hypochlorite solution for 24 hours. After thoroughly washing with distilled water, the teeth were mounted on a platform and coated with gold palladium for SEM observation or carbon for x-ray dispersion analysis. For observations of the organic components by SEM, the teeth were fixed and etched according to the method of M. A. Crenshaw and H. Ristedt [in *The Mechanisms of Mineralization in the Invertebrates and Plants*, N. Watabe and K. M. Wilbur, Eds. (Univ. of South Carolina Press, Columbia, 1976), p. 355.
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10. The x-ray diffraction studies, infrared spectra, and electron microprobe analysis of tooth styli from other species of Chitonidae showed that ACP is present and when heated to 500°C converts to dahllite.
11. Combined SEM and x-ray dispersive analyses show that infilling by ACP of the phosphatic subunit of the tooth caps occurs from the periphery toward the center.
12. The x-ray diffraction patterns also confirm an earlier observation that the magnetite crystals show no preferred orientation [K. M. Towe and H. A. Lowenstam, *J. Ultrastruct. Res.* **17**, 1 (1967)].
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23 July 1984; accepted 23 August 1984

Amazon Rain-Forest Fires

Abstract. *Charcoal is common in the soils of mature rain forests within 75 kilometers of San Carlos de Rio Negro in the north central Amazon Basin. Carbon-14 dates of soil charcoal from this region indicate that numerous fires have occurred since the mid-Holocene epoch. Charcoal is most common in tierra firme forest Oxisols and Ultisols and less common in caatinga and igapo forest soils. Climatic changes or human activities, or both, have caused rain-forest fires.*

Natural and human-caused fires have altered the Holocene vegetation of North America (*1*). In this report we demonstrate that South American lowland rain forests also have experienced fires within the past 6000 years. Moderate-level disturbance has been proposed as a mechanism for the maintenance of high diversity in tropical forests (*2*). We propose that fire be considered a moderate-level disturbance for tropical rain forests when it occurs repeatedly, infrequently, and at low intensity.

Currently, forest fires occur widely in some areas of the tropics (*3*). In the Neotropics, it is grassland and savanna areas with lengthy dry seasons that burn most often. Lowland rain forest has generally been thought to be immune to burning (*4*). Although the fire history of the region has not, to our knowledge, been investigated, charcoal has been found in the soils of several South American rain-forest sites (*5*). Because charcoal has been found in association with ceramic artifacts, its presence is frequently attributed to human occupation.

We present evidence here that mature rain forests of the upper Rio Negro region of Venezuela have been repeatedly disturbed by fire during the last six millennia. Evidence of mid- to late-Holocene fires occurs not only in areas of known human settlement but also in the soils of several types of primary rain forest. We know of no previous effort to quantify or date Amazon charcoal from primary rain forests that have no associated artifactual evidence of human occupancy. Earlier studies have been confined to sites where the presence of ceramic pieces or "terra preta" Anthrosols, or both, confirmed human occupation (*6*).

The upper Rio Negro region of Venezuela (Fig. 1) is a relatively wet portion of the Amazon Basin. At San Carlos de Rio Negro (1°56′N, 67°03′W), the mean annual precipitation is 3530 mm. An average of more than 200 mm of rain falls in all months of the year. Of the three generally recognized forest types (*7*) (Fig. 2), only the tierra firme forests (which cover about 30 percent of the land area) are cut and burned for agricultural purposes (*8*). Disturbance of the forest by shifting cultivators is currently small in scale and largely restricted to the area bordering major rivers where the very sparse (±0.05 person per square kilometer) human population is concentrated. Because of the oligotrophic nature of the region's soils and the scarcity of faunal resources, human settlement was presumably very low (by Amazon standards) in pre-Columbian periods (*9*).

Near San Carlos (within 20 km) we sampled at eight mature tierra firme forest sites to a depth of 1 m with a total of 27 0.25-m^2 pits and 32 cores 8 cm in diameter (Fig. 1). At three mature caatinga forest sites near San Carlos we sampled with a total of 13 pits. We found charcoal in seven of eight tierra firme sites and one of three caatinga forest sites.

In areas more distant from San Carlos,

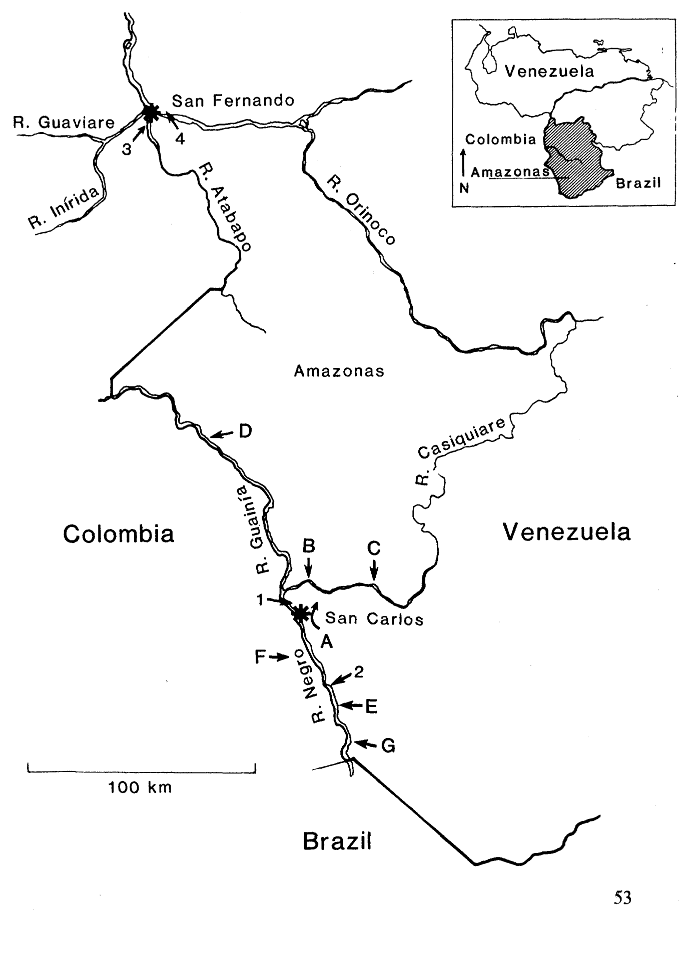

Fig. 1. Regional map and sample locations: A, tierra firme and caatinga forests within 20 km of San Carlos; B, Anthrosols along the lower Casiquiare River; C, 6-km transect near Guispero; D, 3-km forest transect near Galito; E, 10.5-km forest transect near Guanabana; F, tierra firme forests along Cano Mayabo, within 20 km of San Carlos; G, 7-km forest transect near Cocuy; 1, wildfire in igapo forest near Guarinuma, January 1982; 2, wildfire in tierra firme forest near Manare, 1983; 3 and 4, wildfires in several mature forests near San Fernando, 1983.

Table 1. Radiocarbon dates of soil charcoal from mature forests near San Carlos de Rio Negro, Venezuela.

Location (see Fig. 1)	Depth (cm)	Age (years B.P. ± standard deviation)
(A) Ultisol, tierra firme forest	0 to 10	250 ± 50
	10 to 20	640 ± 50
	20 to 30	1560 ± 60
(A) Oxisol, tierra firme forest	0 to 5	250 ± 60
	10 to 20	400 ± 80
(A) Spodosol, caatinga forest	30 to 40	1400 ± 140
(F) Ultisol 1, tierra firme forest	0 to 10	350 ± 70
	20 to 30	1540 ± 80
	60 to 70	3080 ± 1120
(F) Ultisol 2, tierra firme forest	60 to 70	6260 ± 110

we sampled at 50-m or 500-m intervals on transects of 1.2, 3, 6, 7, and 10.5 km (*10*) (Fig. 1). We examined soil cores for the presence of and for amounts of charcoal to a depth of 1 m, to the water table, or to an impenetrable layer of plinthite, whichever came first. Charcoal was found at 63 of 96 sampling locations including 80 percent of the tierra firme cores, 25 percent of the caatinga cores, and 36 percent of the igapo cores.

We calculated the weight of charcoal in the uppermost meter of tierra firme forest soils for three sites, each on a different transect. Dry weight values (in metric tons per hectare) were 4.6 ± 1.8 (standard error), 6.9 ± 3.6, and 13.9 ± 6.6.

Charcoal taken from an Oxisol and Ultisols in two tierra firme areas near San Carlos was radiocarbon dated (*11*). Ages ranged from 250 ± 50 years before present (B.P.) to 6260 ± 110 years B.P. (Table 1). Soil charcoal from the caatinga forest near San Carlos was dated at 1400 ± 140 years B.P. (Table 1). These dates represent the maximum time since the last burn because they may include the accumulated age of the material at the time of combustion.

Charcoal from the Oxisol site (Table 1) came from depths of 0 to 5 cm and 10 to 20 cm. This 1-ha forest has served as the control tierra firme site for many research projects at San Carlos. It is considered floristically diverse (83 species ≥10 cm in diameter at breast height) and physiognomically mature [canopy height, 20 to 30 m; dry weight biomass, ~309 ton/ha (*12*)]. However, during the past 500 years at least two fires have deposited charcoal in the soil profile of this forest. The other two tierra firme forests (on Ultisols) are likewise considered physiognomically mature and also provide evidence of repeated burning (*13*) (Table 1).

Charcoal is also abundant in Anthrosols in the San Carlos area, where it is mixed with ceramic potsherds. On the lower Casiquiare River we found 11 Anthrosol sites along one 42-km stretch of river (Fig. 1). These sites represent the cumulative effect of long-term or episodal human occupation in areas with good fishing, good agricultural soils, or both (*6*). The oldest evidence of human presence in the area has been reported to be at 1400 years B.P. (*14*). We obtained a thermoluminescence date of 3750 years B.P. ± 20 percent (standard deviation) for a ceramic potsherd taken from an Ultisol close to a side stream near San Carlos. This is the oldest evidence of human presence in the interior Amazon Basin.

We have observed two sites near San Carlos where recent rain-forest wildfires have killed mature trees (Fig. 1). In the dry season of 1982, approximately 8 ha of low igapo forest burned, probably during an unusually dry January. In 1983 12 ha of poorly developed tierra firme forest (growing on a rock substrate) burned after 23 consecutive rainless days in January and February. In both cases these fires (of human origin) were confined to the rootmat-litter layer. This evidence illustrates that currently (under exceptional climatic conditions) forests occasionally burn near San Carlos.

In contrast, we have observed that wildfires (both igapo and tierra firme) are relatively common and extensive (100 ha or more) in the vicinity of San Fernando de Atabapo, 260 km north of San Carlos (Fig. 1). The mean annual precipitation at San Fernando is 2900 mm with three consecutive dry season months that average ≤100 mm of rainfall. A slight alteration of climatic regime in these more northerly Amazon forests may generate wildfires that burn well-developed tierra firme and igapo forests.

One explanation for the presence of charcoal in mature forest soils is that it is solely the result of ancient slash-and-burn agriculture. Larger populations or more long-term habitation, or both, could have resulted in extensive burning of tierra firme forests, including forests well removed from streams and rivers. Charcoal could have been alluvially removed from (higher) tierra firme soils and deposited in Spodosols.

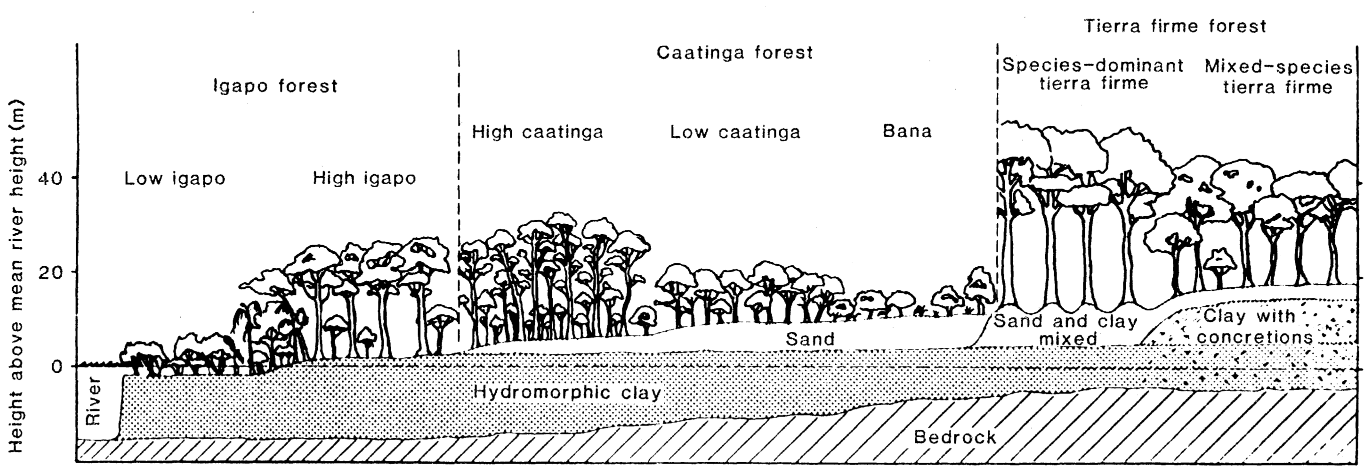

Fig. 2. Forest types near San Carlos vary with pedologic conditions and elevation above mean river height. Igapo forests occur in seasonally flooded areas, caatinga forests on Spodosols, and tierra firme (nonflooded) forests on Ultisols and Oxisols.

The earliest evidence of fire in these forests is considerably older than the earliest evidence of human presence. Recent palynological findings indicate that climatological changes in the Amazon Basin may have been relatively frequent during the late Holocene. Dry phases are recorded from the Amazon Basin between 6000 and 4000 years B.P., 2700 and 2100 years B.P., and at about 1500, 1200, 700, and 400 years B.P. (*15*). Under drier climatic regimes, wildfires may have destroyed large areas of forest, resulting in a large-scale mosaic of successional forests. This pattern would account for the amounts and extent of charcoal that we have found in tierra firme forests as well as the presence of charcoal in nonagricultural (caatinga and igapo) forest soils.

It can no longer be assumed that lowland tropical rain forests have been free of fire disturbance. The abundance of charcoal of mid- to late-Holocene origin commonly found in rain-forest soils of the upper Rio Negro suggests that fire has for a long time been a disturbance factor in these tropical forests. Episodes of fire disturbance have modified the forests during the mid- to late Holocene, perhaps as a result of different climatic circumstances, perhaps as a result of human intervention alone, or possibly as a result of the interaction of human disturbance and climate. The fire ecology of tropical rain forests should now be considered in both an ancient and a present-day context.

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25 June 1984; accepted 2 October 1984

Climatic Forcing: Effects of El Niño on a Small, Temperate Lake

Abstract. *Temperature profiles measured regularly for 21 years reveal the interannual differences in winter-to-summer heat gain in Castle Lake, California, a small subalpine lake. Year-to-year changes in large-scale climatic surface forcing, especially the amount of snowfall from February through April (which determines the date of thaw) coupled with the early heating and wind mixing after thaw, causes this interannual variation. The seasonal thermal structure for years in which the lake gains significantly more or less heat than normal—all of the El Niño years and several others—shows that the depth of the mixed layer and the mixing of heat into the stratified thermocline region control the storage of heat. The temperature of the mixed layer does not reflect abnormal thermal storage. Variations in mixing during early spring, which controls the heat content at Castle Lake, may also affect the annual average of the primary productivity.*

The magnitude of year-to-year variation in climate has increasingly become a concern of ecologists, oceanographers, hydrologists, agriculturalists, resource planners, and policy analysts (*1*). The El Niño of 1982 to 1983, the eruption of El Chichón, and the possible "greenhouse effect" (*2*), have become of general interest. There are scant data concerning the responses to interannual variability of natural systems that average climatic effects over different periods of time. Such systems include watersheds, active glaciers, ocean sediments, long-lived trees, and lakes. We have analyzed a long-term record of data from a small lake that reacts to variability in climate. We show that some parameters of this data are a function of climatic effects.

Castle Lake in Northern California (*3*) has been intensively studied during the last 25 years (*4*). Researchers have paid particular attention to details of the processes controlling the rate of photosynthesis of the phytoplankton community (that is, primary productivity) (*5*). Care has been taken to ensure consistent data collection, and, during the ice-free months (*6*), many limnological parameters (including physical, biological, and chemical quantities) are measured approximately every 5 days; measurements are taken less frequently during the winter (ice-covered) months.

Once the surface is free of ice, the lake quickly gains heat because of the balance between solar radiation, net infrared exchange, evaporation, and sensible heat transfer at the air-water boundary (*7*). Wind stress at the surface stirs the lake, mixing heat downward (*8*). The lake continues to gain thermal energy so long as the net flux of heat is positive (*9*). The maximum amount of heat stored (*10*) and the time it takes to reach this maximum varies from year to year. The reasons for interannual variation in maximum heat content may involve large-scale (regional or global) climatic effects. For example, a heavy snowfall can move the date of thaw to more than 1 month later in the spring. Local processes may also play a