A contribution of diatom analysis to Lateglacial and Holocene environmental reconstructions of Colombian lowland and montane ecosystems
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Citation for published version (APA):
Velez, M. A. (2003). A contribution of diatom analysis to Lateglacial and Holocene environmental reconstructions of Colombian lowland and montane ecosystems Amsterdam: IBED, Universiteit van Amsterdam

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Diatoms are algae, unicellular and eucaryotic, that live on aquatic places, such as rivers, lakes, ponds and humid soils. They occur on a global scale, from the pole to the equator and from the tropical lowlands to the high mountain lakes. Diatoms produce an outer 'shell', or frustule, which is made of silica and range in size from 5 μm to 500 μm. Diatoms derive their energy from photosynthesis. Reproduction is mainly by binary division, but sexual reproduction can also occur. The cell of the diatoms is made of silica (SiO2nH2O); it is divided into two valves and a series of structures that link the valves. The entire structure is known as the 'frustule'. The epitheca is the older valve and contains the linking structures; the other valve is called the hypotheca, and usually is smaller and younger. The size, shape and ornamentation of the valves forms the basis for taxonomical identification, which is typically possible to the species level.

Paleo-environmental reconstructions using diatoms are based on a number of assumptions: (1) that the species composition of a modern diatom assemblage depends on habitat, water chemistry, turbidity, and nutrient levels, (2) that these environmental preferences were also valid in the past, and (3) that fossil assemblages are reasonable representations of the living communities. Diatoms can be extracted from the sediments by standard laboratory techniques. Hence the ecological preferences of modern diatoms can be used to reconstruct past environments qualitatively. Diatom records provide information on changes of the lake level, changes in water chemistry, and disturbance of the local ecosystem by human activities. The latter has been tentatively traced by pollen in the selected cores but needs confirmation from other proxies.

In summary, diatoms are well established as indirect indicators of climatic change which is expressed through changes in water balance, changes in habitat availability and changes in lake chemistry. They provide a record
of local environmental change which compliments the more regional picture provided by pollen-based evidence. Given their size and productivity they may also be able to respond to rapid environmental fluctuations of short duration.

In the context of concern about future global change resulting from anthropogenic activities, it is important to understand the nature and magnitude of natural variability in the climate system and the sensitivity of different ecosystems to these changes. Knowledge about paleoclimatic and paleoenvironmental change in northern South America is largely based on pollen studies and geomorphology. For Colombia there is large body of pollen-based evidence of climatic change, derived from records of vegetational change. However, due to the fact that changes in the local vegetation also result from edaphic and geochemical changes, and that changes in the vegetation could be a result of internal dynamics within the ecosystem caused by individual changes of taxa, there was the need to calibrate pollen records. Diatom assemblages are directly controlled by chemical and hydrological factors which are in most cases, climate dependent; in this form diatom-based evidence is supplementary to pollen and sedimentological evidence. The introduction of diatom records to paleoenvironmental reconstructions in Colombia, and more general in northern South America, is new.

During the past 35 years a large body of palynological evidence concerning natural climatic change and the dynamics of ecosystems became available for Colombia. Most of the pollen cores originate from high elevations, from the Eastern Cordillera in particular. They show changes in the Colombian upper montane forest belt (at present located from 2300 to 3200 m altitude), the paramo belt (at present from 3200 to 4800 m altitude), and in ecosystems located around the uppermost forest line at c. 3200 m. The lower montane forest belt (at present from 1000 to 2300 m), and the tropical lowland belt (from 0 to 1000 m) have been little explored and the history of these ecosystems is poorly known. These lowland ecosystems include the savannas (Llanos Orientales), rain forests (Chocó and Amazonas), and several interandean valleys with dry forest vegetation.

Modern key questions in paleoclimatology concern the tropical lowlands: e.g. the estimation of the temperature depression during the Last Glacial
Maximum (LGM) at sea level is still under debate in the international literature. Terrestrial evidence and marine evidence are more in harmony than a decade ago, but much basic understanding is still missing. Also the understanding the history and amplitude of savanna, and tropical rain forest ecosystems, and the transitions between both are little explored but play an important role in the 'forest refugia' debate.

In this study we examined four lakes and one swamp with different ecological and limnological settings and climatic conditions, in order to ensure that our research encompassed a wide variety of ecosystems and climates and a diverse assortment of diatoms. Our choice of water bodies took into account the diversity of their morphology, depth and extension. From west to east, these lakes and some of their general features are the following (Figure 1):

- lake El Caimito (2°32' N, 77°36' W) at 50 m above sea level (asl), is located in the Pacific Coast, the wettest part of Colombia, with a precipitation range between 2000 and 12,700 mm per year. The temperature oscillates between 26° and 28°C. The Pacific coast features predominantly rain forest vegetation;

- the Patía swamp (2°02'N, 77°W) at 760 m asl, is located in the Patía Valley between the Central and Western Andean Cordilleras. This area has a mean precipitation of 1800 mm per year and a mean annual temperature of about 27°C. The Patía Valley is almost completely deforested, featuring mostly grassy vegetation, shrubs, and isolated trees. Small patches of forest, possibly the remnants of a formerly dry forest, are also present;

- lake Fúquene (5°27'N, 73°46'W) at 2580 m asl, is located in the Eastern Andean Cordillera. This is a relatively arid area with 900 to 1000 mm of annual precipitation and an average of about 13°C. In the area of Fúquene the main vegetation is composed of dry montane forest and wet montane forest;

- lake El Piñal (4°08'N 70°23'W) at 180 m asl, is located in the eastern savannas or Llanos Orientales. The precipitation in the area is about 1200 mm per year and has a temperature range between 26° and 27 °C.
- lake Las Margaritas (3° 23’ N, 73° 26’ W) at 290 m asl, is located in the Llanos Orientales, with a precipitation of about 2500 mm per year and temperature of 26°C. Savanna vegetation predominates in the Llanos Orientales, but this site is located in a transitional area where forest and savanna are competing and merge into each other.

The reconstructions in question are descriptions of the vegetational, limnologic, hydrologic and climatic changes that occurred in and around given bodies of water, mostly lakes, in the past. Each involves, on one hand, a local reconstruction of the history of the lake, including its origin and changes over time in water level and chemistry, and on the other hand, a regional reconstruction of changes in the surrounding vegetation. The combination of these proxies generates both a local limnologic story and a regional story of changes in the entire basin that facilitates the recognition of a climatic signal.

The cores were drilled and extracted using a modified Livingstone piston corer, or a Dachnowsky corer, both hand operated drilling equipment. The Livingstone corer extracts meter-length sediment sections packed in aluminium tubes, and is used to extract cores from lake centres or deep sectors. The Dachnowsky corer extracts sections of 25 cm packed in plastic tubes, and is mostly used for the drilling of littoral areas. Most of the cores drilled for this study were taken from the deepest part of the lake. Only the core from lake Fúquete was drilled on its northeastern margin. In the laboratory, the cores were sampled for diatoms, pollen, element geochemistry, and loss on ignition (LOI) analyses, radiocarbon dating, and stratigraphic description. As far as possible, samples for diatom and pollen analyses were taken from equivalent depths, in order to ensure that the diatom-based story was synchronous with the pollen-based story.

The limnologic history of each lake – that is, its origin and changes in water level and chemistry over time – was reconstructed on the basis of analyses of its diatom assemblages, pollen from the aquatic vegetation, and from the lithological sequence. For changes in lake level we used as indicators the ratio between planktonic and epiphytic-benthonic diatoms, and the ratio between plants from deep water and those from the littoral.
The regional environmental history was reconstructed on the basis of changes in the surrounding vegetation, particularly from the relation between taxa from arboreal and open vegetation. We used LOI as an indicator of the organic carbon content from which to infer lake productivity. Element geochemistry was used to make inferences concerning the input of allochthonous elements and littoral erosion.

Scientific studies of this kind are important because they help us to understand past environments and climates. The better our understanding of the past, the better our understanding of the present and our predictions of the future. Through the comparison of regional studies in the tropics with those from higher latitudes, it is possible to unveil distant climatic links, and then to use this information both to understand how global climatic variables influence localities and to predict these effects more precisely. Our understanding of such climate dynamics is of value for the judicious design of programs for environmental management and prevention of natural disasters. The impact of climate changes on agriculture, fishing and cattle ranching, among other economic activities, adds further to the importance of the development of our knowledge of climate dynamics.
Figure 1. Location of the studied sites.