Vegetation history and climate records of Colombian lowland areas: rain forest, savanna and intermontane ecosystems
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Citation for published version (APA):
Wille, M. (2001). Vegetation history and climate records of Colombian lowland areas: rain forest, savanna and intermontane ecosystems
Late Holocene environmental history of southern Chocó region, Pacific Colombia; sediment, diatom and pollen analysis of core El Caimito

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Abstract

A multi-proxy study of pollen, diatoms, grain size, and major elements of a 610-cm core from lake El Caimito, located in the humid rain forest of southern Chocó, Pacific Colombia, is presented. We arrived at an integrated reconstruction of the local basin development, characteristics and changes of the water body and of the regional vegetation setting which is possibly related to the tectonic activity of an unstable coastal area. Time control is based on seven AMS $^{14}$C dates that show that the record represents the last 3900 cal BP.

From 3900-2700 cal BP sandy deposits, low carbon content, absence of diatoms, and low diversity of the pollen spectra indicate the site was under the influence of the fluvial system. Erosive event(s) removed part of the sediment record and we observed a hiatus representing 700 years. After that, the basin became more isolated from the drainage system. From 2010-1430 cal BP the lacustrine environment with accumulation of mainly clay was repeatedly interrupted by river pulses that left sandy and silty horizons in the record. Water chemistry was stable. Benthic and littoral-benthic diatom species indicate a shallow water body. Mangrove forest was close to the lake. Regionally, the main elements were palms, Moraceae-Urticaceae, Melastomataceae, Leguminosae and a number of other families and genera, characteristic of lowland rain forest.

From 1430-810 cal BP the river impact gradually diminished. Each riverine event damaged the local forest, was followed by an expansion of Cecropia dominated pioneer forest. Decreasing intensity of forest disturbance coincides with an increase in the diversity of fossil pollen taxa, possibly reflecting an increasing plant diversity of the forest. The impact of
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mangrove forest diminished, indicating that the coastline moved seaward and suggesting tectonic uplift of the coastal area. Between 810 and 580 cal BP mangrove forest was closer to the lake again, reflecting an inland migration of the coastline, suggesting tectonic subsidence. From 580-300 cal BP the last riverine events were recorded. Diatom associations indicate oligotrophic and acidic water. The mangrove belt moved seaward again, suggesting tectonic uplift. Palms and Cecropia became more abundant, suggesting increased human impact in the near shore lowland forest. During the last 300 years, stable lacustrine conditions and lowland rain forest with the highest floral diversity is registered.

2.1. Introduction

The strip of rain forest along the Pacific coast of Colombia, known as Chocó Biogeographic Area, is known for its high precipitation values, up to 12,000 mm/year, and high plant diversity. The geological history of this area since the Miocene has been discussed by a.o. Hooghiemstra and Van der Hammen (1998) and Hoorn et al. (1995). There is substantial evidence from the Amazonian rain forest that its present extension was reduced during dry intervals of the last glacial period, during the last glacial maximum in particular (a.o. Van der Hammen and Absy, 1994; Van der Hammen and Hooghiemstra, 2000; Hooghiemstra and Van der Hammen, 1998), but this evidence is debated by others (a.o. Colinvaux et al., 2000). There is insufficient understanding how high plant diversity in the neotropical rain forests was generated during the Neogene and Quaternary time (a.o. Bush, Colinvaux, 1987; Colinvaux, 1997; Colinvaux, 1998; Colinvaux et al., 2000; Schneider et al., 1999). According to Colinvaux (Colinvaux, 1997; Colinvaux et al., 2000) speciation can be understood in an 'engine model' or in an 'museum model'. From Amazonia there is important evidence that shows high internal dynamics in the rain forest, a.o. caused by migrating rivers and periodic changes in precipitation related to the migrating belt of maximum solar insolation (precession cycle of orbital forcing). As the setting of Chocó rain forest differs from Amazonia, it is unclear to what degree environmental instability is also characteristic of the rain forests in Chocó. Therefore, sediment cores in three lakes were collected during an expedition in 1997. The objective is to reconstruct the regional, as well as the local history of these basins. In southern Chocó the pollen record from Laguna Piusbi (Behling et al., 1998), and in northern Chocó the pollen record from Laguna Jotaordó (Berrio et al., 2000) and the sedimentological study in the San Juan Delta (Ramirez and Urrego 1999) documented for the first time in Chocó environmental change during the last c. 4500 years. After the initiation of lakes Piusbi
and Jotaordó, related to tectonic activity and/or river dynamics, a stable forest history was inferred.

In the present study we aim at a multi-proxy analysis of the core from Laguna El Caimito; integration of data from pollen (analysed by M. Wille), diatoms (analysed by M. Velez) and sediments (analysed by M. Velez and J. Vandenberghe) in order to provide a maximum understanding of regional environmental change. Moreover, use of different proxies enables us to test the interpretation of a single proxy (as is the case in the studies of Lagunas Piusbi and Jotaordó) to other ones and provides the opportunity to validate current calibration tools.

We try to relate the environmental history of Chocó to observed changes in the climatic setting of the Colombian savannas (Behling and Hooghiemstra, 2000; Behling et al., in prep., Berrio et al., in review).

2.2. Environmental setting

2.2.1. Geography

The Pacific coast of Colombia, where the Chocó biogeographic area is located, is an tectonically active area. Earthquakes are relatively frequent and some of them have caused subsidence of parts of the Pacific coastline (Herd et al., 1981). The area lies on a Cretaceous oceanic basement, overlain by Tertiary sediments which originated from fluvial terraces, and covered by Quaternary pyroclastic and alluvial deposits (Galvis et al., 1993).

Lake El Caimito (2°32' N, 77°36' W) is located at 50 m elevation in the southwestern part of the Department of Cauca, southwest Colombia (Fig. 2.1. It lies half-way between Buenaventura in the north and Tumaco in the south. The lake has a maximum depth of c. 4 m deep, has a diameter of some 200 m, and covers an area of c. 0.5 km$^2$. The water catchment extends approximately 1000 m east-west, and 800 m north-south. The lake has steep slopes and there is no shore around the lake. The main inlets to the lake come from the east and northeast. In the western part the El Caimito creek forms the outlet which flows from southeast to northwest. After about 6 km this creek meets the Rio Guapi which reaches the Pacific Ocean near the town of Guapi. The Pacific coast, made up by many relatively small islands separated by creeks and larger water ways, is located c. 40 km to the northwest of the lake. Some 30 km to the east of the lake the Western Cordillera (Serranía de San Juan) rises up to a maximum altitude of some 1500 m.
2.2.2. Vegetation

The vegetation around Laguna El Caimito consists of very wet evergreen rain forest. The steep slopes ensure lake shore vegetation is absent. For the vegetation around Laguna Piusbi (Fig. 2.1; Behling et al., 1998) Moraceae, Melastomataceae, Lauraceae, Fabaceae, Caesalpiniaceae, Mimosaceae, Rubiaceae, Myrtaceae and Arecaceae were identified as the most important families. Along the coast there is a c. 10-20 km wide belt with mangrove forest. The forest in the hinterland of Guapi is named 'guandal' (del Valle, 1996), a floristically diverse forest in which the following taxa are important for the pollen record: *Campnosperma panamensis, Socratea exorrhiza, Otoba gracilipes and Ocotea oblingifolia*.

2.2.3. Climate

The Pacific Coast of Colombia receives some of the highest precipitation in the world. Mean annual precipitation ranges from 2000 mm in the south to 12,700 mm in the north. Seasonality in precipitation is related to the latitudinal movement of the Intertropical Convergence Zone (ITCZ). Maximum precipitation occurs from April to June, when the ITCZ shifts north, and from September to November, when the ITCZ shifts to the south. Periods of marked decrease in precipitation are rare and short (one week) and may occur during El Niño events (West,
1957). In 1983, a well known El Niño year, the weather station in Guapi recorded the following reductions in precipitation relative to the same period in 1982: January -37%, February -50% and March -43% (IDEAM, pers. comm.). Mean annual precipitation is c. 6500 mm, and mean annual temperature 26°C (IDEAM, pers. comm.). The diurnal temperature range in Tumaco and Buenaventura is less than 5°C (Del Valle 1994).

2.2.4. Human occupation of Chocó

The Pacific coast of Colombia and the area of Guapi have been under the influence of human settlements since the second century AD. According to Patiño (1988) early populations lived in the coastal area and did not reach further inland. However, the pollen record of Laguna Piushbi recorded human impact since about 3460¹⁴C yr BP based on an increase of palms and grassy vegetation (Behling et al., 1998). Agricultural activities in the area of Laguna Piusbi, shown by the presence of *Zea mais*, were recorded since about 1700¹⁴C yr BP.

2.3. Methods

2.3.1. Core recovery, pollen and diatom analysis

The 610-cm core was drilled in 100-cm increments by H. Behling and H. Hooghiemstra in the centre of the lake with a modified Livingston corer. Presence of sand prevented further sediment recovery. The 100 cm sediment intervals, collected in aluminium tubes, were not extruded in the field and transported in the original aluminium tubes to the laboratory in Amsterdam. Sediments were stored under cold (4°C) and dark conditions. Separate samples of 1 cm³ for diatom and pollen analysis were taken at 5 cm intervals along the core. Diatoms were prepared according to Van der Werff and Huls (1963). The following literature was used for diatom identification and ecology: Germain (1981), Patrick and Reimer (1966), Krammer and Lange-Bertalot (1986, 1991, 1997), Hustedt (1930, 1959, 1961-66), De Oliveira and Steinitz-Kannan (1992), Hickel and Hakansson (1991), Steinitz-Kannan et al., (1986), Steinitz-Kannan et al., (1982), Moro and Fürstenberger (1997), and Moro (1998). In each sample a minimum of 400 valves were counted; only the interval from 504 to 475 cm contained insufficient diatoms to reach that sum. Diatoms are grouped into the following habitat preferences, 1) planktonic, 2) benthic, 3) littoral and 4) aerophylous.
Pollen samples were prepared using standard treatment, including sodium pyrophosphate, acetalysis and heavy liquid separation by bromoform (Faegri and Iversen, 1989). Before treatment, tablets with exotic *Lycopodium* spores were added to each sample for calculation of pollen concentration and pollen influx values. Pollen samples were mounted in a glycerin gelatin medium. A minimum of 300 pollen grains was counted. The pollen sum consists of taxa representing the regional forest; aquatic taxa, fern spores, fungal spores and algae colonies are excluded from the pollen sum. For pollen and spore identification we used publications by Behling (1993), Graf (1992), Herrera and Urrego (1996), Hooghiemstra (1984), Murillo and Bless (1974, 1978), Roubik and Moreno (1991), and the reference collection of modern pollen and spores of the Hugo de Vries-Laboratory. The software MS EXCEL, TILIA, TILIAGRAPH AND CONISS was used for calculations, graphing the diagrams, and for cluster analysis of the diatom and pollen diagrams.

### 2.3.2. Time control of the sediments

Seven bulk samples of 1 cm$^3$ were collected for AMS $^{14}$C dating at depths where significant changes in the pollen record occurred. The sample at 546 cm had a volume of 4 cm$^3$ due to low organic content. Samples were cleaned of roots and dated at the Van der Graaff-Laboratory of the University of Utrecht (Van der Borg et al., 1987). The $^{14}$C ages were calibrated with the Cal20 software (Van der Plicht, 1993). The calibrated ages were determined after visual inspection of the probability distributions (2s) along the dendro-calibration curve. We tried to fix the calibrated dates relatively in the middle of the probability distribution curves and there at highest probability values. Due to this procedure we give no standard deviation or time intervals for the calibrated ages.

### 2.3.3. Sediment analysis

Samples for grain size analysis were taken every 5 cm at adjacent depths to those used for pollen and diatoms sampling; from 500 to 610 cm core depth we sampled with 10 cm increments. Samples were prepared for sedimentological analysis according to Konert and Vandenberghe (1997) and analysed by a FRITSCH A22 'Laser Particle Sizer'. Sand is >63 μm, clay is <5.5 μm, and silt represents the range from 5.5 to 63 μm. The sediments were described with a Munsell colour chart. To analyse the total organic content of the sediments,
samples for loss on ignition (LOI) were taken every 10 cm and processed after Speranza et al. (2000). Major element analysis was carried out using atomic emission spectrometry for samples taken at 20 cm increments along the core.

2.4. Results

2.4.1. Time control and stratigraphy

The seven AMS $^{14}$C ages (Tab. 2.1.) of core El Caimito show the sediment core represents the last c. 3900 calendar years before present (cal BP).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>$^{14}$C yr BP</th>
<th>cal BP</th>
<th>$\delta^{13}$C (p.mil)</th>
<th>UIC-No</th>
<th>COL-No</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>-1621 ± 28</td>
<td>modern</td>
<td>-32.4</td>
<td>8365</td>
<td>1186</td>
</tr>
<tr>
<td>151</td>
<td>522 ± 30</td>
<td>535</td>
<td>-33.0</td>
<td>8366</td>
<td>1187</td>
</tr>
<tr>
<td>266</td>
<td>879 ± 31</td>
<td>775</td>
<td>-32.1</td>
<td>8367</td>
<td>1188</td>
</tr>
<tr>
<td>398</td>
<td>1516 ± 31</td>
<td>1405</td>
<td>-33.8</td>
<td>8368</td>
<td>1189</td>
</tr>
<tr>
<td>498</td>
<td>2040 ± 60</td>
<td>1975</td>
<td>-32.9</td>
<td>5790</td>
<td>1107</td>
</tr>
<tr>
<td>546</td>
<td>3003 ± 34</td>
<td>3175</td>
<td>-25.6</td>
<td>8369</td>
<td>1190</td>
</tr>
<tr>
<td>598</td>
<td>3492 ± 35</td>
<td>3760</td>
<td>-28.3</td>
<td>5789</td>
<td>1106</td>
</tr>
</tbody>
</table>

The depth-age diagram curve (Fig. 2.2.) shows a sedimentary hiatus between 546 and 498 cm. In the sedimentary record there is a distinct change at 504 cm; this core depth has a calculated age ranging from 2700 to 2010 cal BP.

We conclude that during that period sediments were eroded and sedimentation started again around 2010 cal BP; as a consequence, there is a hiatus in the record of almost 700 years. From 498 cm to the top a constant decrease of the sedimentation rate can be recognised.

We suggest that this decrease is related to the gradually decreasing availability of sediment in the small catchment area after the lake came into existence. This interpretation is supported by the decrease in sand content in the upper part of the sediment column. The stratigraphy of the core is summarised in Tab. 2.2. Downcore changes of the percentage of clay, silt, and sand, and changes in LOI are shown in Fig. 2.3. (appendix); this diagram includes 57 samples for LOI, 106 samples for grain size and 35 samples for major elements.
Fig. 2.2. Depth vs. age graph of sediment core El Caimito (Chocó, Colombia). Shaded curve: sand content.

### Tab. 2.2. Stratigraphy of the core El Caimito.

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-112 cm</td>
<td>soft dark greenish/grey fine detritus mud with leaf fragments; horizons with melastomataceous leaves at 15 and 84.5 cm</td>
</tr>
<tr>
<td>112-182.5 cm</td>
<td>peaty, dark grey detritus mud; horizons with leaves at 112, 140 and 162 cm; wood fragments at 167 cm</td>
</tr>
<tr>
<td>182.5-183.5 cm</td>
<td>light grey clay</td>
</tr>
<tr>
<td>183.5-215.5 cm</td>
<td>dark greenish/grey fine detritus mud; horizon with leaves at 215 cm</td>
</tr>
<tr>
<td>215.5-508 cm</td>
<td>dark grey organic rich clay; few leaf remains; horizons with leaves at 367 and 451 cm</td>
</tr>
<tr>
<td>508-607 cm</td>
<td>light brown/grey silt</td>
</tr>
<tr>
<td>607-610 cm</td>
<td>hard brown sand</td>
</tr>
</tbody>
</table>

### 2.4.2. Concise description of the zonation of the pollen, diatom and sediment records

Downcore changes in the diatom content is shown in Fig. 2.4, (appendix); this includes 99 samples. A total of 68 diatom species were identified. Species with less than 1% representation were not graphed and not used for the interpretation; most represented benthi c and periphytic taxa. Planktonic diatoms were limited to only a few species. Downcore changes in the pollen associations are shown in Fig. 2.5, (appendix); this diagram includes 119 samples. Below 605 cm no pollen was preserved; between 605 and 540 cm pollen was absent or the pollen content was too low to reach a meaningful sum. In total 168 different fossil pollen and spore types were identified. An additional 25 pollen and spore types remained unknown. Pollen grains represent mainly arboreal taxa (about 90%). Between 605
and 500 cm also herbaceous taxa reach about 20% of the total pollen sum. Aquatic pollen was almost absent.

Results from the major element analysis (Fig. 2.3., appendix) indicate that the lake has become gradually less productive and depleted in nutrients (decrease in P₂O₅). The increasing MgO/Al₂O₃ ratio indicate a gradual increase in the input of Manganese into the lake. CaO content is positively correlated to the increase of silt. Therefore, Calcium seems to be allochthonous and probably derived from the Cretaceous limestones. Elements such as Aluminium and Iron have been relatively stable in the lake.

Fig. 2.6. (appendix) shows a selection of the most important pollen and diatom taxa. The zonation is based on results from cluster analysis of the pollen diagram, cluster analysis of the diatom diagram, the grain size analyses, and visual inspection of the CONISS dendrogram. Thus, the zonation of Fig. 2.6. (appendix) is based on all proxies. Six different zones, CAI-1 to CAI-6, can be recognised.

In zone CAI-1 (605 - 504 cm) sediments are mainly composed of sandy silts (25% sand and 44% silt) and a smaller proportion of clay (30-35%). The colour of the sediments (2.5Y 4/4) and the low LOI values (5-10%) indicate a low organic matter content. The percentages of the major elements are low; only SiO₂ is abundant (64%). No diatoms are preserved in this core interval. It is likely that the high porosity of the sandy deposits prevented preservation. Also pollen grains are badly preserved. Especially in the lower part of this zone (605-540 cm) pollen content is low and mainly grains of Leguminosae (32%-50%), Moraceae/Urticaceae (40%), and Melastomataceae (15%-30%) are found. Between 540 and 504 cm the representation of Leguminosae decreases to 35-10%, whereas the percentages of Moraceae/Urticaceae and Melastomataceae increase slightly. Selaginella (15%), other fern spores, and Asteraceae (30%) reach maximum values. This interval includes the radiocarbon age of 3492±35 ¹⁴C yr BP (3760 cal BP) at 598 cm, and 3003±34 ¹⁴C yr BP (3175 cal BP) at 545 cm.

Zone CAI-2 (504-402 cm) starts with a change in sediment: from non-humic silty sediments in CAI-1 to a humic clay (10YR 4/2) in this zone. The stratigraphic contact between both types of sediments is sharp. This abrupt change is also recorded by the LOI which rises suddenly from 8.3% to 29%. The sharp contact and the shift in the depth vs. age graph (Fig. 2.2) points to a hiatus at 504 cm. In the lower part of zone CAI-2 the sand fraction is high (15%) but it gradually decreases towards the top of the zone (< 4%). The contribution of clay varies between 30% to 74%, whereas the silt fraction is relatively stable around 30%. Most of the elements show a marked increase at the bottom of the zone, except for SiO₂ (average
64%-35%). TiO₂ (average 0.9%-0.7%) and the MgO/Al₂O₃ ratio (average 0.09%-0.055%) which decrease. From this depth to the upper part of the core, the percentages of Fe₂O₃, Al₂O₃, TiO₂ are relatively constant (Fig. 2.3, appendix).

Diatoms are scarce and badly preserved at the bottom of zone CAI-2; they appear at 475 cm. First the assemblage is dominated by *Frustulia rhomboides* (55%), *Pinnularia* spp. (50% in the bottom to 15% in the middle part) (bad preservation prevented further identification), *Cymbella gracilis* (15%) and *C. spicula* (15%). The middle and upper part of the zone is dominated by *Frustulia rhomboides* (30%-45%), *Aulacoseira cf. herzogii* (c.30%), *Anomoeoneis brachysira* (20%-30%). *Cymbella* and *Pinnularia* species are reduced to about 5% or less. Species of *Eunota*, *Actinella guianensis*, *Navicula* spp. and *Achanthes subatomoides* appear for the first time (Fig. 2.4., appendix).

The pollen record shows at the bottom of CAI-2 a sharp increase of *Rhizophora* (5%-10%) and *Cecropia* (5%-15%). Towards the upper part of this zone representation of *Rhizophora* is increasing from 10% to 25%. *Selaginella* disappears, and representation of Asteraceae and Leguminosae drop to low values (5%). The contribution of Moraceae/Urticaceae is stable in the whole pollen zone (50%), whereas percentages of Melastomataceae decrease from 30% to 15%. This interval includes the radiocarbon age of 2040±60 yr BP (1975 cal BP) at 498 cm.

In zone CAI-3 (402-274 cm) sediments are dominated by clay (around 70%). The silt fraction is relatively stable (around 28%) and the sand fraction is low (< 2%). At 294 cm and 341 cm there is a marked increase in sand (15% and 5%, respectively). LOI values are relatively constant between 25% and 30%. P₂O₅ is relatively high (0.65%) but decreases to the top of the zone to 0.51%. The CaO/Al₂O₃ ratio is low (average 0.0144%) with maxima at the bottom (0.0071%) and in the upper part of the zone (0.0061%). At 340 cm most of the major elements have a sharp increase (Fig. 2.3., appendix) except for phosphorous.

The diatom assemblage is dominated by *Anomoeoneis brachysira* (55%-60%) and *Frustulia rhomboides* (25%). Other main taxa are *Eunotia intermedia*, *Cymbella gracilis*, *C. spicula*, *Aulacoseira cf. herzogii* and *Pinnularia* spp. In this zone *Eunotia* species become more common and *Pinnularia* spp. are less common than in the previous zone (Figs. 2.4. and 2.5., appendix).

In the pollen record Moraceae/Urticaceae and Melastomataceae (both around 20%) are most abundant. *Rhizophora* decreases from 30% at the bottom of the zone to 20% at the top. *Cecropia* values increase from 5% at the bottom to 15% at the top. This interval includes the radiocarbon age of 1516±31 yr BP (1405 cal BP) at 398 cm.
In zone CAI-4 (274–174 cm) sediments are still dominated by clay (around 70%). The content of silt and sand is similar to the previous zone. The proportion of sand increases sharply at 273 cm (up to 10%) and 219 cm (up to 7%), and at these horizons the contribution of clay decreases to 45% and 49%, respectively. LOI values decline from 27% at the bottom to 18% at the top of the zone, probably related to the increasing sand content. P2O5 values decrease from 0.47% to 34%, values of other elements are stable during this interval. The diatom assemblage is dominated by *Anomoeoneis brachysira* (45%-55%) and *Frustulia rhomboides* (c. 40%). Important taxa, in decreasing order of abundance, are: *Aulacoseira* cf. *herzogii*, *Eunotia intermedia*, *Cymbella gracilis*, *Cymbella spicula*, *Eunotia* aff. *glacialis* and *Pinnularia* spp. *A. brachysira* tends to decrease towards the top, whereas *F. rhomboides* and *A. cf. herzogii* tend to increase. Common elements are *Anomoeoneis serians* and *Actinella guianensis*. *E. septentrionalis* disappears from the record.

The pollen assemblages are still characterised by a stable representation of Moraceae/Urticaceae (20-30%) and Melastomataceae (15%). The contribution of *Cecropia* increases to 15% at the middle of the zone, falls to 3% around 200 cm, and increases to 13% at the top of CAI-4. The values of *Rhizophora* range between 10% and 30% and representation is contrary to the representation of *Cecropia*. This interval includes a radiocarbon age of 879±31 yr BP (775 cal BP) at 266 cm core depth.

In zone CAI-5 (174–91 cm) sediments are composed mainly of clay (around 80%). At 119, 124, 167, 173 cm core depth, there is a marked increase in sand content (12%, 6%, 20%, and 4% respectively) and a concomitant decrease in clay. At 119 cm there is a marked increase in the grain size as there are sand particles of 500 μm diameter. Values of LOI have a minimum of 13% at 165 cm, and maxima of 30% (125 cm) and 32% (115 cm); during the remaining part of this interval values are low (17-18%). At 120 cm depth all major elements show a marked decrease: P2O5 from 0.35% to 0.24%, TiO2, from 0.9% to 0.7%, Fe2O3/Al2O3 ratio from 0.4% to 0.3%, and SiO2 from 46.5% to 39%. Only the ratio CaO/Al2O3 increases from 0.01% to 0.004%. In the remaining upper part of the core average values of the previous zone are reached again.

The diatom assemblages are dominated by *Anomoeoneis brachysira* (20%-45%), *Frustulia rhomboides* (c. 35%-40%) and *Aulacoseira* cf. *herzogii* (10%-30%). Common species are *Anomoeoneis serians*, *Eunotia intermedia*, *Cymbella gracilis*. *Cymbella spicula*, *Eunotia* aff. *glacialis*, *Eunotia subarcuatooides*, *Eunotia minor*, *Eunotia trigibba*, *Actinella guianensis*, *Pinnularia* spp. are rare and tend to disappear.
The pollen assemblages show average values of Melastomataceae of 15-20% with two maxima at 150 cm and 110 cm; at the top of the zone only 10% is noted. The percentages of Moraceae/Urticaceae decrease to 10%. *Rhizophora* values decrease to 3% in the middle of the zone, but increase to 10% at the top. The representation of *Cecropia* increases from 7% to 10%. The representation of Arecaceae, mostly with values of 3-4% in the core, reach in the middle of the zone relatively high values of 10%. This interval includes a radiocarbon age of 522±30 yr BP (535 cal yr BP) at 151 cm.

In zone CAI-6 (91-0 cm) sediments are dominated by clay (around 75%). At 73 cm the clay content decreases from 70% to 44% coinciding with an increase in silt of 28% to 55% . LOI values are stable around 17% . The contribution of most elements are stable, except for the increase in the ratios of MgO/Al2O3 (average 0.068%-0.078%) and Fe2O3/Al2O3 (average 0.3%-0.47%).

The diatom assemblages are dominated by *Anomoeoneis brachysira* (c. 40%), *Frustulia rhomboides* (25%) and *Aulacoseira* cf. *herzogii* (10-20%). This zone shows high representation of *Eunotia intermedia* (increase from 5% to 10%), *Eunotia praerupta* (c. 5%), *Cymbella gracilis* (c. 5%), and *Eunotia subacuortoides*. *Pinnularia braunii* appeared again in this interval.

The pollen assemblages are characterised by increasing values of Moraceae/Urticaceae from 14% to 25% and decreasing percentages of Melastomataceae from 15% to 10% minimum. *Rhizophora* values show an average around 10% with two spikes of 15%. *Cecropia* percentages increase from 10% to 15% at the top of the zone. This interval includes a radiocarbon age of -1621±28 yr BP (modern) at 11 cm.

**2.5. Reconstruction of environmental change in the study area**

Zone CAI-1 (estimated period from 3840 cal BP to 2700 cal BP; 605-504 cm): The abundant deposition of sand and silt, and the low organic matter content of the sediments (low values of the LOI record) indicate that during this period the site was a depression influenced by fluvially transported material. Abundant coarse sediments are indicative of a high-energy environmental setting. Reducing conditions in the sediments might be indicated by relatively low values of Fe2O3. The coarse deposits provided unfavourable conditions for preservation of diatoms and pollen grains and, as a consequence, the pollen and diatom association may be biased. The presence of *Selaginella* ferns (common in active drainage systems) is indicative of a high energy environment, as well as abandoned parts of a drainage system. Presence of
Leguminosae, Asteraceae and Melastomataceae may be indicative of an arboreal vegetation that occurs in coastal areas out of the reach of floodings of brackish water (del Valle, 1996): mangrove forest (*Rhizophora*) is absent in the catchment area of the basin. Arboreal taxa, such as *Piper, Acalypha, Alchornea*, Solanaceae, *Hedyosmum* and Cyatheaceae reflect more inland lowland forest.

As discussed before, the transition from zone CAI-1 to CAI-2 coincides with a hiatus in the sedimentary record of some 700 years. This points to a period of erosion that lead to the formation of a depression in the landscape where 500 cm of sediments accumulated during the last 2000 years. Our study area is well known for its tectonic activity and episodes of subsidence (Herd et al., 1981). A tectonic event might have caused a change in the river system allowing the formation of El Caimito lake.

Zone CAI-2 (estimated period from 2010 cal BP to 1430 cal BP; 504-402 cm): The increase in clay and total carbon content of the sediments suggest that sedimentation occurred under quiet lacustrine conditions where organic material from the surrounding vegetation could accumulate. The amount of silt and sand at the beginning of the period indicate that the sedimentary basin was not fully isolated from the regional drainage system and at least experienced periodically input of coarse sediment under higher energy conditions. However, the coarse sediment fraction diminished rapidly and indicate that the basin became isolated in some 200 years. Shallow conditions are indicated by the abundance of benthic and littoral-benthic diatom species, such as *Frustulia rhomboides, Anomoeoneis brachysira, Pinnularia* spp. *Cymbella spicula, Cymbella pseudogracilis* and species of *Eunotia*. This diatom association suggests the lake was acidic (pH range between c. 4 and 6 is indicated), oligotrophic, and the water had low conductivity. Riverine influence during the second half of this period is supported by the presence of *Aulacoseira cf. herzogii* which requires turbulence (Van Landingham, 1964) and prefers some turbidity (Jewson et al., 1993). The diatom association, grain size characteristics, LOI values, and major elements indicate that sedimentation in a proper lacustrine environment started in this period.

Most conspicuous in the pollen record is the presence of mangrove forest. Marine palynological studies (Muller, 1959; Hooghiemstra and Agwu, 1986) have shown that significant representation of mangrove pollen is only found at a short distance from the source area and there is no evidence that wind transport is an important factor in the distribution of *Rhizophora* pollen. We therefore assume that the mangrove forest was at a close distance to the lake. At the present day brackish water penetrates few kilometres inland and the mangrove forest penetrates the coastal forest along the water ways. As the mangrove forest was closer to
the site, we infer that the coastline was closer to the lake. This situation is very plausible as tectonic uplift and/or fluvial deposition of material from the Western Cordillera might cause shifts of the coastline. In the regional forest Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Leguminosae, *Piper*, *Acalypha*, Solanaceae, *Alchornea*, Sapotaceae and Sapindaceae were important taxa. Significant representation of *Weinmannia* may be related to regional forest at higher elevation, but Gentry (1986) noted presence of 'montane trees' in the lowland forests of Chocó under extreme precipitation values (see the discussion in Van der Hammen and Hooghiemstra, 2000). *Cecropia* is a typical pioneer tree which occupies barren land after riverine disturbance. Highest representation of *Cecropia* coincides with peaks of silt and sand fractions, suggesting that expansion of *Cecropia* forest follows riverine disturbance of local forest. In between these events of forest disturbance mature forest, dominated by Melastomataceae, Leguminosae and Arecaceae, was common.

Zone CAI-3 (estimated period from 1430 cal BP to 810 cal BP; 402-274 cm): The coarse fraction is almost absent and sediments consist almost purely of clay and silt. Apparently, the drainage system had no influence any more on the lake. Events with increased sand content, and changes in major elements, indicate that there were two main pulses of increased riverine energy. The first one occurred between 1160 and 1130 cal BP (340-346 cm). The marked change in major elements, in particular the increase in TiO2 and Fe2O3, indicates more soil erosion followed by an increased input of heavy minerals and detrital material into the lake. The second pulse occurred around 900 cal BP (295 cm). Indeed, *Cecropia* responds to these events and pioneer forest expanded. Also the high representation of 'indeterminate pollen grains' (Fig. 2.5) may be related to riverine supply of a wider variety of pollen taxa from the watershed area to the basin. Benthic species dominate the diatom assemblages and sediments mainly consist of clay; it is plausible that the lake reached in this period the present setting with a water depth of some 4 m. The *Rhizophora* record reaches highest values in the beginning of this zone (around 1430 cal BP) and mangrove forest, possibly occurring as narrow zones along the river system, must have been at close distance to the lake. During this period the proportion of *Rhizophora* decreased; apparently the belt with mangrove forest shifted westward between 1430 and 810 cal BP. We infer a westward migration of the coastline, possibly related to regional tectonic uplift. Compared to the previous zone, the regional forest hardly changed in floral composition. Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Leguminosae, *Acalypha*, Solanaceae, *Alchornea*, Sapotaceae and Sapindaceae were important taxa, but *Piper* and *Acalypha* became less common. The proportion of *Weinmannia* remained unchanged compared to the previous zone.
Zone CAI-4 (estimated period from 810 cal BP to 580 cal BP; 274-174 cm): This period shows alternating maxima of clay and silt, pointing to a stable lacustrine setting. Three spikes of the coarse fraction (sand and silt) at 275 cm, 225 cm and 174 cm document occasional riverine input of sediments. The first two events are, as in the previous events, followed by expansion of Cecropia dominated pioneer forest. Also the increase of Aulacoseira cf. herzogii might indicate an increase of depositional energy, as this diatom species requires turbulence and turbidity to float (Van Ladingham, 1964; Jewson et al., 1993). The representation of Rhizophora first increased (until about 720 cal BP), but diminished between about 640 and 580 cal yr BP and remained at a low level up to recent time. We interpret the second major expansion of mangrove forest in this record either as an inland migration of the coastline (in the direction to lake El Caimito) related to tectonic activity, or a significant re-organisation of the system of water ways in the coastal area near Guapi. The latter may also be related to tectonic activity. The pollen record shows little evidence for changes in the floral composition of the regional lowland forest, compared to the previous zone. Palms (Iriartea in particular), Sapotaceae and Protium became more common in the forest, whereas the gradually increasing values of 'indeterminate pollen grains' (not occurring as spikes any more; Fig. 2.5, appendix) is considered to reflect a floristically more diverse forest.

Zone CAI-5 (estimated period from 580 cal BP to 300 cal BP; 174-91 cm): Grain size shows a continuation of the conditions in the previous zone. There are two main spikes of coarse sand and silt which represent occasional pulses of high riverine energy. The oldest one occurred at c. 570 cal BP and the other at c. 420 cal BP. Both events relate to abrupt maxima in the total organic content of the sediments. It is plausible that this organic matter was supplied by the river and caused a more productive lake. Considering the total record, this zone reflects a low energy environment with maximum accumulation of clay, and an input of organic matter that reflects the autochthonous production in and around the lake (high energy riverine events supply coarse fraction as well as allochthonous organic matter). The diatom association, Anomoeoneis brachysira, Eunotia spp. and Frustulia rhomboides in particular, indicates oligotrophic and acidic water with low conductivity. The peak of Aulacoseira cf. herzogii and the concomitant decrease in benthic diatoms during the last high energy riverine event support a more energetic environment, a disturbed bottom lake and an increased in turbidity and water turbulence. The pollen record shows from this zone onward (the last 580 years BP) low representation of Rhizophora. The belt with mangrove forest apparently shifted to the west and reached the
greatest distance from lake El Caimitó recorded in the last 2000 years. This may be indicative of some tectonic uplift of the coastal area. From this zone onward, the representation of *Cecropia* and palm trees (*Arecaceae*) increased markedly suggesting more inland areas along the rivers were disturbed by river dynamics. A response of the palm record was also noted in lake Piusbi (southern Chocó; Behling et al., 1998), Amazonia (Berrio et al., 1999), and in the savannas of the Llanos Orientales (Behling and Hooghiemstra, 1998, 1999) and interpreted as increased human disturbance, because palms are intensively used in human settlements. On the other hand are palms very abundant in floodplain forest in Chocó and reflect probably forest dynamics, due to changes in the river system. The proportion of 'indeterminated pollen grains' has higher values reflecting an increase of the floral composition of the coastal forest.

Zone CAI-6 (estimated period from 300 Cal BP to present day): Sediments are dominated by clay and silt indicative of stable lacustrine conditions without riverine influence. Low LOI values indicate that the level of carbon input by the local ecosystem in and around the lake was low. The diatom assemblages indicate acidic (estimated pH 4-6) and oligotrophic water with low conductivity. The increase of *Eunotia praerupta* and *P. braunii* indicative of iron (Moro and Fürstenberger, 1997) matches the increased values of FeO. Therefore, we infer the water was richer in iron.

The pollen record shows a regional forest type in which Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Leguminosae, *Piper*, *Acalypha*, *Sapotaceae*, *Protium*, and *Ficus* are most important. The proportion of 'indeterminate pollen grains' has the highest values reflecting higher floral diversity of the forest. The relatively high proportion of *Cecropia* and palms are considered as a reflection of increased river dynamics. The contribution of potential 'montane trees' to the pollen spectra (*Weinmannia, Hedyosmum, Ilex*) is low and may reflect the natural proportion of these taxa to super-humid lowland rain forest. We expect melastomataceous trees to be most important in the forest close to the mangrove belt (see zone CAI-1); the decrease reflects the present day environmental stability in the study area.
2.6. Discussion

As demonstrated in the previous section, integration of pollen, diatom, grain size, and major element proxies appears to be very helpful to infer in more detail the development of a dynamic environment and should be taken as a stimulus for multi-proxy studies.

The record demonstrates a development from: (1) a high energy (coarse sediments) river-influenced basin, at close distance to the coastal mangrove forest, from 3800 to 2700 cal BP (zone CAI-1), to (2) a period of riverine erosion in the depression, causing a hiatus in the record from 2700 to 2010 cal BP, to (3) a lake system that is periodically affected by events of high energy by the regional drainage system (repeated abrupt input of coarse sediments in a matrix of clay and silt, followed by an expansion of *Cecropia* dominated pioneer forest in riverine disturbed areas) and at very close distance to mangrove forest along the drainage system from 2010 to 580 cal BP (zones CAI-2 to CAI-4), to (4) a lake isolated from regional riverine system disturbance (high content of fine grained sediments, a total carbon content of the sediment that reflect only the local input and production in the lake) surrounded by a floristically diverse forest with probable impact of human activities (during the last 580 cal BP, but especially during the last 300 years).

During zones CAI-2 to CAI-5 (2010 to 300 cal BP), six distinct horizons with a high content of sand and silt (430-420 cm, 1593-1536 cal BP; 310-290 cm, 990-885 cal BP; 275 cm, 808 cal BP; 223-220 cm, 685-677 cal BP; 173-167 cm, 580-568 cal BP; 120-124 cm, 432-413 cal BP) indicate periodic events of high energy by the river system. But the intensity of these events (based on the sand and silt record) seems to decrease and matches the decreasing content of total organic matter. During zones CAI-2 and CAI-3 the basin received allochthonous carbon but during zones CAI-5 and CAI-6 only locally produced carbon reached the sediments. The floristic composition of the forest responds clearly to the periodic high energy events: expansion of the *Cecropia* dominated pioneer forest follows each event of high energy and forest rich in melastomataceous taxa prevail during the stable periods when mainly clay is deposited. Decreasing flooding intensity in lake El Caimito also matches with the observed succession in the pollen record: periodically damaged lowland rain forest at close distance to the mangrove belt (zones CAI-2 to CAI-4) becomes gradually floristically richer (increase of unidentified pollen types) when soils are better drained and the distance from the study site to the belt with mangrove forest increases.

We observed that periods of higher riverine energy interrupted more quiet lake deposition (clay deposition and less than 0.4% sand) periodically after 1570. By using linear
interpolation of the calibrated radiocarbon ages we calculated 57, 119, 9, 24, 21, 27, 77, 39, 19 and 210 years time between these high energy events. The occurrence of those periods could be related to the El Niño/Southern Oscillation (ENSO) frequency. According to Anderson et al., (1982) long term ENSO variability is expressed in cycles of 50, possibly 22 and between 80 to 100 years.

The diatom associations from lake El Caimito are dominated by *Anomoeoneis brachysira*, *Frustulia rhomboides*, *Aulacoseira cf. herzogii* and species of *Eunotia*, and *Cymbella*. This association points to acidic and oligotrophic conditions in a relatively shallow and stable water body during the last 1840 years. Decreasing abundance of *A. brachysira* and the P2O5 content in the sediments, might indicate that this species was favoured during the first part of the record by the relatively high nutrient content of the water. Maximum abundance of *Aulacoseira cf. herzogii*, indicative of increased turbidity and turbulence, coincided and followed episodes of higher energy in the ecosystem.

The diatom assemblages found in the El Caimito sediments are very similar to those found in modern lakes in Brazilian and Ecuadorian Amazonia (De Oliveira and Steinitz-Kannan, 1992; Moro and Fürstenberger 1997; Steinitz-Kannan et al., 1982, 1988). They are characterised by being poor in planktonic, and rich in periphytic and benthic species. Such water bodies are also frequently dominated by a *Eunotia-Frustulia* coenose (Uhertovich and Franken, 1989 in de Oliveira and Steinitz-Kannan, 1992).

![Fig. 2.7 Map showing the tentative changes of the geographical position of the coastline and the mangrove belt in the study area.](image)

Together with the pollen records of Laguna Piusbi (Behling et al., 1998) and Laguna Jotaordó (Berrio et al. 2000) (Fig. 2.1) the pollen record of El Caimito is the third document of environmental dynamics in the lowland rain forests of Chocó. All sedimentary basins originate from a dynamic and high energy fluvial system and developed into a lake system.
more of less isolated from the regional drainage pattern. Continuous records were registered from 4300 $^{14}$C yr BP in Piusbi, around 2010 $^{14}$C yr BP in El Caimito, and around 1440 $^{14}$C yr BP in Jotaordó. Lakes Piusbi and El Caimito are both located in the coastal plain and register the presence of mangrove forest. Migrations of the belt with mangrove forest near the coast were inferred from the pollen record (Fig. 2.7). The movement of the coastline can be explained by the tectonic instability (uplift and subsidence) (Herde et al., 1981) and/or fluvial deposition of material coming from the Western Cordillera. Shifting coastlines inferred from pollen records were earlier documented for Guyana and Surinam by Wijmstra (1971).

The floral composition of the regional forest near Piusbi and El Caimito is similar, but differs from Jotaordó. This is due to the different setting of the Jotaordó site which has no contact to the coastal area and is located in a broad river valley with a meandering drainage system.

Acknowledgments

Diatom research was funded by NWO-WOTRO grant WB 75368 to H. Hooghiemstra / M.I. Velez. Pollen research was funded by NWO-GOA grant 750.197.08 to H. Hooghiemstra / M. Wille. The core was collected by H. Behling, A. Negret and H. Hooghiemstra during a NWO-GOA funded post-doc project (grant 750.195.10 to H. Hooghiemstra / H. Behling). We thank the director of the 'Corporación de Cauca' in Guapi for providing transport and the local population along the Guapi River for support with carrying our coring equipment through the rain forest. We thank the Tropenbos-Colombia office in Bogotá (dr J. Saldarriaga and dr C. Rodriguez) for logistic support during our expeditions in one of the wettest areas on the globe.

We thank Jody dos Santos for invaluable support from our laboratory in Amsterdam. Nico de Wilde (Amsterdam) is acknowledged for major mineral analysis, Annemarie Philip for preparing the pollen samples, dr. Kay Beets (Vrije Universiteit) for supporting the interpretation of mineral records. We thank Martina Hagen and Martin Konert (Vrije Universiteit) for their support in the sediment analysis.

References


Sediment, diatom and pollen analysis of core El Caimito, Chocó


Sediment, diatom and pollen analysis of core El Cairnito, Chocó


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Sediment, diatom and pollen analysis of core El Caimito, Chocó


