



Forest response to climate changes in Atlantic Equatorial Africa during the last 4000 years BP and inheritance on the modern landscapes

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Abstract

This review paper synthesizes the recent published palaeoecological results obtained in Atlantic Equatorial Africa (ECOFIT program) on the history of forest ecosystems and inferred climate changes during the past 4000 years. Evidence are mainly provided by pollen analysis carried out at nine sites from Congo, Cameroon and Ghana, locally supported by macroflora remains, phytoliths, diatoms, $\delta^{13}\text{C}$ and mineralogical data.

At all the sites, except Lake Bosumtwi (Ghana), following a large expansion of rain and mesophilous forests until 3000 years BP, a major change is registered, affecting floristic composition, structure and geographical distribution. According to the hydrological sensitivity of the different sites, local openings of the forests with development of heliophilous formations and/or isolated enclosed savannas are observed at the most humid sites; complete disappearance of forested formations at the driest. The agreement between pollen records, hydrological and hydrobiological data definitely demonstrates that an arid event has been the primary driving factor of this change and is responsible for the main features of the modern landscapes in Atlantic Equatorial Africa. Moreover, the most recent palaeoecological data obtained in Congo (Lake Sinnda), indicate that this Late Holocene increasing aridity was of longer duration, from 4000 to 1300 years BP, and more progressive than previously inferred. A new expansion of forests is locally detected *c.* 900–600 BP despite increased human impact.

Keywords

Pollen, multi proxydata, forest, climate, Atlantic Equatorial Africa, Late Holocene.

Until the last three decades, extremely little was known of the past history of the tropical lowland forest formations. Thereby, these forests have been longer considered as the most stable ecosystems of the Earth and their great floristic diversity has been often interpreted in terms of persistence or of very slow change through time compared to drier vegetation types. Based on recent palaeoecological studies carried out from 1970

onwards, the Equatorial forests are now believed to have been the subject of drastic modifications (floristic, structural and palaeogeographical ones) in response to global climatic changes.

During the Quaternary, African lowland forests, like Amazonian ones (Bush *et al.*, 1990; Servant *et al.*, 1993; Van der Hammen & Absy, 1994; Turq *et al.*, 1996; Colinvaux, 1997), have been largely affected by long time-scale duration and large amplitude climatic fluctuations. Thus, the dry and cold period of the Last Glacial Maximum led to their fragmentation, to the isolation of forested communities in refugia and to the presence of montane biotopes in the lowlands

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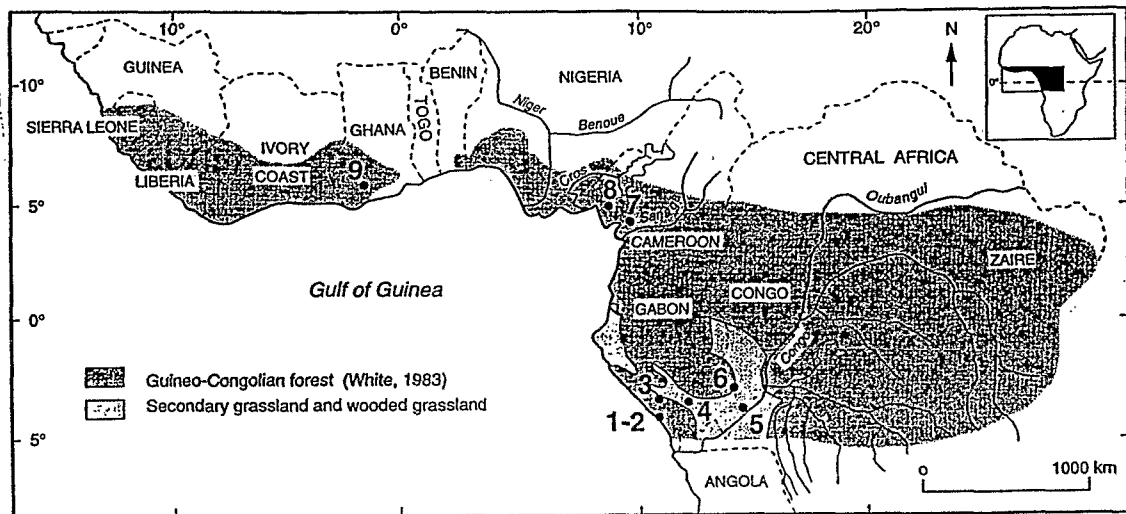


Figure 1 Location map of the pollen sites inside the Guineo-Congolian phytogeographical region as defined by White (1983): 1, Songolo; 2, Coraf; 3, Kitina; 4, Sinnda; 5, Ngamakala; 6, Bilanko; 7, Ossa; 8, Barombi Mbo; 9, Bosumtwi.

(Maley, 1987, 1989, 1991, 1996; Elenga *et al.*, 1991; Elenga, 1992; Maley & Elenga, 1993). These forests have also suffered of shorter climatic events, such as this which took place during the last 4000 years BP (Maley, 1991, 1992; Elenga *et al.*, 1992, 1994, 1996; Elenga, 1992; Vincens *et al.*, 1994, 1996a, 1996b, 1998; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera *et al.*, 1996; Maley & Brénac, 1998).

This paper summarizes the recent published Late Holocene palaeoecological researches carried out in Atlantic Equatorial Africa, mostly relevant to the ECOFIT program (CNRS-ORSTOM). For the purpose of the reconstruction of past vegetation patterns, the synthesis will be based primarily on palynological sources from nine sites, a method which is still widely used for such a work. The interpretations will be completed, on some sites, by sedimentological, limnological and phytoliths results proceeding from the same sedimentary sequences, or, on some others, by macroflora remains and $\delta^{13}\text{C}$ data obtained in their vicinity.

THE POLLEN SITES STUDIED

The available well radiocarbon dated palynological sequences, recovered by coring in lakes or swampy depressions, come from three African Atlantic Equatorial regions (Fig. 1 and Table 1). They are, from the South to the North, the following.

The Congo with: (a) the Coraf and Songolo sites located on the littoral, today occupied by short grass-savannas with locally swampy herbaceous or dense arboreal formations (Makany, 1963; Elenga *et al.*, 1992; Elenga, 1992; in preparation); (b) the lake Kitina, on the western escarpment of the Mayombe Massif, inside the semideciduous forest (Cusset, 1987; Elenga *et al.*, 1996); (c) the lake Sinnda, in the Niari valley today covered by tall grass-savannas with locally more or less well developed patches of remained semideciduous forest (Koechlin, 1961; Vincens *et al.*, 1994, 1998); (d) the Ngamakala and Bilanko sites, two swampy arboreal depressions, located

Table 1 The pollen sites from Atlantic Equatorial Africa. Geographical location and mean annual rainfall values.

Sites	Latitude	Longitude	Altitude	Mean annual rainfall
1 Songolo	4°45'S	11°51'E	5 m	1260 mm
2 Coraf	4°S	11°E	0 m	1260 mm
3 Kitina	4°15'S	11°59'E	150 m	1500 mm
4 Sinnda	3°50'S	12°48'E	128 m	1100 mm
5 Ngamakala	4°04'S	15°23'E	400 m	1300 mm
6 Bilanko	3°31'S	15°21'E	600 m	1500 mm
7 Ossa	3°48'N	9°61'E	8 m	2950 mm
8 Barombi Mbo	4°40'N	9°24'E	300 m	2400 mm
9 Bosumtwi	6°30'N	1°25'W	100 m	1550 mm

on the Bateke plateaus occupied by grass or wooded savannas (Descouings, 1960; Makany, 1976; Schwartz, 1988; Elenga, 1992; Elenga *et al.*, 1994).

The Cameroon with: (a) the lake Ossa, inside the Atlantic littoral forest with *Sacoglottis gabonensis* and *Lophira alata* (Letouzey, 1968, 1985; Reynaud & Maley, 1994; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera *et al.*, 1996); (b) the lake Barombi Mbo, located inside the Biafrean evergreen forest with numerous Caesalpiniaceae (Brénac, 1989; Maley, 1991, 1996; Maley & Brénac, 1998).

The Ghana, with the lake Bosumtwi whose basin is occupied by semideciduous forest (Hall & Swaine, 1981; Maley, 1987, 1989, 1996).

According to the sites, the time resolution of the pollen data ranges from 20 to 300 years, except at lake Bosumtwi where only four samples were analysed for the past 4000 years.

SYNTHESIS AND INTERPRETATION OF THE DATA

The synthesis proposed for the last 4000 years BP in Atlantic Equatorial Africa is given in Fig. 2. The studied sites and their

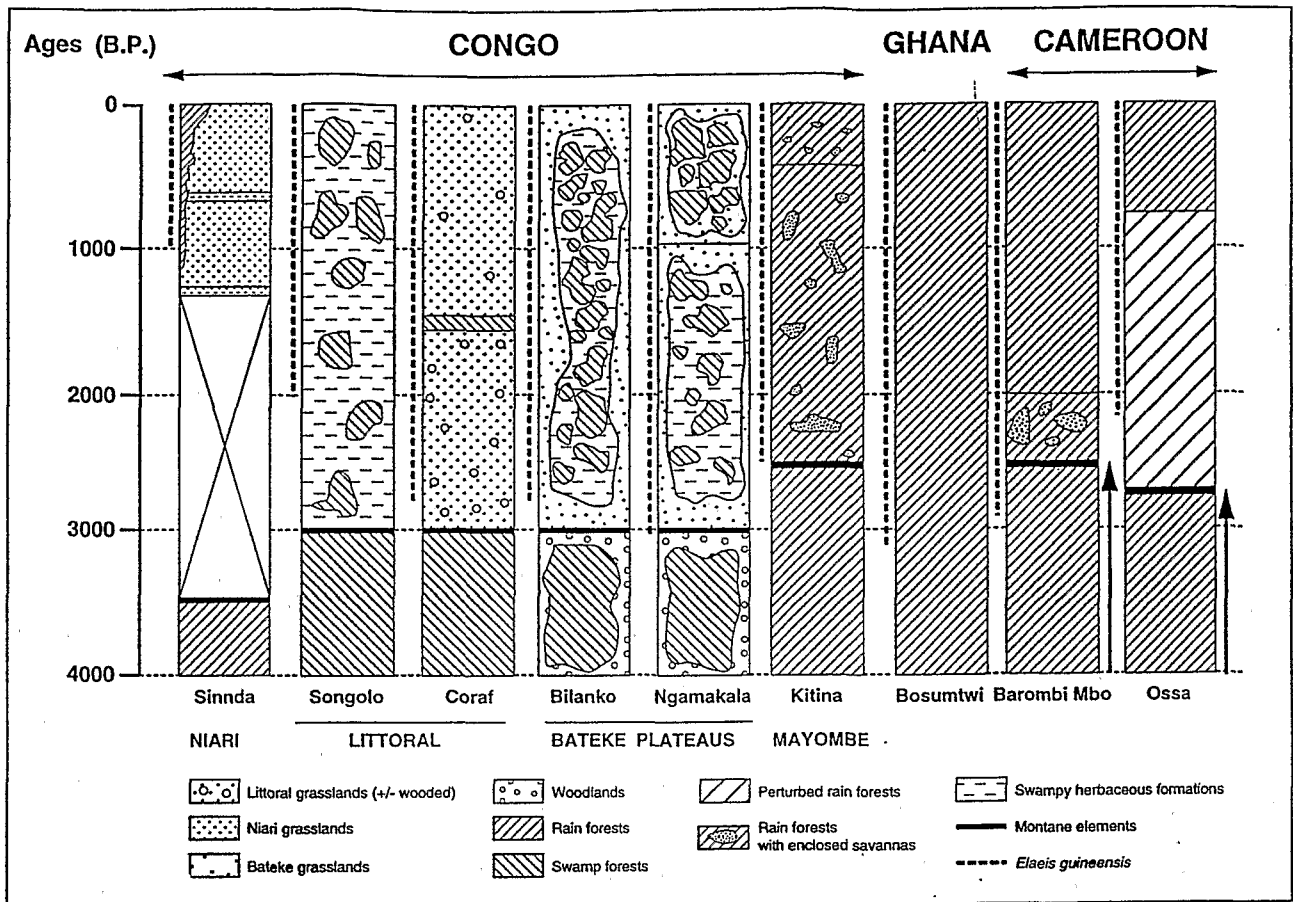


Figure 2 Synthesis of the pollen and macroflora remains data from Atlantic Equatorial Africa and vegetation reconstruction during the past 4000 years.

vegetation reconstruction are arranged, from the right to the left, according to the modern mean annual rainfall values registered near each site (Table 1), from the driest site (Sinnda) to the most humid one (Ossa). The timescale was extrapolated from non calibrated ages obtained along the different sequences. The list of these ages can be found in Maley (1989), Giresse *et al.* (1994), Elenga (1992), Elenga *et al.* (1992, 1994, 1996), Vincens *et al.* (1994, 1998), Reynaud-Farrera (1995) and Maley & Brénac (1998).

This synthesis clearly shows that between 4000 and 3500 years BP, all the sites were occupied by forested communities. These forests were of two main types.

- Mainland forests are found, with a semideciduous facies well developed at Sinnda (Congo) and Bosumtwi (Ghana) as testified by the abundance of *Celtis*. Around the lakes Ossa and Barombi Mbo (Cameroon), forests of Briafrean type dominated by Caesalpiniaceae are present. At Kitina, *Anopyxix*, *Martretia*, *Dacryodes* are well developed in the environment of this site, with locally fringing arboreal swamp formations with *Hallea*, *Anthostema* and *Syzygium*.
- Dense swamp forests occur on hydromorphic soils, such as on the congolese littoral, with abundance of *Symphonia globulifera*, *Hallea* and *Uapaca* on the Songolo site, or of

Syzygium at Coraf. In this region, pollen data are completed by macroflora remains (wood and tap-roots) of *Monopetalanthus (microphyllus)* dominant, *Sacoglottis gabonensis* and *Jaundea pinnata* recovered at Coraf and southward at Loango (Dechamps *et al.*, 1988a; Schwartz *et al.*, 1990).

In the hydromorphic depressions of the Bateke plateaus, *Syzygium* is largely developed on the Bilanko site, associated with numerous Sapotaceae at Ngamakala. Concerning the vegetation which occupied the Bateke plateaus, macroflora remains indicate the occurrence of woodlands during this period (Dechamps *et al.*, 1988b).

Centered around 3000–2500 years BP, a major vegetation change is registered, which has not the same pattern according to the sites.

On the modern most humid sites, forests persist but a fragmentation of these forests is observed and isolated enclosed savannas develop. This change is clearly shown on the Kitina and Barombi Mbo sites, at c. 2500 years BP, where Gramineae become abundant in the pollen diagrams, synchronous, at Kitina, with an expansion of swampy and heliophilous arboreal taxa such as *Pandanus*, *Raphia*, *Macaranga*, *Alchornea*. Around the lake Ossa, a vegetational deterioration is registered

c. 2700 years BP, marked by the substitution of the primary forest by a colonizing one rich in pioneer species (*Alchornea*, *Macaranga*). Only the forests which occurred around the lake Bosumtwi do not seem to be affected by such a change. But, this site would need more detailed palynological studies (higher time resolution of the data) to confirm this persistence.

On the modern driest sites, the former forested environment completely disappears with, synchronously extension of open formations of savanna type around the lake Sinnda (Niari valley), or of more or less wooded grasslands on the Coraf site (littoral).

In the hydromorphic depressions, a fragmentation of the swampy forests is demonstrated with, at the same time, expansion of hygrophytic herbaceous formations dominated by Cyperaceae and *Raphia* at Songolo (littoral), by Cyperaceae, *Stipularia africana*, *Laurembergia tetrandra* and *Xyris* at Ngamakala and Bilanko on the Bateke plateaus. On this last site, palynological data coupled with $\delta^{13}\text{C}$ measures on the same core, clearly show that the development of Gramineae observed in the pollen diagram is not local but corresponds to the extension of open grasslands on the plateaus (^{13}C data from Mariotti non published in Elenga, 1992).

During the last millenium, a new expansion of forest communities is registered on the sites where these formations had never completely disappeared c. 3000–2500 years BP. Thus, at Ossa, Biafrean and Atlantic littoral rainforests re-extend from 700 years BP onward; at Kitina, a progressive reforestation of the enclosed savannas and a decrease of heliophilous elements take place c. 500 years BP; at Ngamakala, swampy forests become progressively more developed. from 900 years BP. Around Sinnda, only a local ring of forest along the margins of the lake expands from 650 years BP. Only the data from the Barombi Mbo site indicate an earlier reforestation dated c. 2000 years BP.

DISCUSSION

The synthesis of the data clearly shows that the African Atlantic Equatorial forests, occurring between 4°S and 7°N, and largely extended during the Middle Holocene, have been subject of important floristic, structural and palaeogeographical modifications during the last 4000 years BP. The main vegetation change centred around 3000–2500 BP is registered on all the sites where high time resolution of the data was available, indicating the great intensity and the large geographical impact of this event.

It is now clear that this major change in the forest communities is linked to an arid event, as far as, at the same time, some lakes such as Sinnda completely dried up between 3800 and 1300 years BP (Vincens *et al.*, 1994, 1998; Bertaux *et al.*, 1996), or such as Bosumtwi and Ossa registered a low lake level c. 3700 and c. 3200 years BP, respectively (Talbot *et al.*, 1984; Talbot & Johannessen, 1992; Nguetsop & Servant-Vildary, 1996; Servant-Vildary *et al.*, 1996; Nguetsop, 1997). So, human impact as early as 3000 BP can be excluded as a primary reason why forests opened or were replaced by grasslands.

As shown above, this change had not the same pattern and

was not synchronous according to the sites. These differential responses can be explained in terms of the former local stability (or fragility) of forests on each site before 3000 BP, stability (or fragility) being mainly governed by local climatic and edaphic conditions (Baumgartner, 1978; Richards, 1981).

On the present driest sites such as Sinnda, climatic and edaphic conditions prevented the persistence of forested ecosystems during this arid event, related with annual rainfall certainly below the minimum values for their survival and low water availability in the soils (Schwartz *et al.*, 1995). Such critical conditions led to the complete disappearance of forests in this area between 3800 and 1300 years BP, just after a first major modification of their floristic composition towards a well marked semideciduous facies c. 4200 years BP (Vincens *et al.*, 1998). The same evidence is registered on the Bateke plateaus c. 3000 years BP where woodlands were replaced by open formations rich in Gramineae (Schwartz *et al.*, 1995, 1996a). Nevertheless, under such critical climatic conditions, some patches of forested formations have locally maintained themselves, particularly in hydromorphic depressions (Ngamakala and Bilanko on the Bateke plateaus, and Songolo on the littoral) where, during this arid event, permanent soil moisture could have compensated for a deficit in rainfall.

On sites where climatic conditions remained above or near the minimum rainfall values for the survival of forests, such as Kitina, Ossa and Barombi Mbo, no drastic and irreversible perturbations are observed. Forests persisted with only local openings after 2700 years BP (development of heliophilous formations or of enclosed savannas). Near the two last sites, the persistence of humid forests rich in Caesalpiniaceae until 2700 and 2500 years BP, respectively, has been linked to the occurrence of stratiform clouds and permanent fogs over this region (Maley & Elenga, 1993).

In addition to pollen data, some other palaeoecological studies have been carried out on the same sedimentary sequences, with similar time resolution. The most recent results obtained agree with the vegetation reconstruction and the climatic interpretation proposed above. They also point to a longer (from 4200 to 1300 years BP) and less abrupt change toward aridity than previously proposed in this part of Africa (Elenga, 1992; Maley, 1992; Schwartz, 1992), with a maximum probably centred around 3000–2500 BP. At Sinnda, when pollen data show a major change to semideciduous trees in the forests surrounding the lake c. 4200 years BP, phytoliths analyses demonstrate a first occurrence of Gramineae which indicates a beginning of fragmentation of the forests with, certainly, development of isolated enclosed savannas (Alexandre *et al.*, 1996, 1997; Vincens *et al.*, 1998). Mineralogical studies carried out on this same site show, from 4300 years BP, a decrease of quartz and kaolinite contents and an increase of calcite and talc interpreted as a progressive reduction of rainfall (Bertaux *et al.*, 1996). At the same time and with the same climatic interpretation, a decrease of quartz and kaolinite fluxes and of siderite precipitation is registered at Kitina (Bertaux *et al.*, 1996; Elenga *et al.*, 1996) but no major perturbation of the local forests is still observed until 2500 years BP linked to their relative former stability on this site.

The refilling of lake Sinnda after 1300 years BP and the recent

expansion of the forests observed around the lakes Kitina (c. 500 BP) and Ossa (c. 700 BP), and in the Ngamakala depression (c. 900 BP), despite increased human impact as shown by the appearance and development of *Elaeis guineensis* (oil palm), confirms the re-establishment of more humid conditions over Atlantic Equatorial Africa during the last millenium. Increased rainfall is also testified from 600 to 500 BP onwards on the Congolese littoral by the resumption of erosion (Sitou *et al.*, 1996). On the least favourable sites, Sinnda and Coraf, the development of open grasslands and their maintenance until today are the result of three main successional and/or cumulative factors: climatic stress, low available water capacity of the soils, and, more recently, fires set by people (Schwartz *et al.*, 1995; 1996a).

Within this recent humid period, a brief drought was registered at Sinnda c. 650 BP, within the interval spanned by the Little Ice Age, as evidenced by a large extension of marsh linked to a short drop in the lake level (Vincens *et al.*, 1998). But, without a time resolution of the data on the forested sites as high as at Sinnda (20 years in the upper part of the core), one cannot infer for the moment the impact of this climatic event on the forests.

CONCLUSION

In Atlantic Equatorial Africa, the agreement between pollen records, macroflora remains, phytoliths, isotopic, hydrological and hydrobiological data definitely demonstrates that climate has been the primary driving factor in the evolution of forests during the last 4000 years BP. It is now clear that the great floristic, structural and palaeogeographical perturbations which have affected these forests are mainly linked to an arid event centred around 3000–2500 BP, but of longer time-scale duration than the one previously proposed, from 4200 to 1300 years BP. This event is responsible to the main features of the modern vegetational landscapes in this region, particularly occurrence of secondary open grasslands in some areas and of enclosed savannas inside the forests.

Such an increasing aridity during the Late Holocene associated with major vegetation changes has been previously observed in other parts of tropical Africa (Servant & Servant-Vildary, 1980; Bonnefille *et al.*, 1991; Taylor, 1992; Ssemmanda & Vincens, 1993; Vincens, 1993; Jolly *et al.*, 1994; Yan & Petit-Maire, 1994) but also in other tropical regions such as India (Bryson & Swain, 1981; Swain *et al.*, 1983; Caratini *et al.*, 1994) or Tibet (Gasse *et al.*, 1996). The regional pattern and the contemporaneity of these records are now a strong argument against an extensive anthropogenic deforestation at this time.

During the last millenium, rehumidation and forest advance despite human interferences are also clearly registered in the data. This pattern continued onwards as shown by historical and ecological results obtained on savanna-forest boundaries in Ivory Coast, Central Africa, Congo and Cameroon (Gautier, 1989; Boulvert, 1990; Schwartz *et al.*, 1996b; Youta Happi, 1998) despite rainfall markedly below normal during the past decades in West Africa (Nicholson, 1994).

After all, such a synthesis now clearly demonstrates that

research into climate change/past vegetation during the Holocene in Atlantic Equatorial Africa needs to resolve timescales shorter than have been previously explored (100 years or less) to lead to more precise and realistic comparisons between sites.

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