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THE FOSSIL DIATOMS OF LAKE YAMBO, ECUADOR. A POSSIBLE RECORD OF EL NIÑO EVENTS

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Abstract

Fossil diatoms from a sediment core of Lake Yambo, a lake in an endorheic, desert region of the Ecuadorian Andes, provide a record of precipitation events that can be linked to the ENSO phenomenon. Abnormally high precipitation in the region during the 1982-83 El Niño caused a substantial drop in the lake's conductivity. The diatom flora in the lake changed from a community dominated by the halophilic species *Craticula halophila*, to one dominated by a fresh water species *Aulacoseira distans*. Similar shifts in dominance can be seen at various points throughout the core. There also appears to be an increase in sediment deposition at these points. This paper provides the first evidence that the use of fossil diatoms from lake cores can be a valuable tool in reconstructing histories of El Niño events.

Key words: *El Niño, Ecuador, Diatoms, Inter-Andean.*

DIATOMEAS FÓSILES DE LA LAGUNA DE YAMBO, ECUADOR. UN POSIBLE RÉCORD DE FENÓMENOS «EL NIÑO»

Resumen

Estudios limnológicos se han realizado cada año desde 1975 en la Laguna de Yambo, ubicada en una parte árida de la región interandina de Ecuador. Estos estudios indican que el agua de esta laguna tiene una alta concentración de sales disueltas y la flora de diatomeas rica en *Craticula halophila,* una especie característica de lagunas salobres. En 1982-1983 uno de los fenómenos «El Niño» más inesperados, intensos y catastróficos, azotó la costa sudamericana del Pacífico y causó un aumento considerable de la precipitación en la región de la laguna. Este aumento hizo que la condutividad del agua sea reducida en un 30% La comunidad de diatomeas respondió a este cambio en la química del agua, y observamos un aumento en la abundancia de la diatomea *Aulacoseira italica,* y una reducción en la abundancia de *Craticula halophila.* Análisis de diatoméas fósiles en sedimentos de la laguna de Yambo revelan las mismas fluctuaciones en estas dos especies. Como la laguna se encuentra en una región muy árida, cambios en la salinidad del agua pueden resultar solamente como consecuencia de cambios dramáticos en la precipitación. Por lo tanto es factible interpretar el récord de cambios en la comunidad de diatomeas de la Laguna de Yambo como la historia de los fenómenos de «El Niño» ocurridos durante los 2500 años de existencia de la laguna.

Palabras claves: *El Niño, Ecuador, Región Interandina, Diatomeas.*

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LES DIATOMÉES FOSSILES DU LAC "YAMBO", ÉQUATEUR. UN REGISTRE SUR LES PHÉNOMÈNES "EL NIÑO"

Résumé

Des études limnologiques effectuées tous les ans depuis 1975 sur le lac "Yambo", situé dans une zone aride de la région inter-andine équatorienne, ont montré que l'eau du lac est à haute teneur en sels dissouts et que la flore de diatomées est riche en *Craticula halophila*, une espèce caractéristique des lacs saumâtres. En 1982-1983, l'un des phénomènes "El Niño" des plus inattendus, des plus intenses et des plus catastrophiques a frappé la côte sud-américaine du Pacifique provoquant une augmentation considérable de la précipitation sur la région du lac. Par suite de cette augmentation, la conductivité de l'eau a diminué de 30%. La communauté de diatommées a réagi à ce changement dans la chimique de l'eau et nous avons constaté une augmentation du nombre des diatomées *Aulacoseira italica* ainsi qu'une diminution des *Craticula halophila*. Des analyses sur des diatomées fossiles en provenance des sédiments du lac "Yambo" montrent les mêmes fluctuations des deux espèces. Étant donné la localisation du lac, sur une zone très aride, les changements dans la salinité de l'eau ne peuvent être que le résultat des changements dramatiques survenus dans les précipitations. Par conséquent, il est possible d'interpréter le registre des changements survenus dans la communauté de diatomées du lac "Yambo" comme l'histoire des phénomènes "El Niño" au cours des 2500 ans de vie du lac.

Mots clés : *" El Niño" , Équateur, inter-andin, diatomées.*

1. INTRODUCTION

Our understanding of the repeated occurrence of El Niño/Southern Oscillation (ENSO) events comes from historical records dating back to 1500 years B.P. (Quinn *et al.*, 1987; Hamilton & García, 1986), and reconstructional studies based on the impact of ENSO events. Archaeological evidence for flooding in Peru indicates that very strong ENSO events occurred around 1100, 1380 and 1460 +/- 20 A.D as well as 500 B.C. (Wells, 1987; Wells *et al.*, 1987; Nials *et al.*, 1979a, b; Moseley *et al.*, 1981; Quinn *et al.*, 1987). In addition, there are recognizable and diverse signals left by past El Niño events in lake, deep sea, and ice-cores, paleosols, beach-ridges, alluvial sequences, tree-rings, coral and mollusk growth records, and guano deposits (Bird, 1987; Wells, 1987; Craig & Shimada, 1986; Thompson *et al.*, 1984; 1986; DeVries, 1986; 1987; Lough & Fritts, 1985; Richardson, 1973; 1978; DeVries & Schrader, 1981; DeVries & Pearcy, 1982; Lemon & Churcher, 1961; Campbell, 1982; Martin *et al.*, 1991). This paper describes fluctuations in the fossil diatom assemblage from a sediment core of a lake in the Inter-Andean plateau of Ecuador. Two distinct diatom assemblages alternate throughout the record. One is similar to the community present today in the lake under normal conditions. The other resembles the assemblage observed in the diatom community as the result of increased precipitation during the 1982-1983 El Niño.

Many paleoecological studies use pollen analyses to describe changes in vegetation resulting from climatic perturbations. Changes in vegetation typically occur slowly, thus palynology best addresses long-term climatic perturbations. The algal communities of lakes, particularly diatoms, respond rapidly to changes in the environment. Thus, they have been employed to document changes in trophic status, water depth, light availability and water chemistry (Davis & Smol, 1986, Smol *et al.*, 1986). The value of diatoms as sensitive indicators of salinity is evident in the agreement between diatom inferred and archival salinities for a North American lake (Fritz, 1990). The acidity and salinity changes are best addressed by diatomology than by palynology (Davis & Smol, 1986, Brugam, 1979, Smol *et al.*, 1986; Davis & Anderson, 1985; Davis, 1987; EPRI, 1986). There is precedence for the use of fossil diatoms as indicators of climatic perturbations; especially, those from lakes in endorheic regions with salinities which are strongly related to hydrological and climatic conditions (Berglund, 1986; Begin *et al.*, 1974; Bradbury *et al.*, 1981; Casse, 1974). The record of desalination of Lake Valencia in Venezuela, as a result of a major water level rise and an opening of the lake system around 8500 years B.P., is based on a change from a saltwater diatom assemblage to a freshwater one (Bradbury *et al.*, 1981). Such applications, based on diatom remains, encouraged this search for ENSO signals in the sediment of a lake in an endorheic, desert region of the Ecuadorean Andes.

2. DESCRIPTION OF THE LAKE

Lake Yambo lies in one of the most arid regions of the Inter-Andean Plateau in south-central Ecuador at 1°05' S, 78°35'W, a t an elevation of 2600 m. (Fig. 1). The annual precipitation in the region is generally less than 500 mm (Pourrut, 1983; Naranjo, 1981). Vegetation surrounding the lake is sparse, and consists primarily of desert shrubs

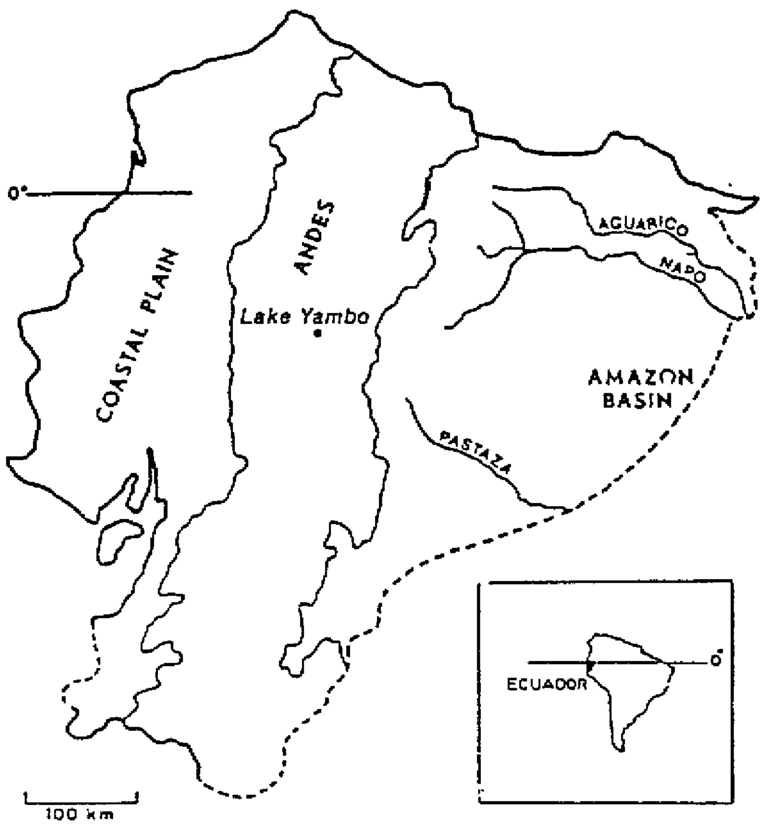

Fig. 1 - Map of Ecuador showing the location of Lake Yambo.

(*i.e.* Cactaceae and Euphorbiaceae) and ruderals (Colinvaux *et al.*, 1988). The lake occupies part of a graben in what appears to be a long, broken rift (Sauer, 1971). It is a closed basin lake 800 m long and 200 m wide. with 24.5 m as its maximum depth. High cliffs of weathered rock form the western face of the basin, and the eastern side has steep slopes of dissected rock and gravel. These steep barren slopes are deeply cut by gullies created by infrequent rain storms (Fig. 2). The littoral zone is densely vegetated with sedges (*Scirpus totora*) at the northern and southern ends of the lake. There is no apparent inlet or outlet; and, unless there is seepage through the cliffs at the sides, the lake loses water only through evaporation. Since evaporation exceeds rainfall in the area a high concentration of dissolved ions is normally found in the lake (Steinitz-Kannan *et al*, 1983). Yambo is alkaline and eutrophic, with an almost permanent bloom of blue-green algae, mainly *Spirulina major*, *Lyngbya limnetica* and *Anabaenopsis* sp. (Whitton, 1968; Steinitz-Kannan, 1979). This community of blue-green algae contributes to the highest levels of chlorophyll measured for an Ecuadorian lake, 175.5 mg chlorophyll / liter (Miller *et al.*, 1984). Samples of planktonic diatoms taken in 1975, 1977, 1978, 1980 and 1981 consisted predominantly of *Craticula halophila*, *Nitzschia amphibia*, *Nitzschia palea*, *Amphora coffeiformis* and *Amphora veneta*. These species tolerate or require high conductivity (Steinitz-Kannan, 1979; Hustedt, 1930; Patrick & Reimer, 1966; Lowe, 1974; Friedman & Krumbein, 1985). Conductivity measurements at the surface of the lake ranged from 1980 to 2010 µmhos / cm during this period. Details on the contemporary limnology of the lake have been previously published (Steinitz-Kannan, 1979; Steinitz-Kannan *et al.*, 1983; Miller *et al.*, 1984).

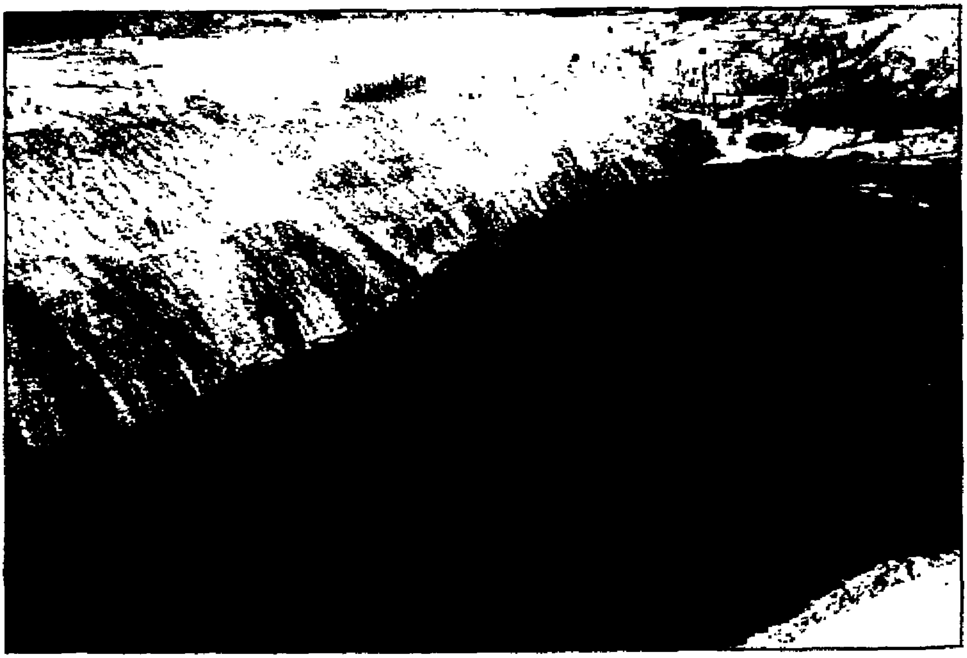

Fig. 2 - Lake Yambo. This photograph taken in 1981 shows the arid landscape of the region, and the steep cliffs that surround the lake.

3. THE EFFECT OF THE 1982-1983 EL NIÑO ON LAKE YAMBO

The 1982-1983 El Niño, which started in April 1982, brought a substantial increase in rainfall to the Lake Yambo region. Precipitation for a single month reached over 200 mm which is nearly half of the average annual precipitation normally experienced by the region (INMH 1986a; b). When we visited the lake in December 1982, the surrounding desert landscape had flourished with the increased precipitation. Land slides along portions of the Pan American Highway near Chunchi, just 105 km south of the lake, were caused by the increased precipitation and cost the lives of hundreds of people. The precipitation caused a dilution of the lake water, with the conductivity falling substantially. The diatom community in the lake also changed. It was characterized by freshwater species *Aulacoseira distans* and *Cyclotella stelligera* and by a noticeable absence of the species that had predominated during the previous years. This community lasted for an extended period. In July 1984, *A. distans* was present and the population of *Craticula halophila* began to recover as the mineral concentration in the lake increased due to evaporation (Fig. 3).

4. MATERIALS AND METHODS

A 743 cm sediment core was taken under 24.5 m of water in the deepest part of Lake Yambo in July 1981, using a modified Livingstone piston sampler. Details of the sampler and coring methodology are described in Colinvaux *et al.* (1988). All core sections were sealed in the field and shipped unopened to the Ohio State University for X-radiography, description of stratigraphy, radiocarbon dating, as well as chemical and palynological analyses. The core sections were preserved in their halved sample tubes, wrapped in three layers of plastic wrap, taped and stored at 4oC. In 1987 the cores were subsampled at the Northern Kentucky University laboratory for diatom analysis. Quantitative samples were removed from the core every 10 cm at approximately the same depths as those for the pollen analysis. Standard 1 cc and 0.5 cc stainless steel sediment samplers were used. Diatoms were processed with concentrated nitric acid, rinsed in distilled water, and were mounted in Hyrax® medium. No fewer than 300 diatom valves were counted per depth. The fossil diatoms were identified using standard identification keys (Patrick & Reimer, 1966; 1975; Schmidt, 1959[1874]; Hustedt, 1930), supplemented with the use of the Northern Kentucky University Diatom Herbarium. The diatom percentage diagrams were constructed using MacPollen® (Eisner & Sprague, 1987; Eisner, 1987), a program designed specifically to handle pollen and diatom counts on Macintosh® computers. Statistical treatment of the data were performed using Detrended Correspondence Analysis (CANOCO© statistical package Version 2.1, Digby & Kempton, 1987; Jongman *et al.*, 1987).

Radiocarbon dating was performed at Teledyne Isotopes, Inc., Westwood, N.J. on bottom sections of the core and by the University of Arizona's National Science Foundation AMS facility in Tucson, Arizona in 1992, for samples from the second and third meters of the core. Mathematica© software for Macintosh® computers (function "ListIntegrate") was used to integrate pollen concentration *vs.* core depth curve (Fig. 4). Pollen methodology and results for this core have been previously described (Colinvaux *et al.*, 1988).

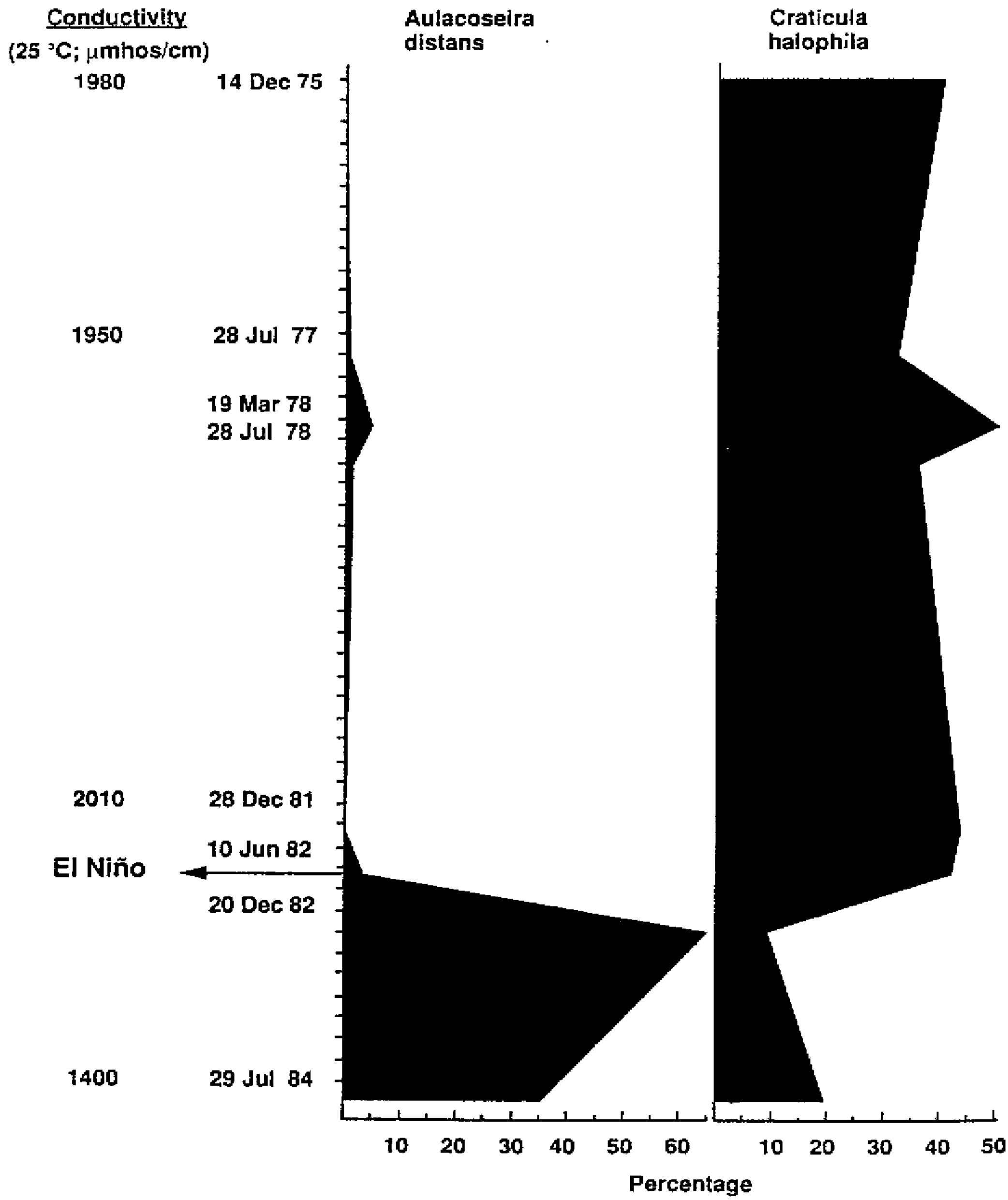

Fig. 3 - The impact of the 1982-1983 El Niño on Lake Yambo. The diatom community changed from one dominated by *Aulacoseira distans* to one dominated by *Craticula halophila*.

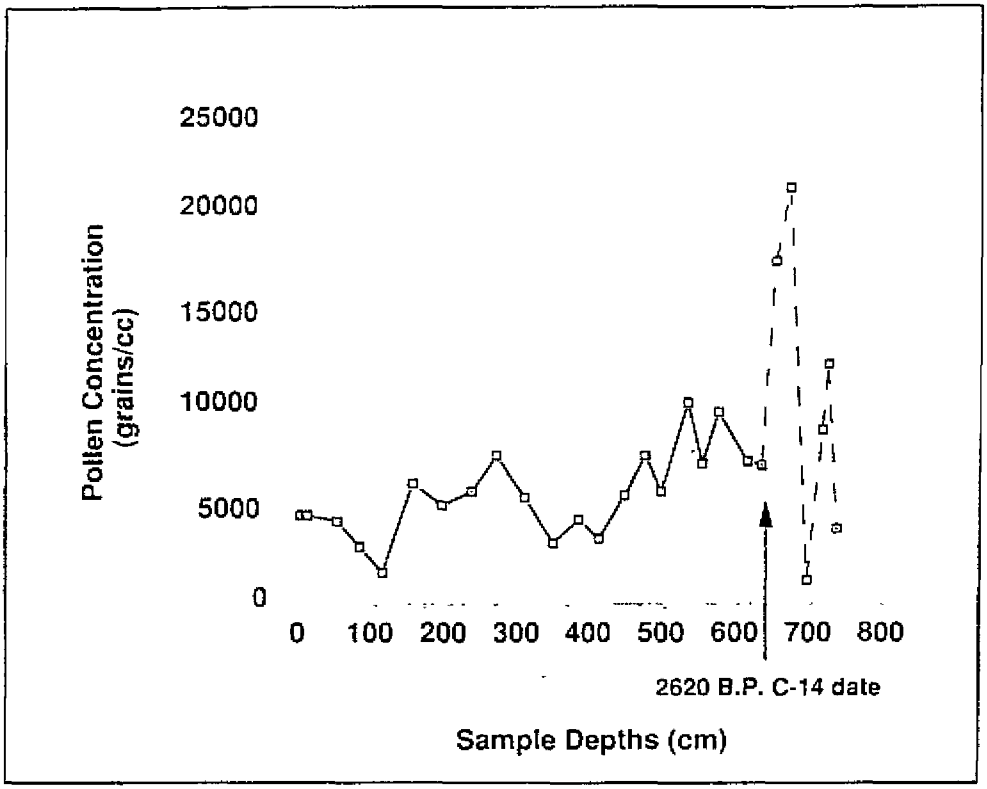

Fig. 4 - Graph of pollen concentration vs. depth of the Lake Yambo core. Pollen concentration values were obtained in the laboratory of Dr. Paul Colinvaux at the Ohio State University. This graph was used to calculate sediment accumulation rates and diatom inferred dates for El Niño events.

5. RESULTS AND DISCUSSION

5.1. The Fossil Diatom Record

Analyses of the fossil diatoms in the core of Lake Yambo reveal shifts in dominance between *Craticula halophila* and *Aulacoseira distans* at various points throughout the core (Fig. 5). These shifts are consistent with changes observed in the 1982-1983 El Niño. Other diatom species found in association with the dominant taxa in the core show similar shifts (Fig. 6). For example, epiphytic diatoms such as *Amphora* spp. and *Gomphonema* spp. become more abundant when *Craticula halophila* is common, and this can be the result of lower lake levels allowing the expansion of shallow water communities. Species of *Nitzschia* are infrequent in the record but are present only when *Craticula halophila* is common. This genus is common in eutrophic waters of high conductivity (Hustedt, 1930).

Five periods characterized by peaks in *Craticula halophila* and *Nitzschia* spp. are apparent in the record (700, 500, 440, 320, 240 cm). The fresh water planktonic species *Cyclotella stelligera* dramatically declines during these periods. These may reflect periods of

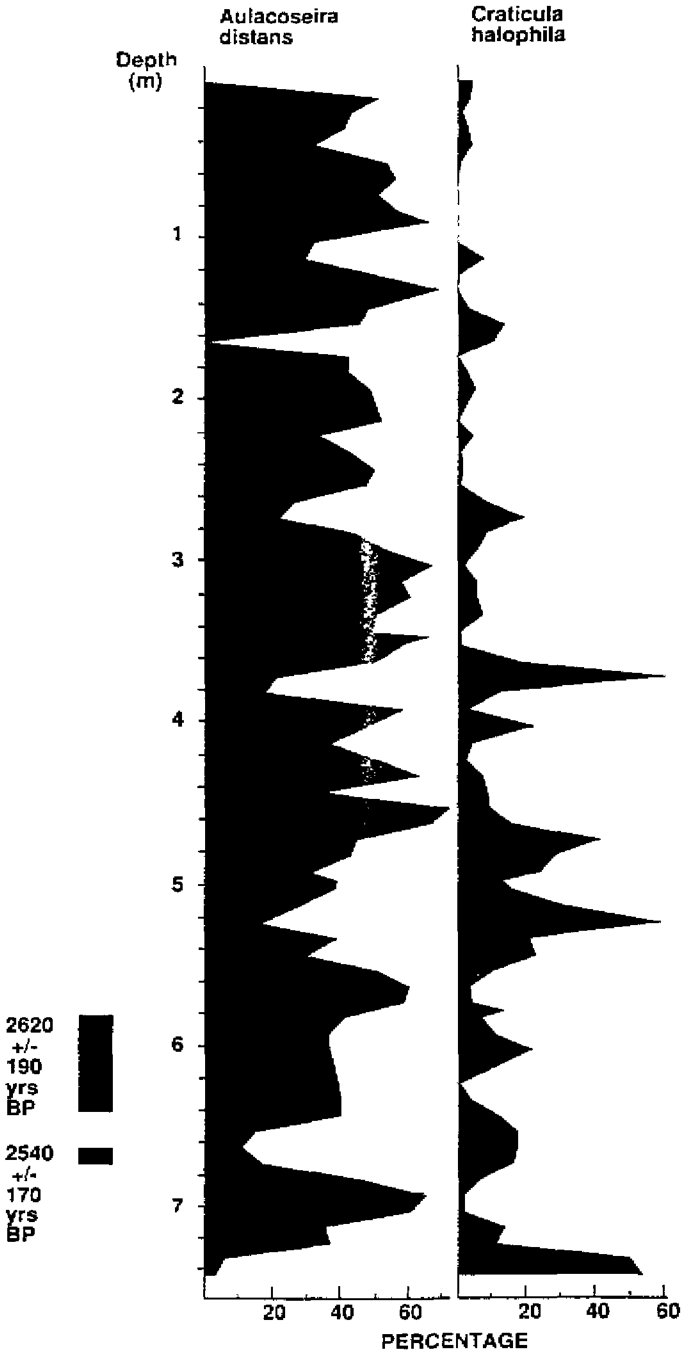

Fig. 5 - Changes in the dominant diatom species in the fossil record of LakeYambo. We postulate these changes result from dilution of the water following El Niño events.

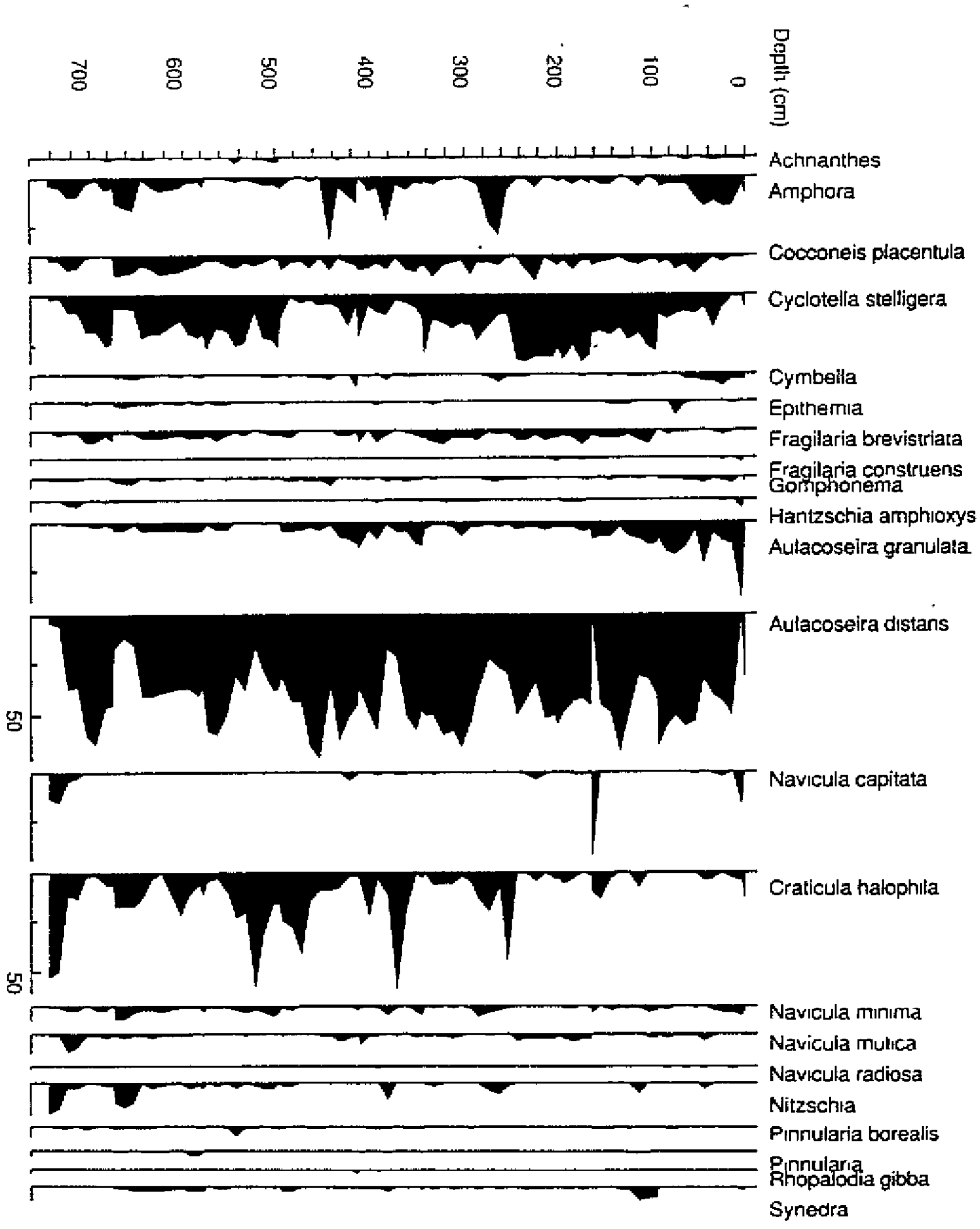

Fig. 6 - Percentage diagram of the fossil diatom assemblages in the core of Lake Yambo.

extreme aridity. These peaks are concentrated toward the bottom portion of the core, which suggests that in the very recent past precipitation has been higher in general in the region of lake Yambo, or the frequency of El Niño events of any intensity has been greater.

The Detrended Correspondence Analysis (DCA) done for all the diatoms in the core (Fig. 7) depicts two diatom assemblages, one of wet periods and one of dry periods. *Aulacoseira distans, Cyclotella stelligera, Aulacoseira granulata* and others, are common in freshwater systems; their presence together suggests low conductivity. *Craticula halophila,*

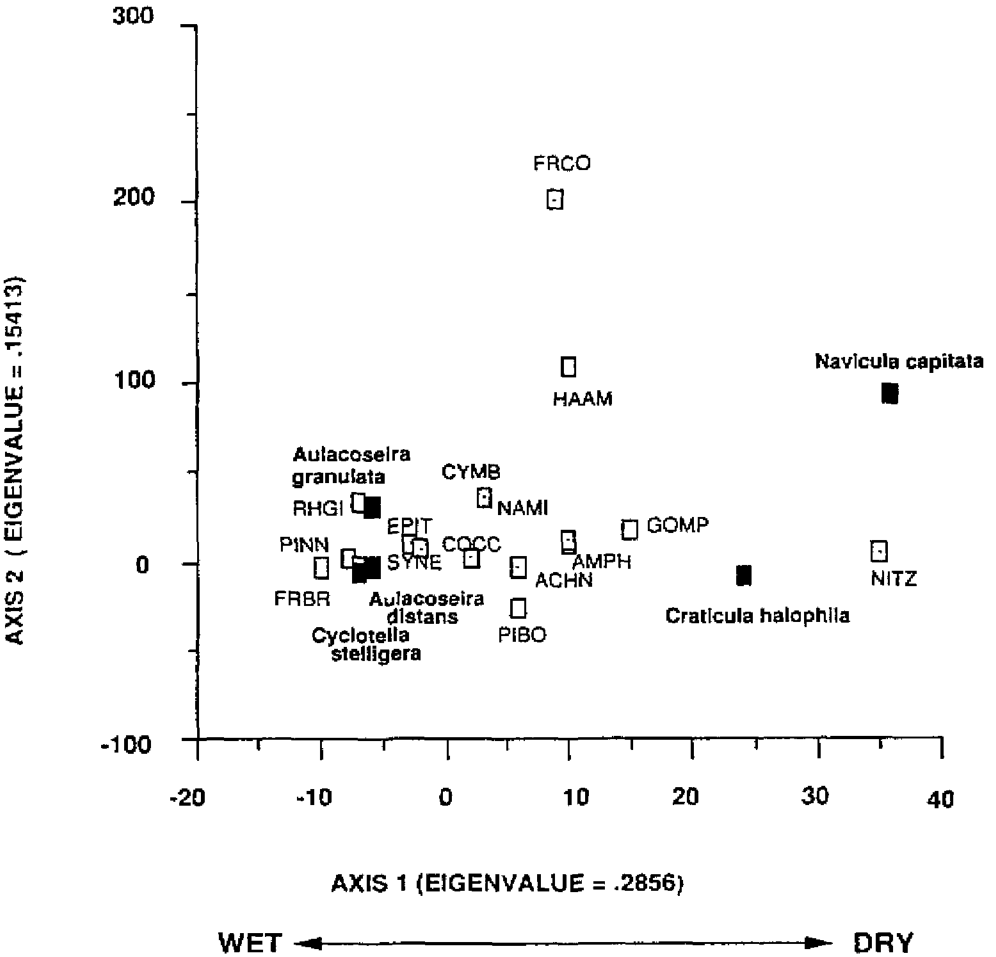

Fig. 7 - Detrended Correspondence Analysis (DCA) of fossil diatoms from the core of Lake Yambo. Two diatom assemblages, one of wet periods and one of dry periods can be recognized in the diagram. Taxon codes: ACHN = *Achnanthes* spp., AMPH = *Amphora* spp., COCC = *Cocconeis* spp., CYMB = *Cymbella* spp., EPIT = *Epithemia* spp., FRBR = *Fragilaria brevistriata*, FRCO = *Fragilaria construens*, GOMP = *Gomphonema* spp., HAAM = *Hantzschia amphioxys*, NAMI = *Navicula minima*, NITZ = *Nitzschia* spp., PIBO = *Pinnularia borealis*, PINN = *Pinnularia* spp., RHGI = *Rhopalodia gibba*, SYNE = *Synedra* spp.

Navicula capitata and *Nitzschia* spp. are characteristic of more brackish waters, and indicate drier conditions. The total number of taxa is lower during the brackish water episodes. This could be due to fewer species being adapted to saline conditions or, could in part be the result of reduced preservation of some taxa, since, as will be discussed ahead, the brackish water episodes are also periods when sedimentation rates are low.

5.2. Difficulties with Chronology

Two radiometric radiocarbon dates were obtained earlier for this core (Colinvaux *et al.*, 1988). The bottom most section spanning 662-740 cm yielded a date of 2540+/- 170 yrs. with a $\partial\,^{13}C$ value of -20.4 *vs.* PDB standard and provided a normalized age of 2610 +/- 170 years B.P.. The section representing 581-642 cm of the core was later dated to be 2620 +/- 190 years B.P. During this study, two additional AMS dates were obtained. A section representing 113-123 cm gave a date of 4715 +/- 60 yrs. B.P. (∂ 13C -26.3, AA-9330) and the section 362-372 cm, a date of 4215+/-55 years B.P. ($\partial\,^{13}C$ -22.3, AA-9331). All the four dates are inverted and suggest varying degrees of old carbon in the entire core. The high alkalinity and hardness of Yambo, the terrain, the steep cliffs surrounding the lake, the episodes of tectonic and volcanic activities in the region, all provide a host of mechanisms for old carbon to work its way into the lake sediment. These dates do not lend themselves to establish reliable chronology for past high precipitation events. The basal dates are also suspect. The young ages they represent for large sections of the bottom of the core suggest a lower degree of old Carbon contamination. Thus the lake could be younger than 2600 years B.P., but is no older than this age.

An attempt to get reliable recent chronology based on ^{210}Pb dating was also frustrated. A 35 cm core raised in January 1992 using a sediment/water interface push corer (Fisher *et al.*, 1992) was not long enough for lead dating as there was still unsupported ^{210}Pb at the base of the core.

5.3. Sediment Accumulation and Precipitation

In lake Yambo which has very sparse vegetation in the watershed and has had no history of agriculture in the immediate vicinity, sediment accumulation is mainly due to precipitation. The variability in sediment accumulation thus can be a measure of the level of precipitation. A high sediment accumulation alternating between levels of low accumulation by itself would indicate heavy precipitation and confirm the diatom inferred changes in water chemistry of Yambo as due to heavy rains in the watershed.

Sedimentary pollen whose origins are different from other materials in the sediment, can be used to estimate variability in sediment accumulation. It has long been recognized that large differences in pollen concentration, while percentages remain constant, are attributable to changes in sedimentation rate (Davis, 1976). Recently, rates of estuarine sediment accumulation have been estimated based on pollen (Brush, 1989). The highest pollen concentrations in the lowest parts of this Yambo core, with a gradual transition to roughly constant concentrations of the upper half of the core has been interpreted as a gradual increase in sedimentation rates over the earlier parts of the history (Colinvaux *et al.*, 1988).

Consistent with this observation, the diatom data indicate more frequent high precipitation episodes in the upper half of the core than in the bottom half. In the pollen concentration *vs.* core depth diagram (Fig. 4) most of the diatom inferred heavy precipitation events are at depths where the pollen concentrations are low.

It is recognized that the intensities of the precipitation episodes can be estimated based on estimates of relative sediment accumulation. The coarse sampling intervals of the available pollen data preclude attempts at these ratios which do not require precise knowledge of elapsed time.

The estimation of the sedimentation rates based on pollen density assumes among other things, a constant average annual pollen accumulation. With this assumption, pollen concentration data can be used for dating between well dated horizons when variable sediment accumulation is more likely than variable pollen accumulation. This approach has been used to compile a chronologic scale for reconstructing the history of bog dynamics (Middeldorp, 1982; 1986). A constant average annual pollen deposition to lake Yambo can be assumed in light of the constancy of the relative pollen percentages for the various taxa, and in the total taxon richness (Colinvaux *et al.*, 1988). If the 2600 yrs B.P. age for Lake Yambo is apportioned to various depths of the core based on the ratios of cumulative pollen concentration up to the various points to the total cumulative pollen for the entire length of the core, the generated dates for the various diatom inferred El Niño events correspond well with published historical and archaeological records. For example dramatic declines in *Craticula halophila* coincide with dates for ten very strong and strong El Niño events described by Quinn *et. al.*, (1987) to have occurred during the past 300 years, and also include possible unknown El Niño events around 1200 yrs. B.P and 750 B.P.

In this study we have uncovered a new tool to expand the historical records of El Niño events to the distant past where such records do not exist. Fossil diatom assemblages can be used to reveal short term changes in water chemistry in saline lakes. These changes may result from heavy rains during El Niño episodes, in a region that otherwise receives very little precipitation. The study site, Lake Yambo, holds a high resolution history of El Niño events, but problems with age determination makes the chronology of these events difficult to decipher. It can only be affirmed from the lake Yambo record that heavy precipitation events have been more frequent in the recent past. Since one site is unlikely to provide enough data to satisfactorily reconstruct the history of El Niño events, a study of a suite of saline lagoons in the Galapagos Islands is in progress to realize this objective.

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