Late Holocene Climatic Changes in Western Equatorial Africa Inferred from Pollen from Lake Sinnda, Southern Congo

Annie Vincens
Centre Européen de Recherche et d'Enseignement de Géosciences de l'Environnement CEREGE, BP 80, 13545 Aix-en-Provence cedex 04, France

Dominique Schwartz
Centre d'Etudes et de Recherches Eco-Géographiques CEREG, 3 rue de l'Argonne, 67083 Strasbourg cedex, France

Jacques Bertaux
Institut Français de Recherche Scientifique pour le Développement en Coopération ORSTOM, lle de France, 32 avenue Henri Varagnat, 93143 Bondy cedex, France

Hilaire Elenga
CEREGE, BP 80, 13545 Aix-en-Provence cedex 04, France

and

Christian de Namur
Laboratoire de Biomathématiques, service 462, Université de St Jérôme, 13397 Marseille cedex 13, France

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Pollen analysis of two cores from the Lake Sinnda, located in one of the driest areas of the southern Congo, reveals a history of vegetation and climate in this region during the past 5000 yr. A major change centered around 3000–2500 yr B.P. is indicated by an abrupt decrease in forest pollen and by a corresponding increase in grassland pollen. Concurrent drying up of the lake shows that climate, in particular aridity, was the major cause of this change. This paleoclimatic reconstruction conforms with evidence for drier conditions in other parts of western equatorial Africa, such as the development of isolated enclosed savannas and of heliophilous forested formations. The aridity is recorded more fully at Lake Sinnda than at the previous studied ones. It probably lasted longer, from 4200 to 1300 yr B.P., and was more progressive than previously inferred. The aridity predates agriculture marked by pollen of the oil palm at Lake Sinnda.

INTRODUCTION

A late Holocene arid event in western equatorial Africa has been inferred from pollen analysis of lacustrine deposits (Richards, 1986; Maley, 1991, 1996; Elenga, 1992; Elenga et al., 1992, 1994, 1996; Vincens et al., 1994, in press a; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera et al., 1996) and soils (Schwartz et al., 1986, 1990, 1992; Schwartz, 1991). This event left its legacy in present landscapes of the region (Schwartz et al., in press; Vincens et al., in press b). For example, it was probably responsible for opening of the forests synchronous with the extension of grasslands in many regions of Congo, Gabon, and Cameroon, effects of which remain evident today. However, opinions are still divided about the event's origin (climatic or anthropogenic), timing, and geographical distribution.

Here we consider the arid event in light of new pollen data from Holocene deposits in the Niari valley, south Congo. The pollen results described here complement mineralogical (Bertaux et al., in press) and phytolith (Alexandre, 1996; Alexandre et al., 1997) data obtained in the same area, as well as previous pollen studies from western equatorial Africa.

GENERAL SETTING

The Niari valley is located in the southern part of Congo, several degrees south of the equator (Fig. 1a). The valley is parallel to the Atlantic coast, from which it is separated by the Mayombe massif in the west. Its eastern part is delimited by the Chaillu massif (Fig. 1b).

Climatically, this region, lying in the rainshadow of the Mayombe where rainfall is about 1500 mm/yr, is one of the
The driest areas of western equatorial Africa. The mean annual rainfall is 1100 mm, with a distinct dry season from mid-May to mid-October (Mpolza and Samba-Kimbala, 1990).

The valley’s vegetation is placed by White (1983) in the Guineo-Congolian phytogeographical region, where grasslands and wooded grasslands extend north toward Gabon and south to Angola (Fig. 1a). These grasslands are generally dominated by one or two species of Gramineae (Poaceae) which represent more than 80% of the total herbaceous biomass. The woody biomass is dominated by *Annona arenaria, Psorospermum febrifugum, Bridelia ferruginea, and Strychnos* sp., and locally by *Hymenocardia acida* (Duvigneaud, 1949; Koechlin, 1961; Descoings, 1969).

Lake Sinnda, whose Holocene sediments we cored and analyzed, is located along the Niari river, north of Loudima (12°48'15" E, 3°50'08" S) at 128 m altitude (Fig. 1b). The nearby vegetation includes grasslands dominated by *Hyparrhenia diplandra*, as well as woody species, mainly *Annona senegalensis, Psorospermum febrifugum, and Bridelia ferruginea*, but not *Hymenocardia acida* (Descoings, 1969).
The northern and southern steep shores of the lake have forests dominated by *Celtis* sp., *Millettia laurentii* associated with *Ceiba pentandra*, *Alchornea cordifolia*, and in swampy areas by *Alstonia boonei* (Fig. 1c). Many climbers are present, particularly *Landolphia*. The forests also contain *Elaeis guineensis* (oil palm) and *Mangifera indica* attributable to human occupation mainly related to fishing. The flat eastern shore has marshes dominated by *Cyperaceae*.

**MATERIAL AND METHODS**

Two sediment cores for palynological analysis (SN 2 and SN 3) were raised in 1992 (Fig. 1c). They contained 3.80 and 2.47 m of sediments, respectively, and were recovered using a vibracorer (Martin and Flexor, 1987) in water 4.70 and 3.50 m deep. Only one of these cores, SN 2, whose preliminary pollen results have been recently published (Vincens et al., 1994), has been the subject of multidisciplinary studies such as mineralogy (Bertaux et al., 1996, in press) and phytoliths (Alexandre, 1996; Alexandre et al., 1997).

**Lithology of the Cores**

Both cores are dominated by clayey sediments, apparently without primary lamination (Fig. 2, 3). The cores further share a major lithological change, located at 0.80 m in SN 2 and between 1.55 and 0.73 m in SN 3. The basal sediments are gray clay, which grades upward to black, organic-rich mud with many plant remains. In core SN 2, mudcracks full of organic matter similar to the uppermost sediments are present between these two main lithological facies (Fig. 2). They have been previously interpreted as evidence for temporary desiccation of the lake at the site of SN 2 (Vincens et al., 1994). Core SN 3 contains pale gray clay, with some interstratified organic-rich layers, that is interpreted as a pedogenetic gley horizon (Fig. 3). Otherwise, core SN 3 lacks lithologic evidence of a hiatus from drying of the lake.

**Radiocarbon Dating**

We obtained five conventional radiocarbon ages and seven accelerator mass spectrometry (AMS) ages on bulk organic matter. The ages are reported only in radiocarbon years except in Table 1, which gives equivalent ranges in calibrated years.

The ages show that the cored sequences expend back to about 5200 yr B.P. In the most complete and well-dated sequence, SN 2, the drying up of the lake inferred from lithology can be dated between 3800 and 1330 yr B.P., the youngest age being obtained from the base of sediments filling the mudcracks (Fig. 2).

**Pollen**

From the two cores, a total of 88 samples (SN 2, 56; SN 3, 32) of about 1 cm³ were analyzed at intervals ranging from 2 (upper part of SN 2) to 20 cm. The resulting time resolution ranges from 20 to 200 yr. A pollen sum of at least 320 to 440 pollen grains was counted for each sample. Identifications were based on the reference collection of some 7000 slides present in the Laboratoire de Géologie du Quaternaire-CNRS, CEREGE, Aix-en-Provence.

The pollen assemblages are diverse in all the samples analyzed, particularly in the lowest part of the two cores, with a maximum of 88 taxa found in one sample (Fig. 4). A total of 149 taxa has been identified. Whenever possible, the identifications were made at the species, genus, or family level, or with a “type” designation if the family (or genus) contains several genera (or species) of identical pollen morphology. The taxa are classified in relation to the physiognomy of the plants which produced them (trees and shrubs, herbs (terrestrial or aquatics), climbers). This classification is based on the “Flore du Congo Belge et du Ruanda-Urundi” (1948–1963), the “Flore du Congo, du Rwanda et du Burundi” (1967–1971), the “Flore d’Afrique centrale (Zaire, Rwanda, Burundi) (1972–1985), and the “Flore du Gabon” (1962–1995).

Pollen results are presented in standard percentage diagrams on Figures 2 and 3 with the samples arranged along a depth scale. Only the major taxa, considered to be the most important ones in the interpretation of the palaeoenvironment of Lake Sinnda by their abundance and their consistent presence, were plotted with the GPAL3 program (Goeury, 1988). Sums include all pollen and spore types, except indeterminables. Zonation of the pollen diagrams was done by visual inspection.

**POLLEN RESULTS AND INTERPRETATION**

The two pollen records show similar trends, with a major abrupt change at 0.80 and 0.69 m in SN 2 and SN 3, respectively (Figs. 2 and 3). This change coincides with lithologic evidence for drying up of the lake—the top of the mud cracks in SN 2 and the top of the pedogenetic gley horizon in SN 3. The change allows definition of two main pollen zones. The ages of the zone boundaries proposed here (and subsequently for the subzones) are based on the assumption of a constant sedimentation rate and on interpolation between two uncalibrated 14C ages.
FIG. 3. SN 3 pollen from Lake Simda showing relative percentages of selected taxa. The pollen sum includes all pollen taxa; indeterminables are excluded.
Zone 2 (SN 2; 3.80–0.80 m; SN 3; 2.47–0.69 m; 5240–3800 yr B.P.). This pollen zone has a diverse assemblage (Fig. 4) with arboreal taxa reaching 50–80% of the total pollen sum. The main components are *Chlorophora excelsa*, *Alchornea*, *Celtis*, *Pausinystalia*-type, *Lannea*, and *Macaranga*. Climbers (*Acridocarpus, Combretaceae, Paulinia pinnata, Iodes*) are common. Herbaceous taxa, particularly Gramineae (generally less than 1%), are scarce. The assem-
TABLE 1

List of 

<table>
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<tr>
<th>Core</th>
<th>Sample depth (cm)</th>
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<th>Lab number</th>
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<td>1330 ± 60</td>
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*AMS dates.

blages imply a forested environment around Lake Sinnda between 5200 and 3800 yr B.P., with climatic conditions more humid than today.

In core SN 2, the most complete sequence, changes in the proportions of the major arboreal taxa suggest three pollen subzones corresponding to three successional stages of this forested environment.

—Subzone 2c (SN 2, 3.80–3.15 m; 5240–5100 yr B.P.). In this subzone, the abundance of Phoenix reclinata, associated with Myrianthus-type, Alstonia-type, Hallea-type, and Pteridophyta (monolete-type), implies that a swampy forest surrounded the lake. Subzone 2c may record the first Holocene filling of the lake, corresponding to the onset of humid conditions known from other parts of western equatorial Africa at 9500–9000 B.P. (Giresse et al., 1982; Maley, 1991, 1996; Elenga et al., 1994). The lake-filling hypothesis is supported by macrofaunal evidence for open woodland rather than forested vegetation at 7000 yr B.P. in the Niari valley (Van Neer and Lanfranchi, 1986). Alternatively, subzone 2c corresponds to a dry episode within the humid period, so that swamps expanded into a lowered lake.

—Subzone 2b (SN 2, 3.15–1.39 m; SN 3, 2.47–1.17 m; 5100–4200 yr B.P.). This subzone is characterized by a gradual increase of Celtis and Alchornea contemporaneous with a decrease of the Moraceae, Pteridophyta, and the

swampy forest elements, particularly Phoenix reclinata. The forest arboreal components include many taxa (mainly Leguminosae and Euphorbiaceae) reaching more than 1% of the pollen sum. The occurrence of Raphia and of some Syzygium implies local swamps.

—Subzone 2a (SN 2, 1.39–0.80 m; SN 3, 1.17–0.69 m; 4200–3800 yr B.P.). A great increase of Celtis is registered in this subzone, where it accounts for 26–29% of the

FIG. 4. Diversity of the differentiated pollen taxa in the core SN 2 from Lake Sinnda related to pollen sum.
pollen sum (35–38% of the total arboreal pollen). In both cores the Celtis is associated with Holoptelea grandis. The abundance of these two taxa in the vicinity of Lake Sinnda indicates an evolution of the forest toward a semideciduous facies that entails drier and/or more seasonal climates (with a longer dry season) in the Niari valley than during the rest of zone 2. The uppermost deposits of this subzone show increasing percentages of Alchornea at the expense of Celtis and Holoptelea grandis, associated in core SN 3 with Tetrorchidium.

Zone 1 (SN 2, 0.80–0 m; SN 3, 0.69–0 m; 1300 yr B.P. to present). This upper pollen zone registers distinctly different pollen assemblages than in zone 2. The assemblages are less diverse (Fig. 4) and the dominant components are herbaceous taxa, mainly Gramineae, that indicate a development of open grasslands in the vicinity of the lake from 1300 yr B.P. onward. These grasslands replaced the forest environment that had prevailed between 3800 and 1300 yr B.P. Many forest taxa, mainly Leguminosae, are missing. Others are recorded by pollen so scarce (less than 1%) that they probably were not living at or near the lake.

Large changes in the frequencies of marshy herbaceous taxa in the SN 2 sequence, mainly the Cyperaceae and Typha, allow the definition of four subzones within zone 1. Each of these subzones is linked more to lake level fluctuations than to widespread vegetational changes.

—Subzone 1d (SN 2, 0.80–0.63 m; 1300–1100 yr B.P.). This subzone has high percentages of Cyperaceae, Typha, and Pteridophyta (monolete-type). These taxa imply the presence of local marshes at the core site SN 2. Subzone 1d marks the start of the filling of Lake Sinnda after its dessication between 3800 and 1300 yr B.P.; it implies the re-establishment of more humid climatic conditions in this area.

—Subzone 1c (SN 2, 0.63–0.31 m; 1100–800 yr B.P.). A decrease in aquatic taxa in this subzone shows that at the core site SN 2, swampy vegetation disappeared as lake level rose. An abundance of arboreal taxa such as Moraceae, Alchornea, some Celtis, and Pausinystalia-type, indicates the beginning of a recolonization of the shores by forests similar to the ones found today north and south of the lake. Pollen of Elaeis guineensis (oil palm) is found for the first time in this subzone (0.49 m). Though only one or two grains, it provides the first evidence of human agricultural activity around Lake Sinnda.

—Subzone 1b (SN 2, 0.31–0.14 m; SN 3, 0.69–0.30 m; 800–550 yr B.P.). A new expansion of swampy taxa implies a new drop of lake level, certainly related to a short arid phase. Additional Elaeis guineensis implies increased agricultural activity.

—Subzone 1a (SN 2, 0.14–0 m; SN 3, 0.30–0 m; 550 yr B.P. to present). Swampy taxa decrease, probably from new rise in lake level. Forests, including Elaeis guineensis, develop until the present day.

DISCUSSION

The Late Holocene Arid Event in Western Equatorial Africa

Pollen evidence from western equatorial Africa has previously shown that an important change occurred during the late Holocene. During this event, forests, which were more extensive in this region during early and middle Holocene, underwent floristic, structural, and paleogeographical changes (Richards, 1986; Maley, 1991, 1996; Elenga, 1992; Elenga et al., 1992, 1994, 1996; Vincens et al., 1994, in press a; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera et al., 1996).

The change, centered around 3000–2500 yr B.P., is synchronous with a large extension of grasslands in many regions of Cameroon, Gabon, and Congo. While some authors have ascribed it to climatic change, others favor an anthropogenic one (Schwartz, 1992). Today it is clear that the development of savannas and their maintenance in these regions are the result of three main successional and/or cumulative factors: climatic stress, local edaphic environment, and (more recently) fires set by people (Schwartz et al., 1995, in press). But details about this dry event, including its onset, termination, spatial variation, and temporal pattern, remain matters of debate (Maley, 1997; Vincens et al., in press b).

The change in pollen assemblages of the two sedimentary sequences from Sinnda between 3800 and 1300 yr B.P. is related to a major climatic event—a time of exceptional aridity that dried up the lake completely. Consequently human impact as early as 3000 yr B.P. can be excluded as a primary reason why forest was replaced by grassland around the lake. Moreover, concurrent changes have been registered in several regions of western equatorial Africa, mainly in Congo (Bateke plateaus and Lake Kitina, Figs. 1a, 1b) and Cameroon (Lakes Ossa and Barombi Mbo; Fig. 1a). These changes, which include development of heliophilous forests and/or isolated enclosed savannas, indicate a widespread event of climatic origin.

Concerning the timing of the arid event, the data from Lake Sinnda, the driest site studied in western equatorial Africa, point to a longer and a less abrupt change than previously proposed in this part of Africa (Elenga, 1992; Maley, 1992, 1997; Schwartz, 1992; Elenga et al., 1994). The new pollen data show a major change to semideciduous trees in the forests surrounding the lake as early as 4200 yr B.P. This change can be interpreted in terms of drier (lower mean annual rainfall) and/or more seasonal climatic conditions than before, maybe with a longer dry season. Phytolith analyses of core SN 2 show that Gramineae coexisted with the forests, which had probably become interspersed with savannas (Alexandre, 1996; Alexandre et al., 1997). This climatic interpretation also agrees with a decrease of quartz and kaolinite content and an increase of calcite and talc from
4300 yr B.P. onward at core SN 2. These mineralogical changes imply a reduction in rainfall (Bertaux et al., 1996, in press). The end of the arid event is probably marked by the refilling of Lake Sinnda, dated to 1300 yr B.P.

The western equatorial African forests reacted to the aridity in various floristic, structural, and paleogeographical ways. These responses can be explained in terms of the former local stability (or fragility) of each site before 3000 yr B.P. Such a stability (or fragility) and the distribution of present forest ecosystems are governed mainly by local climatic and edaphic conditions (Baumgartner, 1978; Richards, 1981; Furley et al., 1992).

It now seems clear that at Sinnda, climatic and edaphic conditions prevented the maintenance of forested ecosystems during the arid event. The annual rainfall was below the minimum values for their survival while low water availability occurred in the clayey soils (Schwartz et al., 1995). Under such critical conditions, a change in floristic composition from 4200 yr B.P. onward logically preceded the complete disappearance of the forests between 3800 and 1300 yr B.P.

At sites where the arid event allowed the survival of forests, such as around Lakes Ossa and Barombi Mbo in Cameroon (Maley, 1992; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera et al., 1996) and Lake Kitina in Congo (Elenga et al., 1996), no early, drastic, and irreversible perturbations occurred about 4000 yr B.P. Forests persisted with only local openings after 2700 yr B.P. (development of heliophilous formations or of enclosed savannas). Humid forests rich in Caesalpinia species persisted near Lakes Ossa and Barombi Mbo until 2700 and 2500 yr B.P., respectively. This persistence has been linked to the occurrence of stratiform clouds and permanent fog over the region (Maley and Elenga, 1993).

On the Bateke plateaus and along Congo’s Atlantic coast, climatic conditions were critical, but during the arid event soils remained moist. This soil moisture, linked to the lack of drainage, compensated for a deficit in rainfall, so that forests persisted locally until 3000 yr B.P. (Elenga, 1992; Elenga et al., 1992, 1994).

We thus infer that the arid event is recorded more fully at Lake Sinnda than at sites where the (climatic and/or edaphic) environment allowed forests to survive. The new data obtained from Lake Sinnda, complemented by those from Kitina (Elenga et al., 1996; Bertaux et al., in press), further argue for a more continuous and progressive trend toward aridity, with a maximum probably centered around 3000–2500 yr B.P. We found no evidence for the succession of shorter and abrupt dry intervals proposed by Maley (1992, 1997).

Recent Climatic Changes and Human Impact on the Landscape Dynamics

The refilling of Lake Sinnda about 1300 yr B.P. and the progressive redevelopment of local forested formations on its shores from 1100 yr B.P. onward, imply the re-establishment of more humid conditions in the region. Nevertheless, forest expansion in the Niari valley was limited by low rainfall, a long dry season, low water availability in the soils and, above all, human burning of grasslands (Schwartz et al., 1995, in press). At the other studied sites of western equatorial Africa, an increase in rainfall during the last millennium is also indicated by expansion of forests around Lake Kitina, ca. 500 yr B.P. (Elenga et al., 1996) and Lake Ossa, ca. 700 yr B.P. (Reynaud-Farrera, 1995, 1997), and by humid conditions on the Bateke plateaus ca. 900 yr B.P. (Elenga et al., 1994). Re-establishment of humid conditions along the Congolese coast has also been inferred for 600–500 yr B.P. onward from the resumption of erosion in the Pliopleistocene deposits outcropping between Pointe Noire and the Kouilou River (Sitou, 1994; Sitou et al., 1996).

Within this recent humid period, a brief drought dropped the level of Lake Sinnda ca. 650 yr B.P., within the interval spanned by the Little Ice Age. This drop in level is suggested by pollen evidence for a large extension of marsh. But the drought had little if any effect on the main vegetational communities occurring in the surrounding region. Like the previous arid event, the lowering of lake level ca. 650 yr B.P. cannot be attributed to human activities.

Concerning human activities in the vicinity of Lake Sinnda, the earliest agricultural evidence is found in the appearance of Elaeis guineensis (oil palm) at 1000 yr B.P. and its expansion after 600 yr B.P. As at the other sites, its occurrence or its expansion is registered after the widespread establishment of grassland savannas (Elenga et al., 1992, 1994) or the temporary opening of the forests (Elenga et al., 1996; Reynaud-Farrera et al., 1996), so after the onset of the late Holocene arid event. Expansion of Elaeis guineensis has been linked to the settlement of proto-agricultural populations associated with Bantu-speaking groups in the region (Clist, 1991; Schwartz, 1992).

CONCLUSION

Pollen data from the Niari valley show that climate has been the major driving factor in the evolution of the environment in western equatorial Africa during the last 5000 yr B.P. The greatest floristic, structural, and paleogeographical changes to the forests in this area during the middle Holocene are linked to an arid event centered around 3000–2500 yr B.P. This event probably lasted from 4200 to 1300 yr B.P.

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