough (Fig. 1, core MC-4 and 5) indicate that marine water influenced the site (Fig. 4). Relative abundances of microfossils and organic debris found in sub-samples taken from Moro Cojo Slough shown in Figure 3 indicate that the abundances of both microfossils and salt marsh plants increase with decreasing tidal energy.

Macrofossils: The native oyster *Ostrea lurida* was the dominant macrofossil found in Moro Cojo Slough and was most abundant from 16-10 m at the mouth of Moro Cojo (Fig. 4, core MC-1). Their apparent absence throughout the rest of the core is due to the larger sampling intervals in this core and the filling in of the main channel through time. ^{14}C dating of the horizon suggests that the oysters were deposited from about 5-4 kya (Fig. 4, Table 1). Oyster communities also appear near the base of a second core in the middle region of the slough (Fig. 1, core MC-2), but the relative abundance is low, compared to numbers found near the mouth of the slough.

Various species of clams, including *Tresus* and *Protothaca*, and the mussel *Mytlius* appear in the cores, but are not abundant macrofossils. Clam deposits found at 23 m in Moro Cojo Slough were dated at 7.41 kya, ±290 (Fig. 4, core MC-1), and are the first indicators of marine influence into the system.

The mussel *Mytilus* appeared once in the core MC-1, but at the much shallower boundary of 9 m. *Mytlius* may have been more abundant than the core data suggest as their shells are commonly found in nearby Indian middens (Dietz and Hilderbrandt, 1986).

The small gastropod *Assiminea* found in Elkhorn Slough was present in even greater numbers in Moro Cojo Slough and was first seen in MC-2, again in MC-3 with a few in MC-4, all lying at a depth of about 5 m (Fig. 4). Because of the low amount of datable carbon in the gastropod shells, the standard error of the age is high (3.46 kya $\pm$ 850), but still provides a useful date which conforms to existing data.

Seeds of *Ruppia maritima* were found in the same horizon as the gastropod, suggesting a brackish water environment in the middle of Moro Cojo Slough between 2-4 kya. The abundance of seeds decreases with increasing distance from the ocean, following the same trend as the *Assiminea.*

Fresh Water Peat Deposits: Non-marine peat deposits with thin horizons of marine clay make up the fresh water communities near the eastern edges of Moro Cojo Slough (Fig. 4, cores MC-4 and MC-5) from about 3.8 kya to present. The fresh water community was inundated by marine water and converted back to a fresh water environment (Fig. 4). The marine water was persistent enough to leave a permanent fossil record, unlike Elkhorn Slough, where there was never enough direct flow into this area to leave behind traces of its presence.

Areal Extent of Fossil Communities

Fossil communities have been divided into time slices to show how the structure of the slough changed through time. These interpretations are based on core data and historical information. Oyster communities in Elkhorn Slough and Moro Cojo Slough from 10-5 kya are shown schematically in Figure 5. The range of oysters is extended farther up the main channel because the known historical occurrence is well documented (MacGinite, 1935; Gordon, 1979). Sea level was approximately 65 m lower than present day conditions (Atwater et al., 1977) and the main channels of both Elkhorn Slough and Moro Cojo Slough were much broader than today.

The distribution of clam communities from Elkhorn Slough and Moro Cojo Slough from 8-3 kya is shown in Figure 6. Sea level had transgressed to 17 m offshore at 8 kya, and infilling of the channels of Elkhorn Slough had begun.

Figure 7 shows the areal extent of both the gastropod community (*Assiminea*) and the fresh water deposits at about 4 kya. The sea level was approximately 5 m further offshore than it is today (Atwater, et al., 1977) and the system looks much like its present configuration.

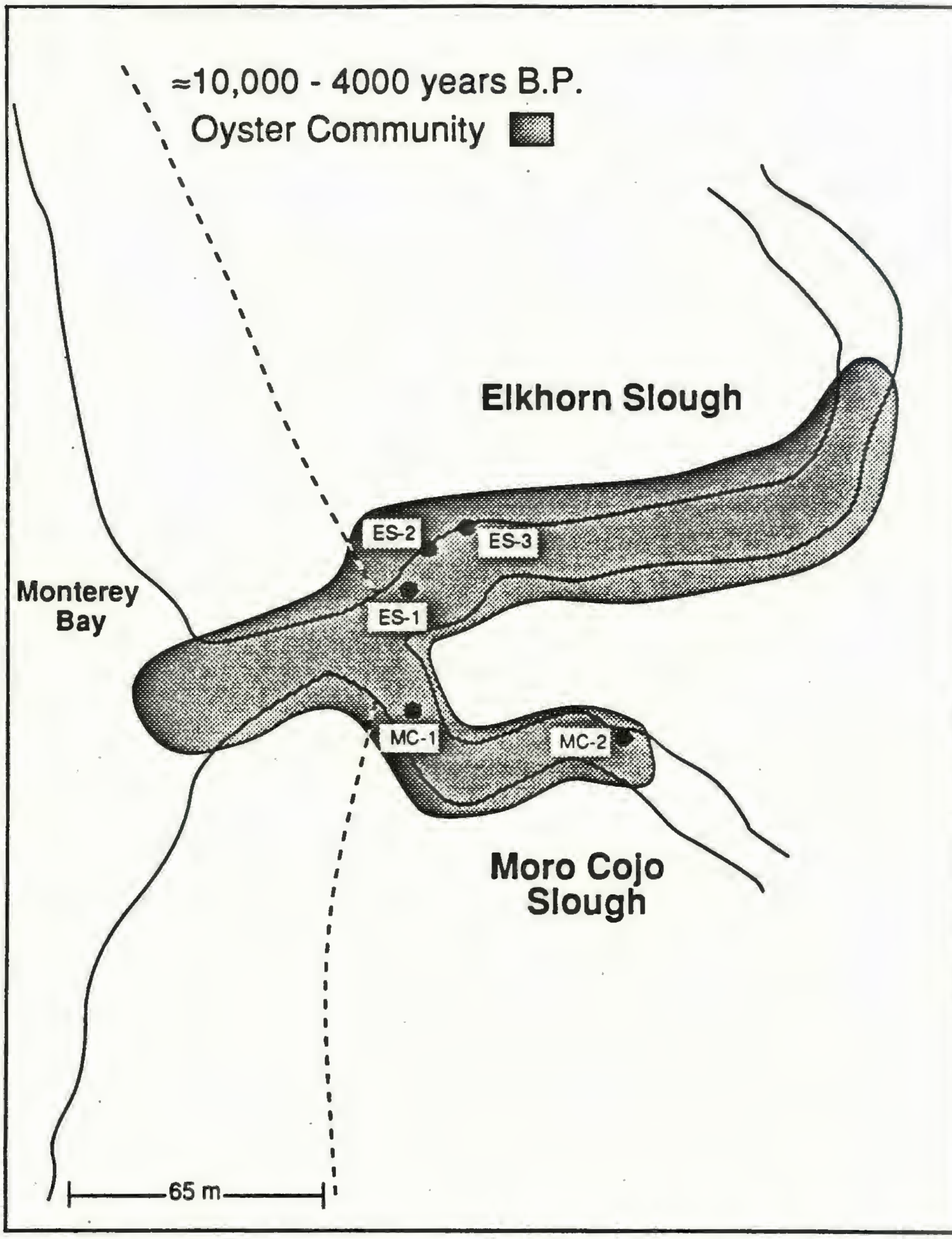

Figure 5: Schematic diagram showing the suggested areal extent of Oyster communities in Elkhorn Slough and Moro Cojo Slough between10,000 and 4000 years ago (black circles show core locations). Solid line is approximate coast line 10,000 years ago and dashed line represents present day coast line (Atwater et al., 1977).

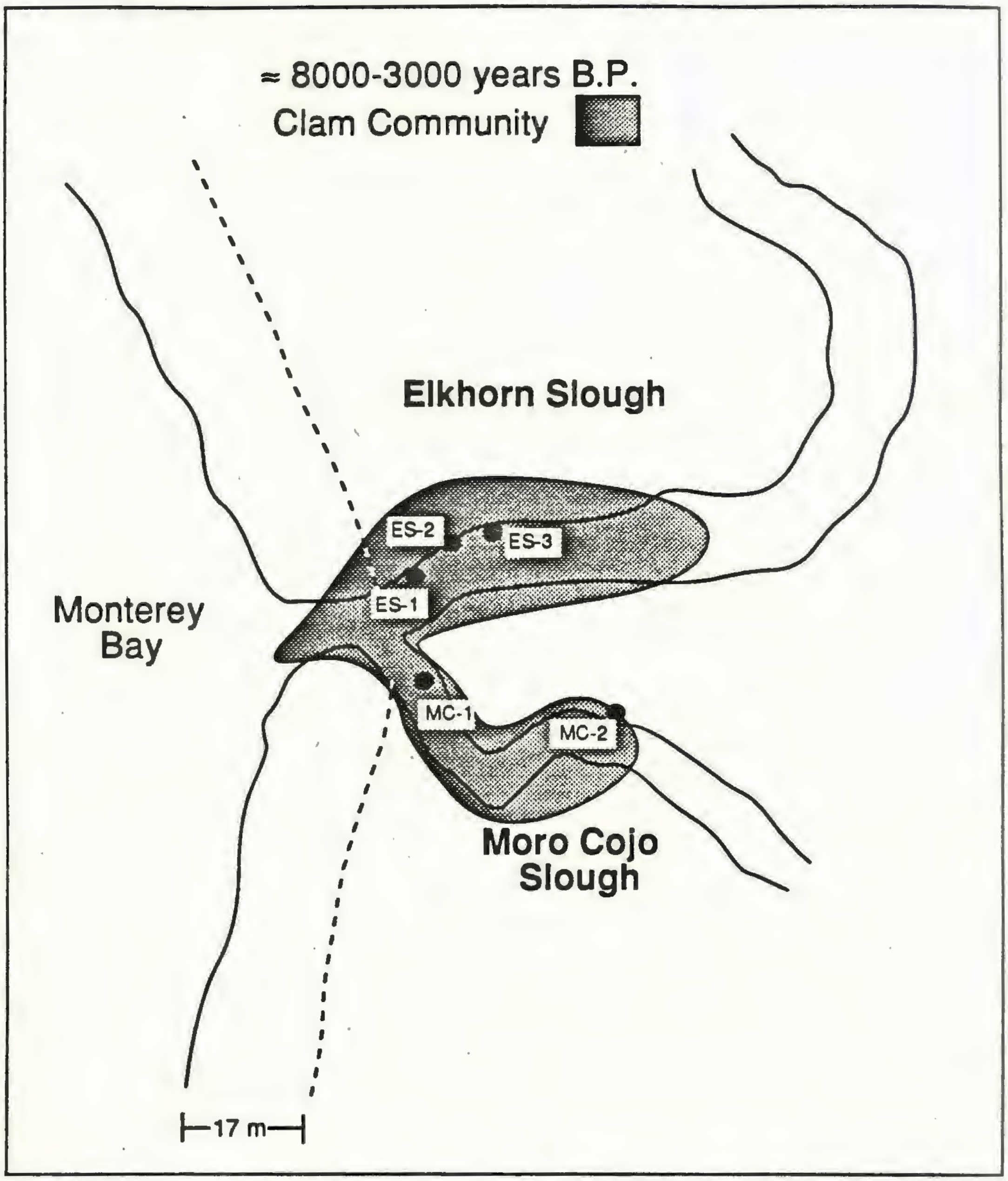

Figure 6: Schematic diagram showing the estimated areal extent of clam communities throughout Elkhorn and Moro Cojo Slough. (black circles show core locations). Dashed line is present day sea level, and solid line represents sea level 8000 years ago.

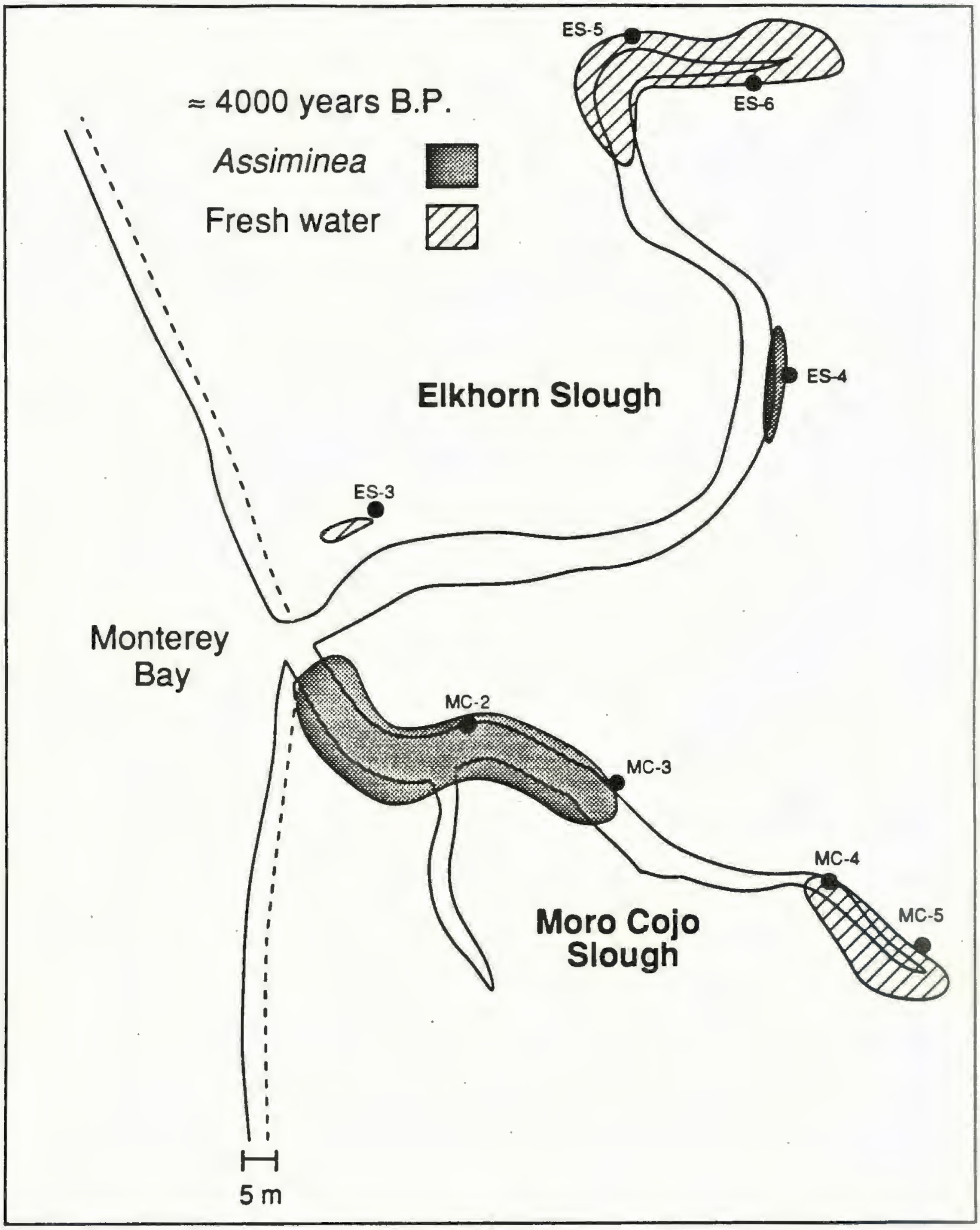

Figure 7: Schematic diagram showing the suggested areal extent of *Assiminea* and fresh water communities in Elkhorn and Moro Cojo Slough (black circles show core locaations). Dashed lines represent present sea level and solid line represents sea level 4000 years ago.

Sedimentation Rates

Sediment deposition in Elkhorn Slough and Moro Cojo Slough correlates closely with the rise in sea level during the last 10 kya (Fig. 5), with sedimentation rates decreasing through time. According to published sea level data along the California coast, sea level rose quickly at a rate of 2 cm/yr between 10-6 kya and slowed to about 0.1-0.2 cm/yr from 6 kya to present (Atwater et al., 1979).

Approximate sedimentation rates in both sloughs were calculated using the ^{14}C dates from selected cores (Table 1), suggesting that between 10-8 kya sediment accumulation rates at the mouth of Elkhorn Slough averaged about 6.0 mm/yr., slowing to a rate of 4.4 mm/yr from 8-7 kya. Using the ^{14}C date at 18 m in core ES-1, the shallowest sample at the mouth, the best sedimentation rate that can be calculated from 7 kya to present is approximately 2.6 mm/year. Sedimentation rates were significantly lower in the northeastern edge of Elkhorn Slough, averaging about 0.67 mm/year from 5 kya to present.

Rates of sedimentation in Moro Cojo Slough followed the rise in sea level curve, with an average sedimentation rate of 5.3 mm/year from 7-5 kya, decreasing to about 2.0 mm/yr between 5-3 kya (Fig. 5). As the sea level rise began to slow, sedimentation decreased to about 1.4 mm/year during the last 3 kya (Fig. 5). Calculations of sedimentation rates near the eastern edge of Moro Cojo Slough averaged 0.93 mm/year during the last 3,780 kya, considerably slower than rates from the mouth of the slough.

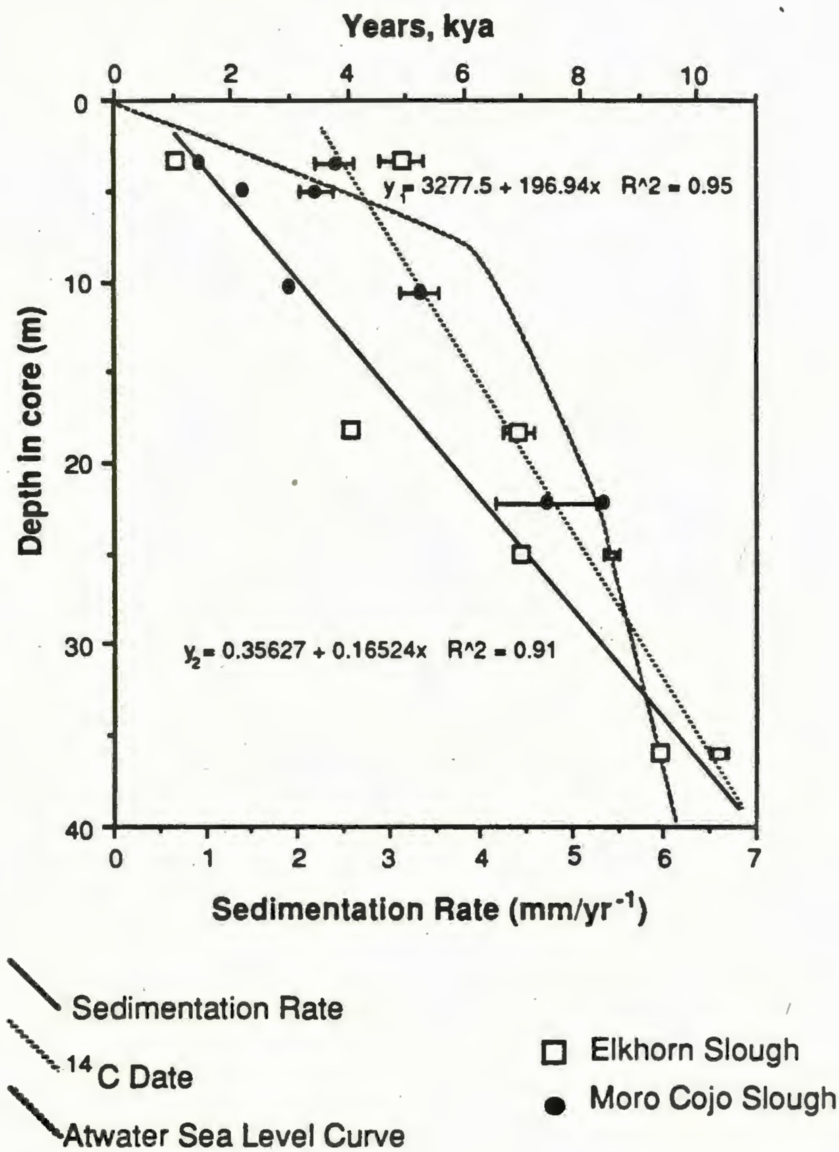

Figure 8: Sediment accumulation rates in Elkhorn Slough and Moro Cojo Slough based on core data from study site (Fig. 1) over the past 10 kya. Dotted line represents Holocene Sea Level rise in southern San Francisco Bay (Atwater et al., 1977).

DISCUSSION

Bridging the gap between long-term geological investigations and short-term ecological studies is necessary to develop a realistic historical model of community development in coastal wetlands. The general characteristic of community development or ecological succession are disputed (Odum, 1969; Drury and Nisbet, 1973; and Connell and Slatyer, 1977). Two potential characteristics are a predictable sequence from an early to a late or climax stage, and a predictable rate of succession for a community or habitat (Odum, 1969). Primary succession is said to occur in a new habitat that has not been previously occupied by ecological communities. The colonization of a shoreline during a sea level progression is an example of primary succession, but because these occurrences are relatively rare and take a long time to complete, they are rarely observed. Nevertheless, primary successions are often thought to display best the characteristics of ecological succession (Odum, 1969; Connel and Slatyer, 1977).

There was no one predictable sequence or rate of succession in the wetland communities of Elkhorn Slough. Adjacent cores showed important differences in community presence and distribution. For example, while some cores contained distinct and persistent communities of *Ruppia martima* and *Assiminea* (e.g., Moro Cojo Slough), other cores showed similar general sedimentary characteristics but this community was absent. The major patterns observed in both Elkhorn Slough and Moro Cojo Slough were not predictable, suggesting that they are dynamic systems. Variations occur over relatively small spatial scales, between cores taken only hundreds of meters apart.

Other investigators have noticed developmental stages and patterns in coastal embayments such as the gradual fining upward sequence of sediment grain size and colonization of marsh plants on mudflats (Redfield, 1971; Atwater, 1977; Lohmar et al., 1980; and Schwartz et al., 1986). Examples of similar sequences can be found in both

Elkhorn Slough and Moro Cojo Slough, but these occurrences appear to be unpredictable and are highly variable. A similar study Jackson et al. (1988) also found no predictable sequences or rate of succession in aquatic vegetation from dune ponds in Indiana. Macrofossil stratigraphy and pollen data showed no significant changes between 3kya-150 years, and determined that the rapid vegetational change at the 150 year boundary was caused by local human disturbance rather than a natural shift between successional stages.

Oysters occurred throughout the cores collected near the mouth of both sloughs and were among the first indicators of sea water invading Elkhorn Slough (Fig. 2, core ES-1). They persisted until historical times. While core data do no indicate extensive oyster habitats after 4 kya, data collected from nearby Indian deposits (Dietz and Hilderbrandt, 1986) and historical observation (Gordon, 1979) indicate that the native oyster beds existed until about the turn of the century. The apparent absence of oysters from the cores at 4 kya show how the margins of the main channel slowly filled in with sediment, shifting the oyster community towards the main channel.

Although their range primarily covers the broad open areas of shallow subtidal environments that were created by the rising sea, small oyster communities were evident in the more protected environment of Bennett Slough, an area of much lower tidal energy (Fig. 1 and 2, core ES-3). The most abundant communities of oysters were found in the marine sand deposits (Fig. 2 and 4, cores ES-1/2; MC-1), but oysters were also present in mudbank environments. Oyster beds were apparently best developed in broad open areas of shallow water.

Clam communities, like the oyster, follow no particular pattern or sequence that supports the idea of a successional progression of organisms during the invasion of a rising sea. Core data suggests that they appear at about 8 kya in both sloughs and persist in core until approximately 2 kya, although they are also known to occur at the mouth of Elkhorn

Slough throughout this century (MacGinnite, 1935; Nybakken et al., 1977). Again, the gradual filling in of the main channel as sedimentation rates exceeded rates in sea level rise accounts for the apparent disappearance of clam communities in the cores.

The areal extent of clam communities is smaller than oyster beds and generally occurred near the slough mouths, where tidal flushing is strong and constant. However, their presence at the mouth of the systems do not exclude occurrences in more protected and shallow water environments (Fig.2, core ES-3; Fig. 4, core MC-3). Clam communities were found in both marine sand and sandy mud, suggesting that clams are not confined to a particular sedimentary environment.

The gastropod *Assiminea* and seeds of *Ruppia* occurred at the 5 m horizon throughout Moro Cojo Slough at 3.5 kya. The same community occurred in a more restricted part of Elkhorn Slough. A morophologically and ecologically similar gastropod, *Tyronia imitator* (California brackish water snail) lives on *Ruppia* in very shallow (usually <1/2 m) in brackish water with relatively poor tidal circulation in Moro Cojo Slough today (Kellogg, 1980). The *Assiminea* and *Ruppia* assemblage probably lived in similar hydrologic conditions.

Although human activities prevent salt water movement into the back of Moro Cojo Slough and Elkhorn Slough today (Gordon, 1979), the eastern margin of these systems has undergone dramatic environmental fluctuations in the geologic past. Fresh water marshes developed in a number of different patterns and sequences as their appearance above, below and between marine deposits suggests that the environmental conditions over the past 5 kya were dynamic. Some marshes originate on fluvial deposits (Fig. 2, core ES-5,6 and 7) and persist until they were converted to salt water habitats by human disturbances (Gordon, 1979). In the eastern region of Moro Cojo Slough, fresh water marshes are also underlain by non-marine fluvial sand, but are replaced by brackish water habitats for as long as 1 kya and then revert back to freshwater (Fig. 4, core MC-5). In other areas, freshwater marshes emerge over extensive brackish water sequences, persist for a period of about 2.5 kya, and are replaced by fresh water deposits (Fig. 4, core MC-4). Spatially and temporally restricted freshwater communities also existed and were probably developed near local springs (Fig. 2, core ES-3).

Although the succession of wetland communities shows little predictable sequences or rates over the last 10 kya, the movement of salt water into Elkhorn Slough is a gradual process. The non-marine gravely sands at the base of core ES-1 show that during the last low stand of sea level, about 16-18 kya (Beard et al., 1982), a large river channel was created in the western region of Elkhorn Valley (Schwartz et al., 1986). Shells dated from this core bottom indicate that sea level began to rise and inundate the mouth of Elkhorn Slough about 10.35 kya and poorly sorted marine sand was replaced with the fining upward sequence of marine sediment common in estuarine environments (Atwater et al., 1979; Schwartz et al., 1986). The hydrologic sequence of salt water invading Moro Cojo Slough is similar to that of Elkhorn Slough, with a record of marine water invading the mouth at about 8 kya, reaching the middle of the slough at about 5 kya and unlike Elkhorn Slough, reaching the eastern edge of the system on a consistent basis as recent as 1 kya.

Rates of sediment accumulation along the west coast of California are similar to the rates calculated for Elkhorn Slough and Moro Cojo Slough and show no obvious discrepancies from the expected norm (Atwater et al., 1977; Schwartz et al., 1986). A sea level curve calculated from data collected in San Francisco Bay can be used to compare sedimentation rates and dates of accumulations in Elkhorn Slough (Fig. 5). The data follow the same general trend, with high rates of sedimentation with the rapid rise in sea level, and slow rates of sedimentation with a decrease in rate of sea level rise.

SUMMARY

The Elkhorn Slough wetland system has undergone several physical and ecological changes during the past 10 kya, when the rise in sea level changed a non-marine fluvial environment into a tidally influenced coastal embayment. Development of ecological communities during the past 10 kya, including oysters, clams, gastropods and fresh water marshes occurred without predictable rates or sequences contrary to some models of ecological succession (Odum, 1969). The most important pattern of habitat and community development include:

1. About 10.35 kya sea level was approximately 65 m offshore of the present day shore line when it invaded the mouth of an ancient river channel, creating an open-water marine embayment. Large occurrences of oyster deposits near the mouth of Elkhorn Slough suggest a well flushed, tidally influenced environment.

2. As sea level continued to rise at a rate of about 2.0 cm/yr., Moro Cojo Slough was inundated with marine water about 8 kya, changing from a primarily fresh water system to a marine and brackish water environment. Evidence of clam communities near the mouth suggest a well flushed, open water system.

3. Rates of sedimentation began to exceed rates of sea level rise about 6 kya, allowing salt marshes to encroach upon the existing mudflats. Communities of both oysters and clams were established in nearby Bennett Slough. Marine water invaded the middle region of Moro Cojo Slough, depositing the marine clay associated with a low energy environment.

4. Isolated occurrences of *Assiminea* and *Ruppia* seeds in the middle regions of Elkhorn Slough and especially Moro Cojo Slough suggest that at about 3.5 kya, both were low energy, brackish water environments.

5. Marine water sporadically invaded the eastern edges of Moro Cojo between 3.5-1 kya, but did not invade the upper reaches of Elkhorn Slough where fresh water peat deposits overlay non-marine fluvial deposits through this entire period.

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Appendix 1. The distribution of microfossils, plant debris and sediment recovered from cores taken in Elkhorn Slough. See Figure 1 for locations.

Elkhorn Slough (ES-1)

DEPTH (m)	Elphidium	Ammonia	Trochemina	Haplophragmoides	Assiminea	Ostracod	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
2 0	0	0	0	0	0	0	0	0	453	453	
3 0	0	0	0	0	0	0	0	12	250	263	
3 3	0	0	0	0	0	0	0	12	255	267	
4 3	1	0	0	0	0	1	0	0	423	425	Well sorted sand
6 6	0	0	0	0	0	0	0	0	479	479	
7 6	0	0	1	0	0	0	0	0	349	350	Well sorted sand
8 3	8	0	1	3	0	10	0	0	526	550	
9 3	0	0	0	0	0	0	0	0	498	498	
11 6	0	0	0	5	0	0	0	0	395	400	>1mm Tegula spp
12 6	0	0	0	0	0	0	4	0	389	393	
13 3	0	0	0	0	0	0	0	1	577	578	Well sorted grey sand
13 5	0	0	0	0	0	0	0	0	463	463	Well sorted grey sand
13 6	0	0	0	0	0	0	0	0	393	393	>1mm few oyster fragments
15 0	0	0	0	0	0	0	1	1	336	338	>1mm Oyster fragments. well sorted grey sand
15 3	0	0	0	0	0	0	1	1	593	595	Well sorted grey sand
16 6	0	0	0	1	0	2	2	9	600	619	>1mm oyster shells. Well sorted grey sand
17 0	1	0	0	0	0	0	6	1	548	556	>1mm clams and oyster shells
18 3	0	0	0	0	0	0	12	4	496	512	>1mm shell fragments
19 3	0	0	0	0	0	0	4	0	394	398	Well sorted sand
20 3	0	0	0	0	0	0	5	5	376	386	>1mm shell fragments. Well sorted med grained sand
21 6	0	0	0	0	0	0	0	0	478	478	
22 0	0	0	0	0	0	0	0	0	363	363	
23 5	0	0	0	0	0	0	1	2	512	515	>1mm Oyster shell fragments
23 6	0	0	0	0	0	0	0	2	479	481	5 clam frags (Tresus & Proto- theca).Well sorted sand
25 0	0	0	0	0	0	0	1	0	423	424	
26 0	0	0	0	0	0	2	5	0	326	333	
26 3	0	0	0	0	0	0	0	0	339	339	Coarser-grained sand
29 3	3	0	7	1	0	13	19	0	304	347	Lots of Oyster fragments >1mm
31 6	1	0	1	1	0	3	0	0	316	326	
32 6	1	0	0	1	0	0	1	0	456	560	
35 0	0	0	1	4	0	0	130	0	293	428	90% Oyster fragments& shells
36 0	0	0	0	1	0	0	13	0	537	551	>1mm Oyster shells &fragments
36 6	0	0	0	0	0	0	0	1	396	397	Poorly sorted grey sand 3shell fragments
37 0	0	0	0	0	0	0	0	0	412	412	Well rounded, poorly sorted sand
38 3	0	0	0	0	0	0	0	0	384	384	Well rounded, poorly sorted sand
38 6	0	0	0	0	0	0	0	0	463	463	Poorly sorted light sand

Elkhorn Slough (ES 2)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Assiminea	Ostracod	Shell fragments	Plant debris	Sediment	Total	COMMENTS
1.6	0	0	0	0	0	0	0	0	509	509	>1mm few shells
2.6	0	0	0	1	0	0	0	40	432	473	>1mm few shell fragments
3.6	0	0	0	0	0	0	0	0	371	371	Well sorted, dark sand
5.2	0	0	0	0	0	0	0	0	521	521	
5.3	0	0	0	0	0	0	0	0	587	587	Well sorted light sand
6.6	0	0	0	2	0	0	1	9	520	532	>1mm clam fragment. Poorly sorted sand
6.8	0	0	0	0	0	0	0	0	473	473	Poorly sorted sand
8.6	0	0	0	0	0	0	0	0	429	429	
10.2	0	0	0	0	0	0	0	0	368	368	Poorly sorted sand >1mm pebbles
10.3	0	0	0	0	0	0	0	0	353	353	Fine gr. weathered sand
10.5	0	0	0	0	0	0	0	0	411	411	Weathered sand
11.6	0	0	0	0	0	0	0	1	437	438	Sandy silt
11.8	0	0	0	0	0	0	0	3	561	564	
12.0	0	0	0	0	0	0	1	1	447	449	Poorly sorted weathered sand. Clam shells >1mm
12.2	0	0	0	0	0	0	2	0	619	621	Poorly sorted weathered sand
13.3	0	0	0	0	0	0	5	0	623	628	
14.3	0	0	0	0	0	0	4	0	439	443	
16.0	0	0	0	0	0	0	2	0	571	573	
16.8	0	0	0	0	0	4	8	14	603	629	>1mm clam fragments, fine grai ned sand
17.0	0	0	0	2	0	0	21	7	453	481	>1mm shell fragments, fine grai ned sand
17.2	0	0	0	2	0	2	3	33	519	559	>1mm shell fragments, fine grai ned sand
18.3	0	0	0	0	0	0	0	0	379	379	>mm few shell fragments
19.3	0	0	0	0	0	0	0	0	401	401	
20.0	0	0	0	0	0	0	0	0	419	419	>1mm Oyster fragments
21.0	0	0	0	0	0	0	0	0	627	627	>1mm shell fragments
21.7	0	0	0	0	0	0	3	5	409	417	Well sorted fine grain sand. >1mm few shell fragments
23.3	0	0	0	2	0	0	6	3	336	347	>1mm Oyster fragments
24.3	0	0	0	0	0	0	0	0	317	317	>1mm Oyster fragments
25.0	0	0	0	0	0	0	0	0	361	361	>1mm Clam & Oyster fragments
26.0	0	0	0	3	0	0	0	1	376	379	
26.8	0	0	0	0	0	1	0	0	327	328	
27.6	0	0	0	0	0	1	0	0	431	432	
28.3	0	0	0	1	0	0	3	0	426	430	fine grained sand
29.3	0	0	0	2	0	2	15	0	307	326	>1mm Clam fragments
30.0	0	0	1	2	0	0	4	0	427	434	>1mm Oyster/Clam fragments
31.0	0	0	0	8	0	0	17	0	321	346	>1mm shell fragments

Elkhorn Slough (ES 3)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Spore Pollen	Ostracod	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
2.2	0	0	0	0	0	0	0	7	426	433	Med grained sand.
3.2	0	0	0	0	0	0	0	2	471	473	
7.3	0	0	0	0	0	0	5	503	0	508	99% Peat
8.3	21	0	4	6	0	57	0	7	321	416	Silty clay
10.6	0	0	0	0	0	7	0	1	316	324	
11.6	0	0	2	3	0	12	0	6	403	426	
14.0	2	0	1	5	0	4	2	11	360	385	>1mm organic debris
15.0	1	0	0	0	0	4	0	2	351	358	
15.6	1	0	5	4	2	19	18	6	404	461	>1mn few Clam fragments
16.6	0	0	0	1	11	0	1	3	361	388	
19.0	0	0	1	3	6	3	1	4	357	381	>1mm organic debris
20.0	2	0	4	2	2	0	9	0	313	333	>1mm organic debris
25.6	0	0	15	5	0	9	12	6	407	454	>1mm organic debris and shell:
26.6	0	0	0	0	0	0	1	7	370	378	Well sorted sand
27.5	0	0	0	0	0	0	1	0	407	408	Poorly sorted sand
27.8	0	0	0	0	0	0	1	0	361	363	Poorly sorted sand
30.8	0	0	0	0	0	0	0	0	376	376	Poorly sorted sand
31.0	0	0	0	0	0	0	0	0	421	421	Poorly sorted sand
34.0	0	0	0	0	0	0	0	0	489	489	Poorly sorted sand
37.3	0	0	0	0	0	0	0	0	309	309	Poorly sorted sand

Elkhorn Slough (ES 4)

DEPTH (m)	Elphidium	Ammonia	Trochamin	Haplophragmoide	Assiminea	Ostraco	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
1.0	0	0	0	0	0	0	0	377	31	407	Mostly recent organics
3.1	0	0	0	0	0	1	0	323	28	353	
3.3	0	0	0	1	0	0	0	423	86	510	Mostly organic (roots)
5.0	146	65	0	0	0	24	0	178	21	432	>1mm Assiminea
5.3	27	10	0	0	8	91	0	147	9	292	>1mm Assiminea
8.0	17	21	3	0	1	41	0	268	6	357	>1mm organics & shell frag ments
8.3	29	21	2	1	3	27	13	252	10	358	>1mm organics & shell frag ments
11.3	0	0	0	0	0	0	0	13	366	379	37 Spore pollen

Elkhorn Slough (ES 5)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Spore Pollen	Ostracod	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
0.5	0	0	0	0	0	0	3	330	129	464	>1mm organic debris
1.0	0	0	0	0	0	0	0	379	8	387	
1.5	0	0	0	0	0	0	0	257	203	720	Poorly sorted sand
1.8	0	0	0	0	0	0	0	207	250	457	
2.0	0	0	0	0	0	0	0	37	329	366	>1mm pebbles, poorly sorted
2.6	0	0	0	0	0	0	0	7	392	399	>1mm pebbles, poorly sorted
3.0	0	0	0	0	0	0	0	3	521	524	Poorly sorted sand-pebbles
6.6	0	0	0	0	0	0	0	0	492	492	Coarse gr. Aromas sand
7.0	0	0	0	0	0	0	0	0	413	413	Coarse gr. Aromas sand

Elkhorn Slough (ES 6)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Spore Pollen	Ostracod	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
0.8	0	0	0	0	0	0	0	271	42	316	Mostly peat
1.0	0	0	0	0	0	0	0	326	7	333	Peat
3.0	0	0	0	0	0	0	0	160	273	433	Peat and sand
3.3	0	0	0	0	0	0	0	319	69	388	Peat
3.6	0	0	0	0	0	0	0	34	491	525	Well rounded sand grains
4.0	0	0	0	0	0	0	0	190	213	403	Peat and sand
5.3	0	0	0	0	0	0	0	0	353	353	Poorly sorted sand
5.8	0	0	0	0	0	0	0	0	469	469	Poorly sorted sand

Appendix 2. The distribution of microfossils, macrrofossils, plant debris and sediment recovered from cores taken in Moro Cojo Slough. See Figure 1 for locations.

Moro Cojo (MC-1)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Assiminea	Ostracod	Shell Fragments	Plant Debris	Sediment	Total Counted	COMMENTS
3.0	23	0	0	0	0	139	0	36	328	526	
9.0	0	0	0	2	0	2	0	4	662	672	Few Muscle shell fragments
10.0	0	1	0	0	0	0	0	0	295	296	
10.5	0	0	0	1	0	4	46	4	339	394	
11.5	1	0	0	1	0	3	11	11	233	260	
14.0	0	2	0	0	0	2	1	0	362	367	
15.0	0	3	0	0	0	0	1	0	319	322	
16.0	0	0	0	0	0	0	1	5	570	576	Few Oyster shells >1mm; Well sorted dark grey sand
18.2	0	0	0	0	0	0	2	7	551	560	Few Oyster shells >1mm; Well sorted dark grey sand
18.3	0	0	0	0	0	0	1	0	476	477	Few Oyster& Clam fragments Well sorted dark grey sand
18.5	0	0	0	0	0	0	3	0	573	576	Clam & Oyster shells, Poorly sorted grey sand
21.0	0	0	0	3	0	0	0	75	429	507	Shell fragments and organics; Fine grain sandy silt
21.2	0	0	2	0	0	0	3	112	403	520	Shell frags and organics, Fine grain sandy silt
22.3	0	0	0	1	0	0	0	9	476	486	Oysters and Clams>1.0mm, Poorly sorted sand
23.3	0	0	0	0	0	0	0	0	423	423	Poorly sorted, non marine sand
25.6	0	0	0	0	0	0	0	0	388	388	Poorly sorted non marine sand

Moro Cojo (MC-2)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Assiminea	Ostracod	Shell Fragments	Plant Debris	Sediment	Total Counted	COMMENTS
0.8	0	0	0	0	0	0	0	366	45	411	99% plant debris (roots)
1.2	0	0	0	0	0	0	0	303	42	345	99% plant debris (roots)
3.0	0	0	0	0	0	0	0	573	28	601	99% Peat and other plant debris
3.5	0	0	0	0	0	176	0	90	107	373	Very fine clay sample
5.5	8	33	0	4	3	0	77	24	225	374	>1mm shell frags & Assiminea
5.6	3	4	0	0	12	108	101	49	72	349	Ruppia seeds & Assiminea >1mm
5.8	32	89	0	1	0	29	36	47	35	269	Ruppia seeds, shell fragments & Assimina >1mm
7.8	1	0	0	1	0	421	2	9	13	449	Clay sediment with lots of whole Ostracods and fragments.
8.0	0	2	0	0	0	127	0	0	186	318	Clay sediment; Lots of Ostracod
11.3	11	8	0	0	0	5	18	12	113	283	Oyster frags >1mm
12.0	3	8	0	4	0	18	2	113	189	337	Oyster frags >1mm
15.0	0	0	0	0	0	0	0	0	367	367	Coarse, poorly sorted Aromas sand
18.0	0	0	0	0	0	0	0	0	429	429	Coarse, poorly sorted Aromas sand

Moro Cojo (MC-3)

DEPTH (m)	Elphidium	Ammonia	Trochamin	Haplophragmoides	Assiminea	Ostracod	Shell Fragments	Plant Debris	Sediment	Total Counted	COMMENTS
1.0	0	1	0	0	0	0	0	321	47	369	90% Plant debris (roots).
1.6	18	27	0	0	0	38	0	23	304	410	
3.3	1	0	0	0	0	0	0	22	309	332	>1mm, few pebbles
3.8	1	0	0	0	0	0	0	74	260	335	
5.0	7	5	0	5	0	15	0	47	359	438	>1mm few shell fragments
6.8	4	12	1	0	0	24	7	11	351	410	>1mm 1 clam fragment, few Assiminea
7.0	10	3	0	0	0	108	0	10	279	408	
10.0	1	7	0	0	0	37	0	294	0	339	95% Plant debris
13.3	0	0	0	0	0	0	0	27	278	305	98% Sandy silt pieces

Moro Cojo (MC-4)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Assimine	Ostracod	Shell Fragments	Plant Debris	Sediment	Total Counted	COMMENTS
0.8	0	0	0	0	0	0	0	298	26	324	99% organic debris (roots)
1.1	0	0	0	0	0	0	0	182	177	359	
1.6	0	0	0	0	0	55	0	219	96	370	
1.8	0	0	0	0	0	2	0	413	90	505	>1mm organic debris
2.0	0	0	0	0	0	1	0	383	17	401	99% peat
3.3	0	0	0	0	0	0	0	270	47	318	99% peat
3.8	0	0	0	0	0	0	0	319	187	506	
4.3	0	0	0	0	0	0	0	179	318	497	
5.0	0	0	0	0	0	4	0	201	179	384	Few Assiminea in s ample
6.6	0	0	0	0	1	9	0	120	281	411	Sandy silt
7.0	0	5	0	0	0	106	0	312	55	480	Sandy silt
8.8	0	0	0	0	0	5	0	497	11	513	99% organic debris (old roots)

Moro Cojo (MC-5)

DEPTH (m)	Elphidium	Ammonia	Trochamina	Haplophragmoides	Assiminea	Ostracod	Shell fragments	Plant debris	Sediment	Total counted	COMMENTS
1.0	0	0	0	0	0	0	0	5	324	329	Sandy silt
3.2	0	0	0	0	0	1	0	439	87	527	
3.5	0	0	0	0	0	0	2	318	111	431	Lots of peat
4.8	0	0	0	0	0	0	0	24	433	457	
5.0	0	0	0	0	0	0	0	20	487	507	
5.3	0	0	0	0	0	0	0	37	337	374	
6.5	11	10	0	43	0	0	0	4	312	380	
6.8	24	32	1	91	0	31	7	18	183	380	Sandy silt/clay
7.0	0	1	0	2	0	1	0	15	283	302	
7.3	0	1	0	2	0	1	0	8	419	431	Poorly sorted weathered sand
8.0	0	0	0	0	0	2	1	2	371	375	Poorly sorted sand
8.5	0	0	0	0	0	0	0	10	281	291	Poorly sorted coarse sand
8.8	0	0	0	0	0	0	0	0	393	393	Poorly sorted sand
9.0	0	0	0	0	0	0	0	13	368	38[illegible]	Poorly sorted sand
9.8	0	0	0	0	0	0	0	7	412	419	Poorly sorted weathered sand
10.0	0	0	0	0	0	0	0	9	341	35	Poorly sorted sand