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Mangrove Distribution during the Holocene in Tribugá Gulf, Colombia[1]

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ABSTRACT

Neotropical mangrove ecosystems have undergone drastic changes in terms of extension and floristic composition during Plio–Pleistocene times. It is unclear if the northern Pacific coast of Colombia has been occupied continuously by mangroves during the last 5000 years, or if their presence is a recent phenomenon. Two basic questions were asked: (1) is the establishment of mangroves recent?; and (2) what were the dominant floral taxa during the late Holocene? In the Gulf of Tribugá, northern Colombian Pacific, 22 sediment cores were drilled to a maximum depth of 2 m in a diverse suite of mangrove substrates and positions relative to the shoreline. Data were gathered from sedimentological descriptions, palynological analyses, and radiocarbon dating of these cores. During the last 4500 years, mangroves in the southern area of the Tribugá Gulf have remained floristically stable and dominated by *Rhizophora.* The abundant presence of *Acrostichum aureum* is recent, probably related to human activities. In contrast, two areas in the northern part of the Gulf show a different history. In the first area, the establishment of mangrove has been relatively recent (*ca* 2600 yr), probably a result of local subsidence due to tectonic faulting; this mangrove forest was and is dominated by *Pelliciera rhizophorae.* In the second area, mangrove pollen was not found in sediments younger than 2500 years, suggesting that the scarce presence of mangrove in the area is a result of recent colonization, and not due to logging as previously thought.

RESUMEN

Ecosistemas Neotropicales de manglar han sufrido cambios dramáticos tanto en su extensión como en su composición florística asociados con cambios climáticos y variaciones del nivel del mar durante el Plio-Pleistoceno. No es claro si la costa norte del Pacífico Colombiano ha sido ocupada por manglares durante los últimos 5000 años. Quisimos responder dos preguntas básicas: Es el establecimiento del manglar un fenómeno reciente? y Cuales fueron las especies que dominaron el mangle durante el Holoceno? Para responder estas preguntas extrajimos 22 corazones de sedimento en el Golfo de Tribugá, costa norte del Pacífico Colombiano. Los corazones, de máximo dos metros de profundidad, fueron analizados con métodos palinológicos, sedimentológicos y dataciones radiométricas. El tipo de sedimento más común fué lodo arenoso verde altamente bioperturbado por actividad infaunal. Los manglares mostraron ser muy estables y dominados por *Rhizophora* en la mayoría de los sitios estudiados, con excepción de los manglares en la Chunga (Utría) y El Valle. Allí los manglares se establecieron recientemente. En la Chunga, un ascenso relativo del nivel del mar hace aproximadamente 2600 años a.p., probablemente local y asociado con la falla de Utría, posibilitó la colonización del sustrato por *Pelliciera rhizophorae*; es incierto determinar si este ascenso aún se esta produciendo. En el Valle, el escaso establecimiento del manglar es un proceso reciente de colonización y no una reducción en la cobertura del manglar producto de actividades humanas como previamente se asumía.

Key words: *Chocó; Pacific; palynology;* Pelliciera; *Quaternary; radiocarbon dating;* Rhizophora; *sedimentology.*

ECOSYSTEMS CHANGE CONTINUOUSLY THROUGH GEOLOGICAL TIME not only in their floristic composition but also in their geographical distribution. The design of management plans for today's ecosystems must bear in mind this ineluctable fact. We need to know the history of a particular ecosystem through time before attempting to predict or manage its future. One ecosystem in particular that has experienced severe changes through time, both in geographical distribution and floristic composition, is the mangrove forest (Van der Hammen 1970, 1974; Graham 1977, 1995; Tomlinson 1986; Woodroffe & Grindrod 1991). Mangrove forests

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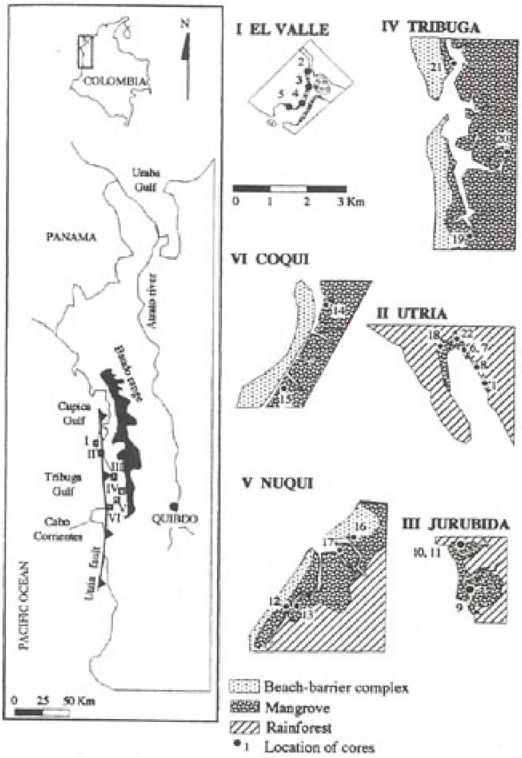

FIGURE 1. Locations of 22 sediment cores extracted from mangrove substrates in the Tribugá Gulf, Colombia.

are adapted to intertidal and supratidal zones having positions that are controlled by a sea level continuously changing through time (Haq *et al.* 1988). During Plio–Pleistocene glaciations, repeated variations in sea level have induced mangrove to change as well. When sea level was high, mangrove distribution expanded, while it contracted when sea level was low (Van der Hammen 1970, 1974).

In this study, we sought to understand the variations in the geographical extent and floristic composition of a mangrove forest on the Pacific coast of Colombia during the last 5000 years (Fig. 1). This mangrove, although reduced in extent, is important because it provides an ecological link between the mangroves of Central America and the extensive mangroves of southern Colombia and northern Ecuador. These mangrove forests are still relatively intact. The planned construction of the Pereira-Nuquí Road and a maritime port in the Tribugá Gulf, however, will increase anthropogenic pressures on this ecosystem. Fundación Natura, a Colombian nongovernmental organization, is developing a conservation plan for these areas, and this research was carried out as part of the planning process.

Palynological and sedimentological techniques were used to answer two basic questions: (1) were mangrove forests present in the Tribugá Gulf during the Late Holocene?; and (2) if so, what were the dominant taxa and have they changed through time?

Managing the mangrove forests of the Tribugá Gulf requires determining first if they were established recently or if they have been present longer. During the last glaciation, mangrove from the northern Pacific of Colombia can be assumed as having been much reduced in extent because the continental shelf there is very narrow, providing little suitable habitat for its development. Most of the ice from the last glaciation disappeared within 14,000 and 9000 B.P. (Crowley & North 1991); the sea level rose and mangrove probably has colonized new areas since then. In some areas (*e.g.*, El Valle; Fig. 1), mangrove forest currently is scarce in distribution, either due to ecological disturbance from log-cutting or to very recent mangrove colonization.

Two of the most important mangrove tree species on the Colombian Pacific coast are *Pelliciera rhizophorae* and *Rhizophora mangle.* The fossil record of *P. rhizophorae* began during the Eocene in northeastern Colombia. During the Oligocene, it was very common in the eastern Caribbean and eastern and central Colombia (Van der Hammen & Wijmstra 1964, Fush 1970). The geographical range of *Pelliciera* decreased drastically during the Miocene and Pliocene. Today, it is restricted to the Pacific coast with some scarce occurrences in the Caribbean (Roth & Grijalva 1991). Reduction in the distribution range of *Pelliciera* may be the result of many factors, including sea level and climate change and/or ecological competition with *Rhizophora* (Graham 1977). *Rhizophora* pollen appeared during the early Oligocene and became the predominant mangrove element during the Miocene–Pliocene (Germeraad *et al.* 1968). Information on Plio–Pleistocene Neotropical mangrove distribution, although limited, suggests a large-scale fragmentation (Woodroffe & Grindrod 1991).

STUDY AREA

The Tribugá Gulf is located in the northern part of the Pacific coast of Colombia. This coast is characterized by cliffs, and occasionally embayments in which mangrove develops (Von Prahl *et al.* 1990). In general, the area is composed of basalts, gabbros, and cherts of late Cretaceous–Paleogene ages (Jaramillo & Castillo 1992). The Tribugá Gulf is bounded to the west by the Serranía del Baudó, a basaltic mountain range (150-km long and 50-km wide) that reaches elevations of 1200 m.

The gulf is comprised of several smaller bays. Mangrove forests in six of these embayments were studied (El Valle, Utría National Park, Jurubidá, Tribugá, Nuquí, and Coquí [Fig. 1]; 5°38'–60°4'N, 77°15'–77°20'W). The oceanic circulation in the area corresponds to the Colombian current, a localized cyclonic current. The sea surface temperature ranges from 22 to 24°C during the dry season to between 24 and 27°C during he rainy season. The tides are semidiurnal with a range of 3.7 m (Von Prahl *et al.* 1990). The area is within the Intertropical Convergence Zone, the mean annual temperature is 25.6°C (range 21–31°C), the relative humidity is 90 percent, and the mean annual rainfall is 5000 mm, with a rainy period from April to December and a relatively drier one from December to March (Vieira 1994). The elevated rainfall decreases average salinity values to <33.5‰. Data on sediment supply by the numerous small streams in the area are not available. The forest vegetation is tropical lowland rain forest characterized by a diffuse differentiation of vegetation strata (Vieira 1994).

The Tribugá mangrove forests are composed mainly of *Rhizophora mangle, R. harrisonii, Laguncularia racemosa, Avicennia germinans, Pelliciera rhizophorae, Mora megistosperma, Conocarpus erectus,* and the fern *Acrostichum aureum*. Pollen of *R. mangle* and *R. harrisonii* cannot be distinguished from each other, but *R. mangle* is significantly more abundant than *R. harrisonii.* Both species require similar habitats and always co-occur.

Mangroves of Utría (Fig. 1) are characterized by large stands of *P. rhizophorae* bounded toward the coast and tidal channels by thin strips of *R. mangle,* and toward the land by *M. megistosperma* (Vieira 1994). Mangroves of Jurubidá, Tribugá, Nuquí, and Coquí (Fig. 1) are characterized by extensive stands of *R. mangle* with occasional patches of *L. racemosa, A. germinans,* and *C. erectus* on more stable substrates (Von Prahl *et al.* 1990). A detailed description of the mangrove structure (*e.g.*, densities, canopy heights, zonations) in the Tribugá Gulf is unavailable; however, the Fundación Natura will undertake such a study in the future (C. Vieira, pers. comm.).

Approximately 8000 inhabitants reside in the area, including Emberá Indians, White colonos, and Black communities. They have exploited the mangroves intensely by collecting invertebrates, fishing, and logging mangrove trees for construction materials, cooking fuel, working tools, or the production of charcoal (Von Prahl *et al.* 1990). No data have been collected on variations in sediment supply due to anthropogenic activity in the populated areas.

MATERIALS AND METHODS

Sediment samples were extracted with a Wright corer to a maximum depth of 2 m. Four cores were taken in the Valle mangrove, six in the Utría National Park, three in Jurubidá, three in Tribugá, four in Nuquí, and two cores in Coquí (Figs. 1, 2). Coring locations were selected on the basis of relative position in tidal zone (subtidal, intertidal, or supratidal), type of substrate (mud, sand, gravel), and dominant tree species (*Rhizophora* or *Pelliciera*) to have at least a representative core from all type of sediments and mangrove forests currently in the area (Table 1).

Each core was longitudinally split in half. One-half was sedimentologically described using a binocular microscope, and samples of pollen were taken at *ca* 40-cm intervals. Some samples also were collected for radiocarbon dating. The other half of each core was preserved for future reference and is stored at Fundación Natura in Bogotá. The sedimentological description of the cores included: color, grain size, composition, sorting, roundness, percentage of matrix, hardness, degree of bioturbation, and physical sedimentary structures. The terminology in descriptions follows Potter (1967).

One core from each type of sediment and forest was analyzed palynologically. The samples for palynology were treated with 50 percent HF and centrifuged twice in a $ZnCl_2$ solution. Part of the float fraction was oxidized using Erdtman acetolysis (Erdtman 1969). Palynological slides were made both from unoxidized and oxidized palynological residues. At least two slides of each sample were scanned at 20X. Pollen counts were made to determine the frequency of each species in each sample. Absolute pollen concentrations were calculated using *Lycopodium* tablets. Taxonomic assignments were made by comparison to a pollen reference collection prepared from samples collected from the Missouri Botanical Garden herbarium and from the field. Comparisons also were made with published illustrations (Nilsson & Robyns 1986, Thanikaimoni 1989, Roubik & Moreno 1991).

Although core top (modern samples) were not analyzed in this study, several studies have shown

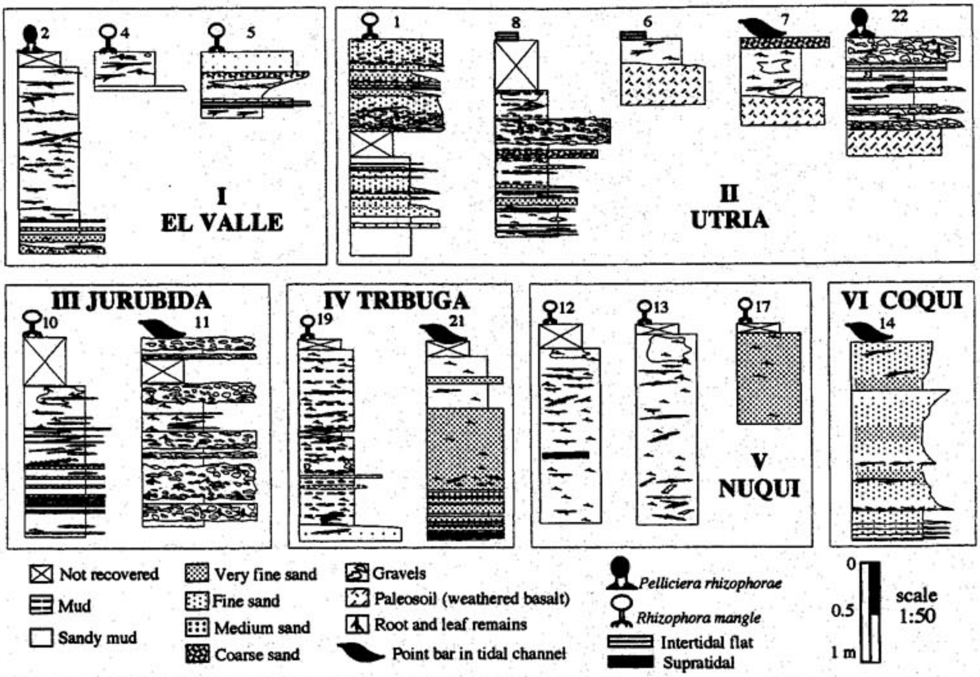

FIGURE 2. Sedimentological description of 16 mangrove substrate cores indicated in Figure 1, descriptions of remaining 8 cores are given in Figure 3.

that the pollen record found in mangrove sediments is a reliable indicator of mangrove vegetation through time (Wijmstra 1969, Bartlett & Barghoorn 1973, Grindrod 1988, Crowley *et al.* 1994). *Rhizophora, Avicennia,* and *P. rhizophorae* pollen are relatively more abundant in sediments near sources of pollen production than in areas removed from the sources (Wijmstra 1969, Bartlett & Barghoorn 1973, Crowley *et al.* 1994). Furthermore, pollen that accumulates in mangrove sediments has low mobility, seldom being redistributed by tides (Grindrod 1985). The mangrove pollen record also permits recognition of variation in relative sea level because mangroves grow in the intertidal zone (Jin-Eong 1995); however, it is important to keep in mind that the pollen record in mangrove sediments also can have an important component representing regional vegetation.

Two samples were radiocarbon dated: one from the base of core 20 in Tribugá and the second from the base of core 18 in Utría National Park (Fig. 3). The first sample was chosen because core 20 was the longest recovered and could provide the earliest dating; the second was located immediately above a paleosoil in which mangrove probably did not grow. Radiocarbon analyses were carried out by Beta Analytic Inc. using the benzene method for sample from core 20; accelerated mass spectrometry was used for the sample from core 18 because of its low content of organic matter.

TABLE 1. *Description of the sediment core locations. For geographical location of the cores, see Figures 1 and 2.*

Core number	Site condition
3	Supratidal zone in which mangrove is not present today.
2	Supratidal zone in *Pelliciera rhizophorae* stands.
18, 22	Intertidal zone in *Pelliciera rhizophorae* stands.
1, 4, 5, 10, 12, 13, 15, 16, 17, 19, 20	Intertidal zone in *Rhizophora mangle* stands.
6, 8	Intertidal flats.
9, 11, 14, 21	Point bars of intertidal channels.
7	Subtidal channel.

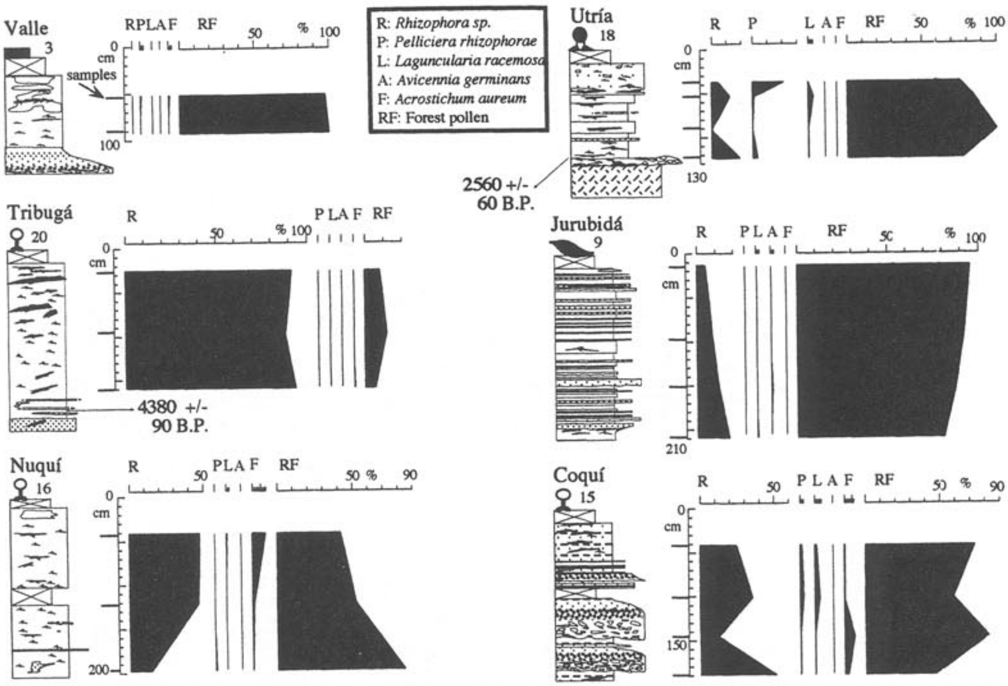

FIGURE 3. Pollen data (%) for mangrove and forest taxa from six cores in the study area. Percentages are calculated from total count, omitting fungi, dinocysts, algae, and non-mangrove fern spores. Large ticks in the pollen scale correspond to ten percent; small ticks correspond to one percent. Total counts will be archived with the Latin American pollen database. Symbol descriptions for the sedimentology of the cores are given in Figure 2.

RESULTS

SEDIMENTOLOGY.—Cores drilled where *P. rhizophorae* is living today were dominated by a dark green sandy mud (cores 1, 2), or by medium-to-fine sand interbedded with sandy mud and gravel (cores 18, 22; Figs. 2, 3). Sediments beneath *R. mangle* stands were dominated by a bioturbated, massive, green, poorly sorted sandy mud, rich in organic matter (cores 12, 13, 16, 19, 20, 21; Figs. 2, 3). Green colored sediments may indicate the presence of ferrous iron, suggesting a reducing environment.

Several cores showed sediment intervals of well sorted, very fine sand to coarse gravel, low in organic matter and low bioturbation, indicating the development of point bars due to lateral migration of tidal channels (Fig. 4; *e.g.*, cores 3, 8, 9, 10, 11, 14, 15, and 21).

In the cores drilled in the La Chunga, Utría National Park (cores 6, 7, 18, 22; Figs. 2, 3), a yellow clayey soil produced by the weathering of the bedrock (basalt) was found at a depth of 25, 60, 230, and 190 cm, respectively.

RADIOCARBON DATING.—Radiocarbon dating of a sample taken at a depth of 185 cm from core 20 in Tribugá gave an age of 4380 ± 90 years B.P. (Beta-86764). A sample taken at a depth of 115 cm from core 18 in Utría (La Chunga) gave an age of 2590 ± 60 years B.P. (Beta-86763). Assuming continuous sediment buildup, these data suggest mean sedimentation rates of 0.4 mm/yr.

PALYNOLOGY.—In El Valle, sediment core 3 was collected in an area in which mangroves are not growing today (Fig. 3). Sediments were characterized by a monotonous sequence of massive, dark green, sandy mud. The fossil pollen record was dominated by pollen from tropical rain forest plants (Fig. 3). Evidence of mangrove was not found in this core, although the sample from 52 cm yielded one percent of *P. rhizophorae,* a value too low to indicate its *in situ* presence. Core 18 in Utría was taken in a *P. rhizophorae* stand. Core sediments were characterized by a yellow weathered basalt at the base of the core, overlaid by an alternating sequence of massive, green to brown sandy mud capped by a fine brown sand. There seems to be no relationship between a particular sediment

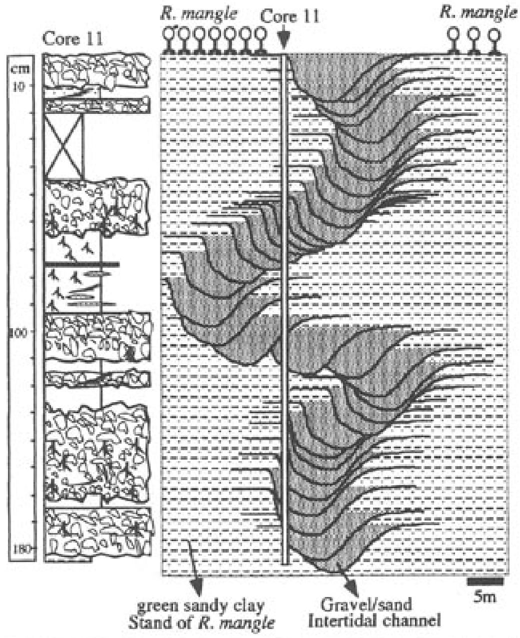

FIGURE 4. Interpretative evolution of a tidal channel point bar during the late Holocene in the area of core 11 (Utría). Channels migrate through time laterally as well as vertically along the intertidal zone. This migration is an important modifier of the landscape, altering or producing new successional processes. Symbol descriptions for the sedimentology of the core are given in Figure 2.

and a pollen type. The pollen record showed that the mangroves were dominated by *P. rhizophorae*, increasing from 2.8 percent at the base of the core to 20.7 percent at the top. *Rhizophora* sp. also was present but in low quantity (3–18%) considering its prolific pollen production. Lowland forest-derived pollen dominated the assemblage (Fig. 3). The pollen record of the Jurubidá core (core 9) taken in a point bar was uniform and dominated by forest pollen. The core sediments were characterized by a sequence of dark and light green, sandy mud interlaminated with very fine, light green, sand. There seems to be a close relationship between the high abundance of lowland forest-derived pollen and the point bar sediments. In Tribugá, the pollen record was dominated by *Rhizophora* sp. throughout the entire core (core 20). Sediment was characterized by a continuous sequence of massive, dark green sandy mud. In Nuquí (core 16), core sediments were characterized by a continuous sequence of massive, dark green sandy mud, and they showed an increase in abundance of *Rhizophora* sp. pollen from the base to the top of the core. In Coquí (core 15), sediments were characterized by a dark green sandy mud at the top of the core, and two grain-sized decreasing sequences at the bottom. The pollen record showed a mangrove forest dominated by *Rhizophora*. Abundance of forest-derived pollen was constant through the study (Fig. 3).

DISCUSSION

Palynological data from Tribugá Gulf on the Northern Pacific coast of Colombia indicate that the floristic composition of the mangrove has been relatively stable in most of the study areas during the late Holocene. *Rhizophora* has been the predominant element in Tribugá, Nuquí, Coquí, and Jurubidá.

The absence of *Acrostichum aureum*, a prolific spore producer, from the palynological record is surprising considering its current high abundance, especially in Jurubidá and Tribugá. This finding suggests that the present abundance of *A. aureum* may have developed in response to anthropogenic disturbance. Probably, the clearing of large areas of mangrove by recent human activity has given *A. aureum* the opportunity to colonize extensive areas.

In contrast to the other sites, Utría and El Valle offer a different picture. In La Chunga (Utría), mangrove development has been a recent phenomenon, probably resulting from a relative sea level rise that began *ca* 2600 yr B.P. (Fig. 5). This scenario is inferred from the presence of soil derived from *in situ* basalt weathering in cores 6, 7, 18, and 22, and because mangrove elements gradually have replaced interior forest elements in the pollen record as shown in core 18 (Figs. 3, 5). The magnitude and extension of this sea invasion and subsequent mangrove development is unknown, but seems to be local in extension since it was not observed in other localities. This relative sea level rise may be related to tectonic movements along the Utría fault. This large fault was probably associated with the opening of the Utría Sound and is still active (Galvis 1980). Pollen records indicate that *P. rhizophorae* has been the dominant element of this recently developed mangrove forest (Fig. 3). More data are required to determine if sea level still is rising, or if the coastline is migrating seaward.

Pollen samples analyzed from El Valle did not provide evidence of former mangrove development, at least during the last 100 cm of sedimentation, that could correspond to 2500 years using the sedimentation rate calculated for La Chunga and Tribugá. The coarse white sand of cores 4 and 5 (Fig. 2) also suggests that the current low abundance of

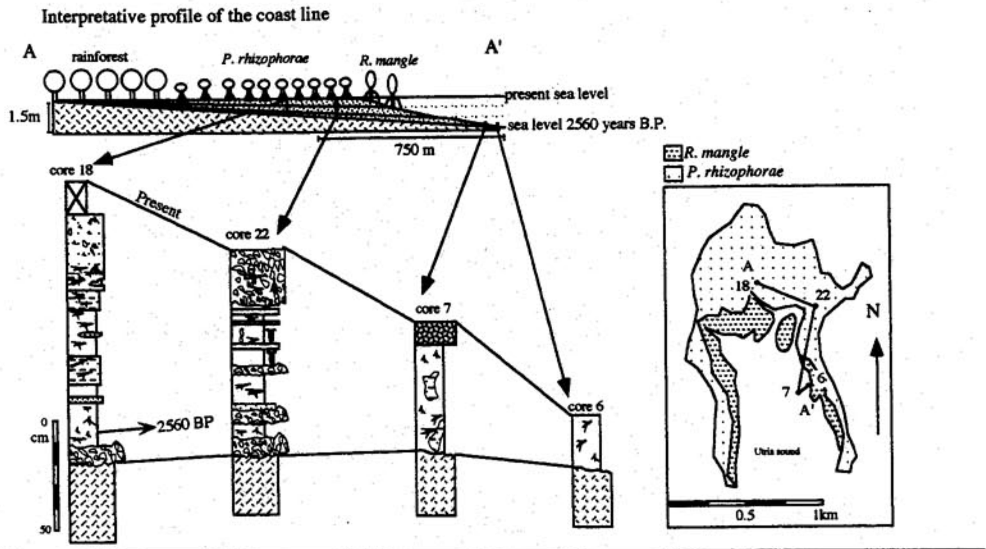

FIGURE 5. Interpretative profile of coastline evolution during the late Holocene showing a relative sea level rise and mangrove vegetation invasion of land previously occupied by rain forest vegetation. The location of the cores and the cross section (A-A' line) and the recent distribution of the two mangrove types are shown in the boxed map on the right. Symbol descriptions for the sedimentology of the cores are given in Figure 2. Pollen data are available only for core 18 (Fig. 3).

mangrove in El Valle is due to its recent development, rather than a result of clear-cutting as previously thought (C. Vieira, pers. comm.).

A long-term sedimentation rate of 0.4 mm/yr was determined for both Tribugá (*Rhizophora*) and Utría (*Pelliciera*) mangroves, although the number of radiocarbon dates used was clearly insufficient. Sedimentation rates reported for mangrove areas vary: 0.12 mm/yr in Tonga (Ellison 1989); 1.00 mm/yr in New Zealand (Chapman & Ronaldson 1958), 3.00 mm/yr in Mexico (Lynch *et al.* 1989), and 6.00 mm/yr in sheltered estuaries during the mid-Holocene of north Australia (Woodroffe 1992). The low sedimentation rates compared to other mangroves of the world might be explained by the low sediment discharge by the creeks that feed the studied mangroves, and the narrow extension of the continental shelf that limits the longshore transport of sediments.

Where *R. mangle* is present, the most common sediment is green sandy mud. By itself, this mud is a very unstable substrate and prone to erosion. The ability of mangroves (especially *R. mangle*) to colonize unstable substrates in intertidal zones has been recognized by several authors (Zimmerman & Thom 1982, Thom 1984, Von Prahl *et al.* 1990, Woodroffe 1992). Mangrove establishment promotes sediment stabilization (Zimmerman & Thom 1982, Thom 1984), a process that is very important in protecting coastlines from erosion (Othman 1995).

Sediment type did not always correlate with the type of dominating mangrove, as was observed in Tundó (El Valle), where mangrove dominated by *P. rhizophorae* is found in a green sandy mud substrate, very similar to those areas dominated by *R. mangle* in the mangroves of Tribugá and Nuquí (Figs. 1, 2). In this case, the low salinity of the Tundó mangrove seems to be the factor controlling the type of mangrove present. Other factors such as flooding frequency, nutrient availability, and associated infauna, however, also may influence the abundance of different mangrove plant species (Smith 1992).

The cores demonstrate that mangrove tidal channel systems are very dynamic. Abrupt lateral movement of tidal channels is clearly observed in cores 8, 11, and 15 (Figs. 2, 3). Interpretation of core 11 (Fig. 4) shows that lateral migration of channels through time is an important modifier of the landscape, altering or producing new successional processes. Erosion and deposition cycles produced by tidal channels have been estimated to range between 0.1 and 300 years (Woodroffe 1992). Intertidal channels also may play an important role in transport of sediments and nutrients in mangroves. The pollen records in point bars of tidal channels, as in the Jurubidá core, generally are dominated by lowland forest-derived pollen, even though the surrounding vegetation is dominated by *R. mangle* (Figs. 1, 3; Table 1). This observation indicates that mangrove-sediment relocation is low compared to the load of sediments transported by the channel.

CONCLUSIONS

During the late Holocene, mangroves from the southern area of the Tribugá Gulf generally have remained floristically stable and dominated by *Rhizophora*. On the other hand, mangroves record a different story in the northern part of the Gulf (La Chunga [Utría] and El Valle). In La Chunga (Utría), mangrove development was relatively recent (*ca* 2600 yr B.P.) and was produced by a sea-level rise probably associated with the Utría fault. This rise made possible the colonization by *P. rhizophorae* of areas previously dominated by lowland rain forest. Preliminary data indicate that development of mangrove in El Valle, where present, has been very recent. The abundant presence of *A. aureum* was a recent phenomena, probably related to clear-cutting that allowed this fern to colonize extensive mangrove areas.

A long-term sedimentation rate of 0.4 mm/yr was determined for mangrove sediments, although the number of radiocarbon dates used was insufficient. The most common mangrove sediment was a reducing, highly bioturbated, green sandy mud with a high organic matter content. Coarse-grained sediments, presumably accumulated in point bars of tidal channels, were present in several cores at various depths, suggesting that channel migrations are active modifiers of the mangrove landscape.

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