Coastal Climate Reflected in $^{13}C/^{12}C$ Ratio of Organic Carbon in Varved Sediment from Santa Barbara Basin

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ABSTRACT: A 1844-1987 time-series of carbon stable isotope ratios from dated sedimentary total organic carbon from the center of the Santa Barbara basin is compared with historical climate and oceanographic records. Carbon derived from ^{13}C-depleted phytoplankton and ^{13}C-enriched kelp appear responsible for a large part of the isotopic variance in sedimentary total organic carbon. El Niño/Southern Oscillation events are recorded by the isotopic response of marine organic carbon in sediments.

Introduction

This study uses the laminated sediment record from the Santa Barbara basin (Schimmelmann *et al.* 1990 and references therein) and the climate history of Southern California (AD 1844-1987) to calibrate the isotopic response of sedimentary total organic carbon (TOC) to oceanographic change, especially to El Niño/Southern Oscillation (ENSO) events.

The stable isotope ratio $^{13}C/^{12}C$ (expressed as $\delta^{13}C$ value) of marine organic carbon is determined by the contributing sources (reviewed by Sackett 1989). $\delta^{13}C$-values tend to decrease in order from macroalgae (kelp) to phytoplankton to terrigenous organic matter. The dominant source of organic carbon in the Santa Barbara basin is phytoplankton (Eppley and Holm-Hansen 1986), but phytoplankton productivity during an ENSO event is greatly diminished (Chelton *et al.* 1982; Lange *et al.* 1987 and 1990).

Until their destruction in the early 1980s, the giant kelp (*Macrocystis* spp.) forests from Point Conception to Santa Barbara were some of the largest in Southern California (Tegner and Dayton 1987). Strong ENSO and severe storm events have been linked to extensive destruction of kelp forests (Seymour *et al.* 1989), causing a short-term introduction of large amounts of ^{13}C-enriched kelp carbon into the coastal ecosystem. The isotopic composition of marine organic carbon is also influenced by isotope effects based on temperature, p[CO_2], light and nutrient availability, and species composition of the biota (Rau *et al.* 1989; Sackett 1989). The sedimentary TOC isotope record integrates all carbon sources, including non-marine sources.

Results of this study suggest terrigenous organic carbon transported by rivers into the Santa Barbara basin is of limited significance for the isotopic composition of sedimentary TOC in the deep center of the basin. The discharge of ^{13}C-depleted sewage into Santa Barbara basin is negligible (Schaefer 1989).

In: J.L. Betancourt and V.L. Tharp, editors. 1991. *Proceedings of the Seventh Annual Pacific Climate (PACLIM) Workshop, April 1990*. California Department of Water Resources. Interagency Ecological Studies Program Technical Report 26.

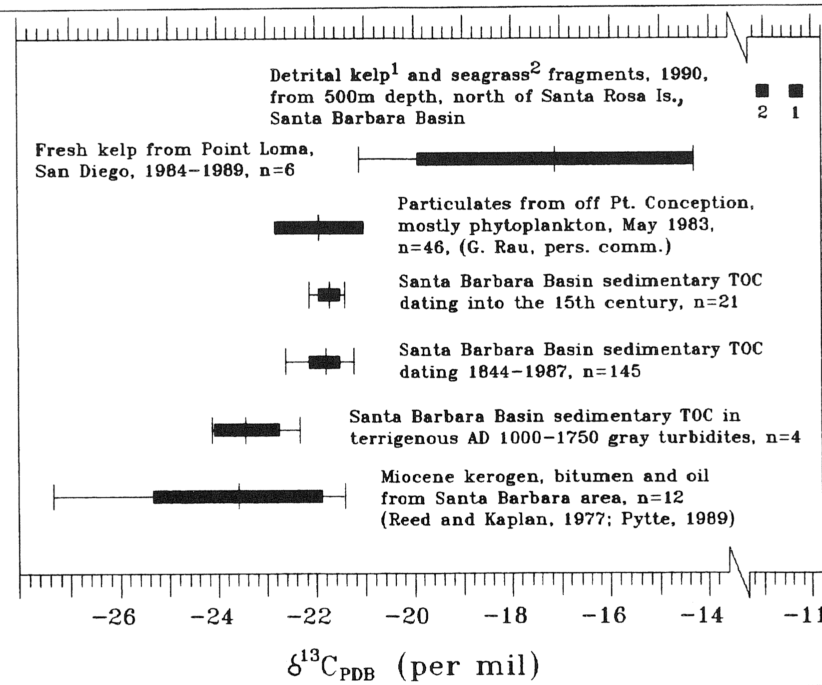
Methods

Retrieval of sediment cores from 590 meters near the center of the Santa Barbara basin, subsampling, and dating procedures are described elsewhere (Schimmelmann *et al.* 1990). $\delta^{13}C$ values from sedimentary TOC, living giant kelp (*Macrocystis pyrifera*) from the Point Loma kelp forest near San Diego, and detrital kelp and seagrass (retrieved at 500-meter depth north of Santa Rosa Island in the Santa Barbara basin) were determined using the method of Nissenbaum and Serban (1987). Isotopic results are expressed in the usual $\delta^{13}C_{PDB}$ notation in per mil, with a precision of ±0.1 per mil.

Results and Discussion

We are confident the observed isotopic differences among carbon sources shown in Figure 1 are systematic and large enough to produce signals that may be interpreted paleoclimatically, in spite of diagenetic *postmortem* isotopic changes (for example, Fenton and Ritz 1988). The stable isotope ratios of kelp samples from Point Loma are comparable with a reported mean of $\delta^{13}C = -17.7$; $\sigma = 2.3$ per mil (n=162) for kelp from Aleutian waters (Duggins *et al.* 1989). Therefore, kelp from the shelf neighboring the Santa Barbara basin should fall in the same range.

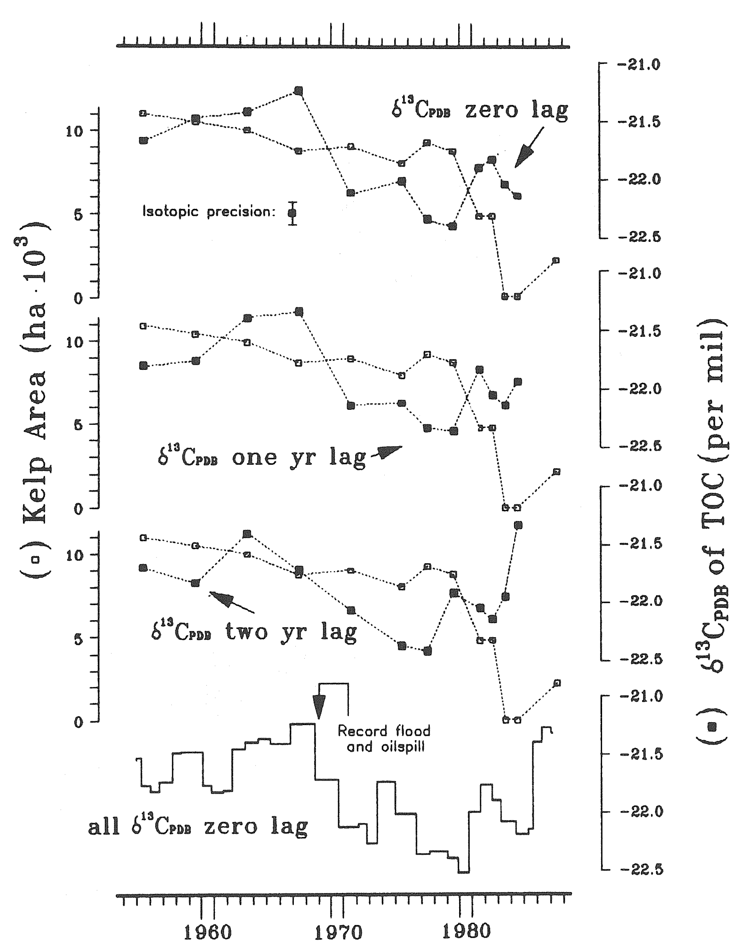
Figure 1
ISOTOPIC MEAN, STANDARD DEVIATION, AND RANGE (where available) OF DISTINCT ORGANIC CARBON POOLS



Our isotopic results from the youngest sediment layers (Figure 2) may not be comparable with older sediment layers, because near-surface varves are richer in living biomass and nonrefractory organic matter (Reimers *et al.* 1990, Schimmelmann unpublished data).

Figure 2
COMPARISON BETWEEN CHANGES IN THE KELP CANOPY AREA AND THE RESPECTIVE TRENDS OF $\delta^{13}C$ OF SEDIMENTARY TOTAL ORGANIC CARGON

The lowermost $\delta^{13}C$ time-series displays continuous, irregularly spaced data. All other $\delta^{13}C$ data (solid squares) represent hypothetical annual intervals matching the years of kelp observation. The same kelp record is compared with $\delta^{13}C$ records lagging zero, 1, and 2 years behind to account for the time needed for transportation of kelp carbon until incorporation into sedimentary TOC.



Isotopic Response of Marine Carbon to Climatic Change

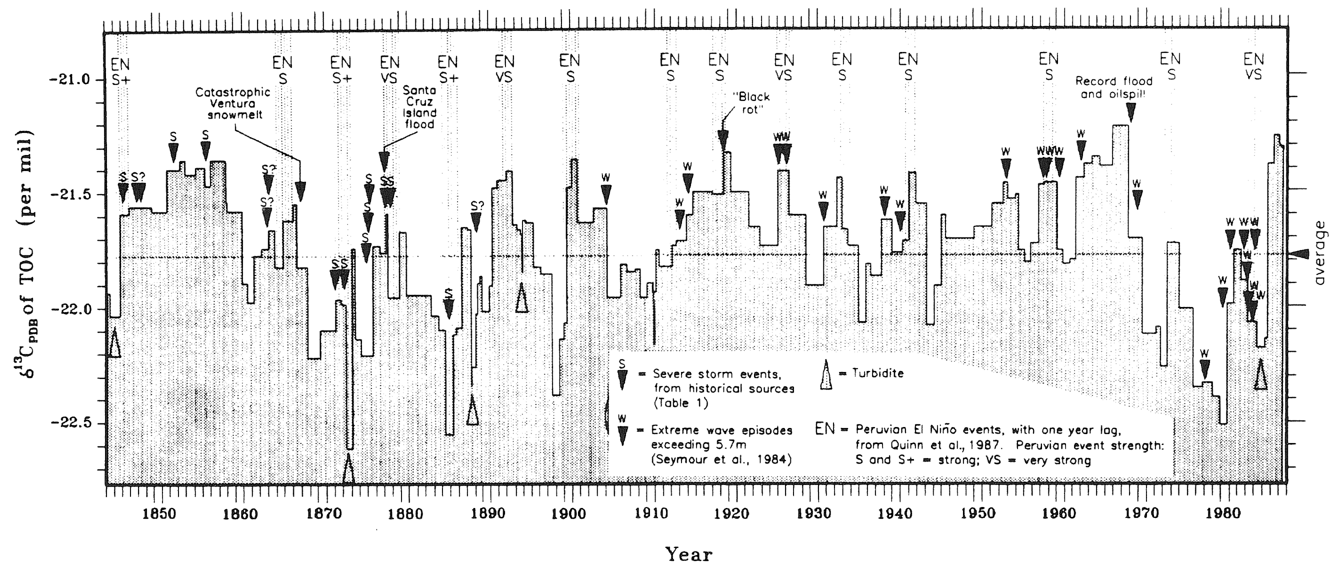
Changes in the kelp canopy area of kelp beds from Santa Barbara to Point Conception were reported for distinct years between 1955 and 1979 by Harger (1983). In addition, estimates for 1981, 1983, 1984, and 1987 from a kelp harvesting company, Kelco (D. Glantz, personal communication; estimated by a different method), were adjusted by us with respect to 1975, for which both sources had estimates. Figure 2 compares the consecutive changes in kelp canopy area with the respective trends of $\delta^{13}C$ of sedimentary TOC.

The same kelp record is also compared with $\delta^{13}C$ records lagging 1 and 2 years to estimate the time needed for transportation of kelp carbon to the center of the Santa Barbara basin. Seven of eight observations from 1955 to 1981 show a negative correlation of trends between kelp area and the isotopic record with lags of zero and 1 year. A 2-tailed binomial test (Conover 1971) indicates the negative correlation is significant for lags of zero and 1 year (p=0.035) but not for a lag of 2 years (p=0.64), where only half of the trends correlate. No significant correlation is observed for 1981-1987, in part because storms and El Niño summers had reduced the standing kelp biomass to a record low (Figure 3) (Tegner and Dayton 1987, Seymour *et al.* 1989).

Figure 3

TIME SERIES OF δ13C OF SEDIMENTARY TOTAL ORGANIC CARBON FROM SANTA BARBARA BASIN

Historical Peruvian El Niño periods, with 1-year lag, are shaded to cover 2-year intervals. For example, the shading of the 1982 El Niño covers 1983 and 1984. Other events are indicated without lag.



Our statistics suggest kelp carbon is an important factor in the isotopic mass-balance of the Santa Barbara basin ecosystem. However, the lack of proportionality between observed changes in kelp abundance and isotopic shift, especially from 1967 to 1971 (Figure 2, zero and 1-year lag), discourages simplistic isotopic mass-balance calculations and indicates the need to consider additional environmental effects.

Isotopic Influence of Non-Marine Carbon Sources

An oceanographically-interpretable, marine-derived signal in the isotopic total organic carbon record can only be expected for times when the marine carbon contribution is large enough to dominate non-marine sources. To evaluate the isotopic influence of river-transported, ^{13}C-depleted organic matter, we compared our 1844-1987 $\delta^{13}C$-time series with statistics of severe historical floods listed by the U.S. Army Corps of Engineers (1975) as "damaging floods ... known to have occurred in the Santa Barbara area in 1862, 1875, 1877, 1883, 1907, 1909, 1911, 1914, 1918, 1938, 1941, 1943, 1952, 1967 and 1969". Less than one-third of these severe floods coincide with or are immediately followed by a severe drop of $\delta^{13}C$ values of TOC in Figure 3 (adapting a 0.3 per mil threshold), even if a 1-year lag is assumed.

A comparison among the 1874-1987 rainfall, the 1930-1985 discharge of the Ventura and Santa Clara rivers, and our $\delta^{13}C$-time series yields a similar result (not shown here). We concluded that only extreme floods and rapid sequences of floods have a significant impact on isotopic composition of TOC in the center of the Santa Barbara basin.

Unprecedented isotopic fluctuations of TOC deposited in Santa Barbara basin in the 1970s deserve special attention as they relate to a few unusual environmental events (Figure 3). A sequence of major oil spills in 1969 introduced large amounts of ^{13}C-depleted fossil carbon into the basin's ecosystem (Kolpack *et al.* 1971). A record flood in early 1969 caused a massive influx of terrigenous ^{13}C-depleted biomass into the basin (Drake *et al.* 1971). Independently from the 1969 events, the productivity of Santa Barbara basin declined significantly from 1968 through 1977 (Lange *et al.* 1990).

Comparison of the 1844-1987 $\delta^{13}C$ Time Series with Historical Records

Figure 3 compares the isotopic TOC time-series with historical climatic records (U.S. Geodetic and Coast Survey 1872, U.S. Coast and Geodetic Survey 1889, Ellison 1937, Mason 1961, Brewer 1966, Ruhge 1987, Seymour *et al.* 1984). Strong and very strong Peruvian El Niño years (Quinn *et al.* 1987) are indicated with a time lag of 1 year to account for progression into the northern hemisphere. Of the 15 listed ENSO events, 12 coincide with or immediately precede $\delta^{13}C$ maxima. Most storm and wave events follow the same pattern, but a rapid succession of kelp-destructing events can yield only one initial $\delta^{13}C$ spike in sedimentary TOC because kelp forests would need time for recovery.

While the correlation between tropical ENSO events and changes in the California Current is very strong, the relationship occasionally breaks down (Chelton *et al.* 1982). It is noteworthy that the Peruvian El Niño events in 1932 and 1972 are represented by $\delta^{13}C$-peaks in Figure 3, although we have little or no physical/ oceanographic evidence of ENSO influence during 1933/34 and 1973/74 in the California borderland.

The finding of a $\delta^{13}C$ maximum in our time series represents insufficient evidence to document an ENSO event. In any case, and especially for pre-1525 sediments, one could identify prospective sediment layers as ENSO event deposits using their distinctive microfossil assemblages (Lange *et al.* 1987 and 1990) and paleoclimatically relevant biomarkers (McCaffrey *et al.* 1990). Our carbon isotopic approach is thus useful for rapid screening of large numbers of sediment samples. Prospective ENSO layers could then be scrutinized by more specialized methods.

Conclusion

In agreement with historical weather records and direct kelp observations, we present evidence from the 19th and 20th centuries that the combined marine-derived organic carbon from phytoplankton and kelp responded isotopically to oceanographic changes. The laminated sediment record of the Santa Barbara basin extends several thousand years into the past. This offers an opportunity to reconstruct the frequency of prehistoric ENSO events as they are recorded in sedimentary organic matter.

Acknowledgments

This work was supported by National Science Foundation grants ATM87-23024 to W.H. Berger and OCE87-00989 to P.K. Dayton and M.J. Tegner.

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