

See discussions, stats, and author profiles for this publication at: <http://www.researchgate.net/publication/232311345>

# Pollen-based vegetation changes in southern Tanzania during the last 4200 years: Climate change and/or human impact

ARTICLE *in* PALAEOGEOGRAPHY PALAEOCLIMATOLOGY PALAEOECOLOGY · OCTOBER 2003

Impact Factor: 2.75 · DOI: 10.1016/S0031-0182(03)00473-5

---

CITATIONS

46

---

DOWNLOADS

259

---

VIEWS

191

7 AUTHORS, INCLUDING:



**Florian Thevenon**

39 PUBLICATIONS 440 CITATIONS

SEE PROFILE



**Maurice Taieb**

Centre Européen de Recherche et d'Enseig...

47 PUBLICATIONS 1,056 CITATIONS

SEE PROFILE



**N. Thouveny**

Aix-Marseille Université

101 PUBLICATIONS 1,566 CITATIONS

SEE PROFILE



ELSEVIER

Palaeogeography, Palaeoclimatology, Palaeoecology 198 (2003) 321–334

**PALAEO**

[www.elsevier.com/locate/palaeo](http://www.elsevier.com/locate/palaeo)

# Pollen-based vegetation changes in southern Tanzania during the last 4200 years: climate change and/or human impact

Annie Vincens\*, David Williamson, Florian Thevenon, Maurice Taieb, Guillaume Buchet, Michel Decobert, Nicolas Thouveny

CEREGE UMR 6635, BP 80, 13545 Aix-en-Provence Cedex 04, France

Received 17 January 2002; accepted 13 May 2003

## Abstract

The age-constrained pollen data of a sedimentary sequence from the crater Lake Masoko, southern Tanzania (9°20'S, 33°45'E, 770 m), display a continuous record of vegetation for the past 4200 years. This record provides evidence that wetter Zambezi woodlands always occupied this area during the late Holocene, reaching a maximum extent between 2800 and 1650 cal yr BP related to increase in summer monsoon intensity. However, three main episodes of decline have been detected, between 3450 and 2800 cal yr BP, between 1650 and 1450 cal yr BP and from 1200 to 500 cal yr BP, for which a climatic interpretation, decrease in the summer monsoon strength, was preferentially advanced. The first is synchronous with lowstand of many tropical African lakes and, so, mainly induced by increased aridity. In contrast, the abrupt change in the pollen record at 1650–1550 cal yr BP is marked by a large extension of grasslands at the expense of arboreal cover, further by an increase in *Ricinus communis* and an intensification of burning. It could thus indicate local clearance of vegetation by man. However, at the same time, the decline of montane forest suggests the impact of a more regional change. During the last episode, between 1200 and 500 cal yr BP, dry climatic conditions are inferred from a combination of pollen, diatom and magnetic proxies, although the occurrence of Late Iron Age settlements in the region means that local human interference cannot be excluded. This study illustrates the difficulties in deciphering ecological and anthropological changes from pollen data in African tropical regions.

© 2003 Elsevier B.V. All rights reserved.

**Keywords:** pollen; late Holocene; southern Tanzania; Zambezi woodland; climate change; human activity

## 1. Introduction

The Zambezi regional centre of endemism (White, 1983) is, after the Sahara, the largest phy-

togeographical region of Africa. Extending from the Atlantic Ocean almost to the Indian Ocean and from 3° to 26°S (Fig. 1), it has probably the richest and most diversified flora and shows the widest range of vegetation types (Lawton, 1978; Malaisse, 1978; Werger and Coetzee, 1978; Campbell, 1996).

In contrast with most other African phytogeographical regions, very few palynological investi-

\* Corresponding author. Tel.: +33-4-42971588; Fax: +33-4-42971595.

E-mail address: [vincens@cerge.fr](mailto:vincens@cerge.fr) (A. Vincens).

gations have been undertaken on vegetation history and inferred climate and/or human impact during the late Quaternary. Some literature is available but the studied sequences are generally not well dated and/or discontinuous, making their interpretation difficult and tentative (Lawton, 1959, 1963; Van Zinderen Bakker and Clark, 1962; Van Zinderen Bakker, 1969; Livingstone, 1971; Tomlinson, 1973, 1974; Roche, 1975; M'Benza-Muaka and Roche, 1980; M'Benza-Muaka et al., 1984; Meadows, 1984a,b). Based on the lack of significant changes in their pollen diagrams, some authors have suggested that vegetation in south central Africa was less sensitive to environmental changes than that from other regions of intertropical Africa, even during the Last Glacial Maximum and the glacial/interglacial transition (Livingstone, 1971; Meadows, 1984a,b). The most recent and detailed studies in this part of Africa (Lake Tanganyika: Vincens, 1989, 1991, 1993; Vincens et al., 1993; Lake Malawi: De-Busk, 1998) now clearly demonstrate that Zambesian woodlands have been widely affected by late Quaternary climatic changes.

In 1994, in the framework of the EEC Rukwa project, several 3-m-long cores were collected in Lake Masoko, a small maar lake from the Rungwe volcanic province in the Mbeya region (southern Tanzania), using a compressed-air Mackereth corer (Mackereth, 1969, 1979). This paper focuses on the pollen analysis from one of these cores, core MM8, which provides a detailed chronology for the last 4200 years. We present here the first high resolution and well-dated pollen record today obtained in central East Africa for the late Holocene period, a record revealing important local and regional vegetation changes for which we will try to define the part of climate and/or human impact. Comparisons with data obtained on the same core or on other sites will be made to complete and support our interpretations.

## 2. Environmental setting

Lake Masoko, south Tanzania (9°20'S, 33°45'E, 770 m above sea level, maximum depth

39 m) is a volcanic crater lake located south of Mount Rungwe (2961 m altitude) and north of Lake Malawi, along the NW–SE relay zone which connects the Tanganyika, Rukwa and Malawi rift basins (e.g. Delvaux et al., 1998) (Fig. 1). According to  $^{39}\text{Ar}$ – $^{40}\text{Ar}$  datings of outcropping basalts from the crater rim and the radiocarbon chronology of a nearby long core (M96-A), the lake was formed between 40 000 and 50 000 years ago (Taieb, unpublished data; Williamson et al., 1999; Gibert et al., 2002). As for all volcanic crater lakes, its catchment area is small (0.57 km<sup>2</sup>) compared to the lacustrine area (0.38 km<sup>2</sup>) (Fig. 2). The lake has no surficial outlet, but is connected to a regional groundwater body which modulates high-amplitude changes in lake level at a seasonal/interannual scale (Bergonzini et al., 2001).

Lake Masoko lies within Walter's tropical summer rainfall zone (Walter and Lieth, 1960–1967; Nicholson et al., 1988). There is a single, well-defined, rainy season from November to June (months with rainfall  $\geq 50$  mm). The average annual precipitation measured at the nearest meteorological stations of Tukuyu at the northwest and Kyela at the southeast is about 2500 and 2300 mm respectively. Such high rainfall is linked to the presence of the large Lake Malawi to the south, and to a series of high ranges to the north and the east (Rungwe and Mbeya Mountains, Kipengere Range; Fig. 1). Mean monthly temperature is c. 25°C with an annual range of 4°C.

Lake Masoko and the adjacent areas are located within the vegetation zone classified by White (1983) as 'wetter Zambesian miombo woodlands' dominated by Caesalpiniaceae, mainly *Brachystegia* associated with *Isoberlinia* and *Julbernardia*. Locally, several other arboreal components occur scattered in these woodlands such as Dipterocarpaceae, Proteaceae and Euphorbiaceae (*Uapaca* dominant) (Werger and Coetzee, 1978; Frost, 1996). At the scale of the Lake Masoko catchment, most of the area (70%) is covered by relatively dense *Brachystegia/Uapaca* woodland and the remaining part, summit of the rim and southern depression of the crater, is occupied by crops. But no detailed floristic inven-

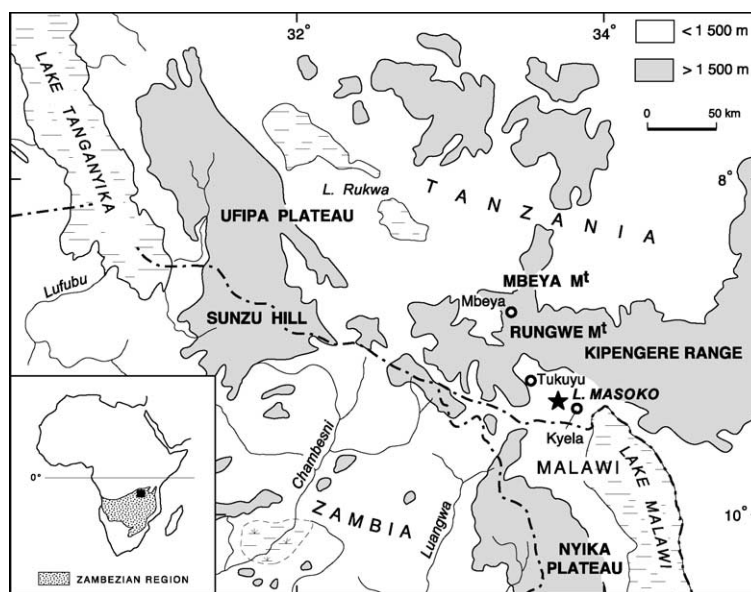


Fig. 1. Location map of Lake Masoko in southern Tanzania.

ories are available for the moment (Schäfer, in progress).

On the surrounding highlands up to 1500 m altitude (Fig. 1), Afromontane formations ranging from montane evergreen forests to montane grasslands are present. They have been partially described by Kerfoot (1964), Lind and Morrison (1974) and Cribb and Leedal (1982).

Throughout the southern Tanzanian region, large areas have been recently altered by man. Lowland woodlands and montane forests are diminishing year by year as the trees are felled for their timber, for charcoal or for cultivation. Most of the remaining natural vegetation is found in government forest reserves and in locally protected areas (McKone and Walzem, 1994).

### 3. Material and methods

Core MM8 (2.8 m length) was collected from the central part of the lake in 38 m water depth (Fig. 2). The cored sediments mostly consist of homogeneous, organic-rich silty muds, with interbedded ash layers between 85 and 110 cm. Multi-disciplinary studies have been carried out on this

core (magnetism, diatoms, pigments, phenols, charcoal) and some proxies have been recently published (Merdaci, 1998; Williamson et al., 1999; Barker et al., 2000; Thevenon et al., 2003). The chronology of core MM8 has been established from six accelerator mass spectrometry radiocarbon datings of total organic matter (TOM), wood fragments or microcharcoal (Gibert et al., 2002). The calibration of radiocarbon dates into calendar ages has been made by using the CALIB 3.0 software (Stuiver and Reimer, 1993) (Table 1).

Forty samples taken every 2–6 cm from the core were selected and analysed for pollen content, excluding the tephra layers. They were chemically treated following the classical method of Faegri and Iversen (1975): dissolution of the carbonates and silicate with diluted HCl (10%) and cold HF (70%), respectively; removal of colloidal silica with warm diluted HCl, and destruction of humic acids by dilution in KOH (10%) solution. The obtained residue is diluted in glycerol. For each sample, at least 400 pollen grains and spores were counted. The identifications were based on the reference collection of some 7000 specimens at CEREGE, Aix-en-Provence, and on specialised publications relevant to East Afri-

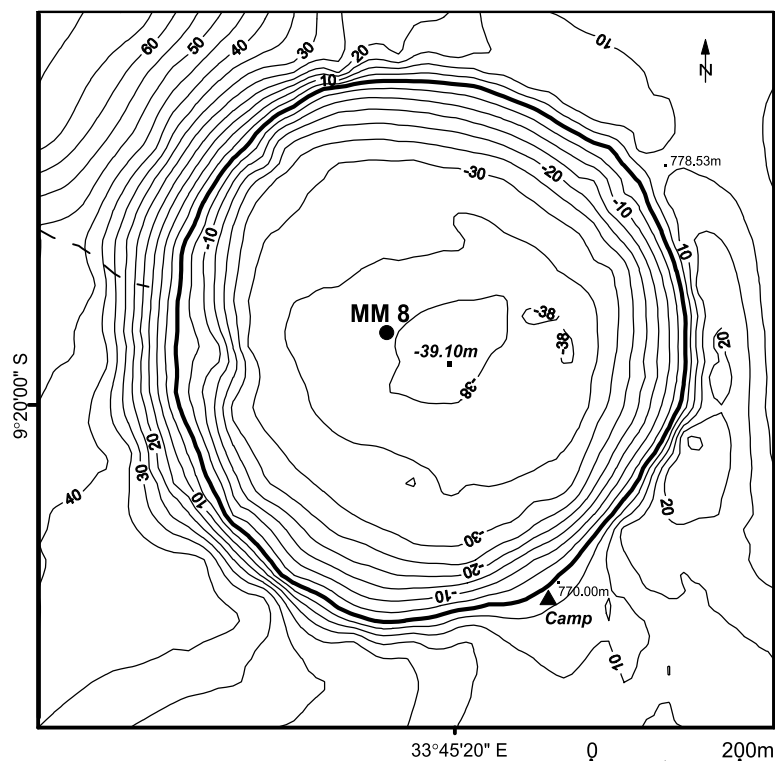


Fig. 2. Bathymetry of Lake Masoko and location of the core MM8 (contours are local altitude with 0 = present shoreline).

can pollen morphology (e.g. [Bonnefille, 1971a,b](#); [Bonnefille and Rioulet, 1980](#)).

#### 4. Results

The results are shown in pollen diagrams ([Figs. 3 and 4](#)) which were drawn using the GPAL3

program ([Goeury, 1988](#)). The vertical scale represents the depth of the samples along core MM8. The horizontal one indicates the relative percentages of the main pollen taxa which are considered to be the most important in the interpretation of the palaeoenvironment of Lake Masoko ([Fig. 3](#)) or groups of taxa classified in relation to the physiognomy of the producing plants

Table 1  
Radiocarbon dates on sediment from core MM8

Depth (cm)	Type	Code (Orsay)	$^{14}\text{C}$ age (yr BP)	Calibrated age (cal yr BP)
2.0	TOM	H1832	270 ± 50	300 (−25/+35)
19.0	TOM	H1836	400 ± 50	475 (−30/+145)
42.0	TOM	H1655	965 ± 70	920 (−10/+100)
143.0	Charcoal	H992	1610 ± 60	1520 (−300/+120)
228.0	Wood	H1172	2940 ± 70	3070 (−140/+110)
258.0	Wood	H1173	3750 ± 70	4090 (−140/+105)

Calendar ages are calibrated using the program CALIB 3.0 ([Stuiver and Reimer, 1993](#))  
Errors represent one standard deviation.

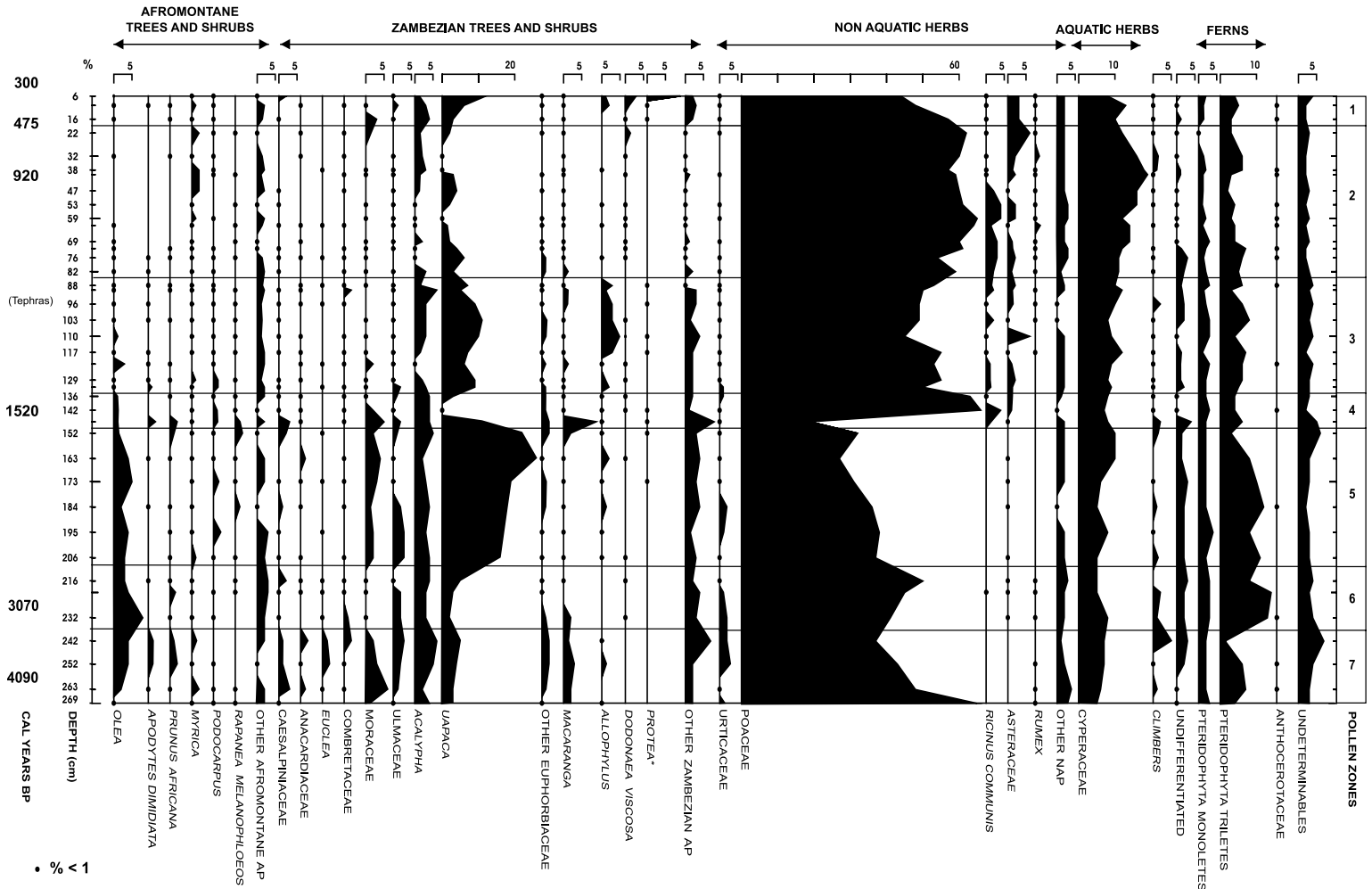


Fig. 3. The MM8 pollen diagram from Lake Masoko (southern Tanzania) showing relative percentages of selected taxa (the pollen sum includes all identified pollen and spore taxa, excluding indeterminate grains).

Table 2

List of identified pollen taxa in core MM8 from Lake Masoko, southern Tanzania

ACANTHACEAE	<i>Acanthus</i> -type [3] <i>Hypoestes</i> -type [3] <i>Isoglossa</i> [3] <i>Justicia</i> -type <i>flava</i> [3] <i>Justicia striata</i> -type [3] <i>Lepidagathis</i> [3] <i>Mimulopsis</i> -type [3] <i>Thunbergia</i> [3]
AMARANTHACEAE	<i>Achyranthes</i> -type <i>aspera</i> [3] <i>Aerva</i> -type <i>javanica</i> [3] <i>Alternanthera</i> [3] <i>Celosia</i> -type <i>trigyna</i> [3] <i>Digera</i> -type <i>muricata</i> [3] <i>Psilotrichum</i> -type <i>elliottii</i> [3] <i>Sericostachys</i> -type <i>scandens</i> [3]
ANACARDIACEAE	Anacardiaceae undiff. [2] <i>Lannea</i> -type [2] <i>Rhus</i> -type [2]
APIACEAE	Apiaceae undiff. [5] <i>Hydrocotyle</i> [4] <i>Steganotaenia</i> -type [5]
AQUIFOLIACEAE	<i>Ilex mitis</i> [1]
ARALIACEAE	<i>Cussonia</i> [1] <i>Polyscias fulva</i> -type [1] <i>Schefflera abyssinica</i> -type [1]
ASCLEPIADACEAE	<i>Tacazzea</i> -type [5]
ASPARAGACEAE	<i>Asparagus buchananii</i> -type [3]
ASTERACEAE	<i>Artemisia</i> [3] <b>Asteraceae undiff.</b> [3] <i>Crassocephalum</i> -type <i>montuosum</i> [3] Lactuceae undiff. [3] <i>Stoebe kilimandscharica</i> -type [1] Vernonieae undiff. [3]
BALSAMINACEAE	<i>Impatiens</i> [3]
BEGONIACEAE	<i>Begonia</i> [3]
BORAGINACEAE	<i>Cordia africana</i> -type [2] <i>Ehretia</i> [2] <i>Heliotropium steudneri</i> -type [3]
BRASSICACEAE	Brassicaceae undiff. [3]
BURSERACEAE	<i>Commiphora edulis</i> -type [2]
CAESALPINIACEAE	<i>Brachystegia</i> [2] <i>Cassia</i> -type <i>didymobotrya</i> [5] <i>Cassia</i> -type <i>italica</i> [5] <i>Isobertlinia</i> -type [2] <i>Julbernardia</i> -type <i>paniculata</i> [2]
CAMPANULACEAE	<i>Campanula</i> -type [3]
CAPPARIDACEAE	<i>Capparis fascicularis</i> -type [2] <i>Maerua</i> -type [2]
CELASTRACEAE/HIPPOCRATEACEAE	Celastraceae/Hippocrateaceae [2]
CHENOPODIACEAE	Chenopodiaceae undiff. [3]
CHRYSOBALANACEAE	<i>Parinari</i> -type [2]
COMBRETACEAE	Combretaceae undiff. [2]

Table 2 (Continued).

COMMELINACEAE	<i>Commelina</i> -type <i>benghalensis</i> [3]
CONVOLVULACEAE	<i>Evolvulus</i> -type [3]
CORNACEAE	<i>Afrocrania volkensii</i> [1]
CUPRESSACEAE	<i>Juniperus procera</i> [1]
CYPERACEAE	<i>Ascolepis</i> [4] Cyperaceae undiff. [4]
DIPTEROCARPACEAE	Dipterocarpaceae undiff. [2]
DRACAENACEAE	<i>Dracaena afromontana</i> -type [2]
EBENACEAE	<i>Diospyros</i> [2] <b><i>Euclea</i></b> [2] Ericaceae undiff. [1]
ERICACEAE	Ericaceae undiff. [1]
EUPHORBIACEAE	<b><i>Acalypha</i></b> [2] <i>Alchornea</i> [2] <i>Antidesma</i> -type [2] <i>Bridelia micrantha</i> -type [2] <i>Cleistanthus</i> -type <i>polystachyus</i> [2] <i>Clutia</i> [2] <i>Croton</i> -type [2] <i>Erythrococca</i> -type [2] <i>Euphorbia</i> -type <i>hirta</i> [3] <i>Flueggea</i> -type <i>virosa</i> [2] <b><i>Macaranga</i></b> [2] <i>Margaritaria</i> -type <i>discoidea</i> [2] <i>Neoboutonia</i> -type [2] <i>Phyllanthus</i> -type <i>fraternus</i> [5] <i>Phyllanthus muellerianus</i> -type [5] <i>Phyllanthus</i> -type <i>rivae</i> [5] <b><i>Ricinus communis</i></b> [3] <i>Shirakia</i> -type <i>elliptica</i> [1] <i>Tetrorchidium</i> [2] <b><i>Uapaca kirkiana</i></b> -type [2] <b><i>Uapaca nitida</i></b> -type [2] Fabaceae undiff. [5] <i>Aeschynomene</i> -type <i>baumii</i> [3] Fabaceae undiff. [5] <i>Indigofera</i> -type [5] <i>Kotschyia</i> -type [3] <i>Vatovaea</i> -type <i>pseudolablab</i> [3]
FABACEAE	<i>Callitriche stagnalis</i> [4] <i>Gunnera perpensa</i> [3] <i>Hymenocardia acida</i> -type [2] <i>Hypericum</i> [5] <b><i>Apodytes dimidiata</i></b> [1] <i>Basilicum</i> -type <i>polystachyon</i> [3] <i>Hyptis</i> -type [3] Lamiaceae undiff. [3] <i>Leucas</i> -type [3] <i>Ocimum</i> -type <i>basilicum</i> [3] <i>Anthocleista</i> [2] <i>Nuxial/Ficalhoa</i> [2] <i>Tapinanthus</i> -type [5] Melastomataceae undiff. [5] <i>Entandrophragma</i> -type [2] <i>Cissampelos</i> -type <i>mucronata</i> [5] <i>Stephania</i> -type <i>abyssinica</i> [5]
HALORRHAGACEAE	
HYMENOCARDIACEAE	
HYPERICACEAE	
ICACINACEAE	
LAMIACEAE	
LOGANIACEAE	
LOGANIACEAE/THEACEAE	
LORANTHACEAE	
MELASTOMATACEAE	
MELIACEAE	
MENISPERMACEAE	

Table 2 (Continued).

MIMOSACEAE	<i>Acacia</i> group I [2] <i>Acacia</i> group III [2] <i>Entada</i> -type [5] <i>Mimosa pigra</i> -type [3]
MORACEAE	<i>Ficus</i> [2] <i>Milicia</i> -type <i>excelsa</i> [2] Moraceae undiff. [2] <i>Myrianthus</i> -type <i>holstii</i> [2] <i>Trilepisium</i> -type <i>madagascariensis</i> [2]
MYRICACEAE	<i>Myrica</i> [1]
MYRSINACEAE	<i>Maesa lanceolata</i> -type [2] <i>Myrsine africana</i> [2] <b><i>Rapanea melanophloeos</i></b> -type [1] <i>Syzygium</i> -type [2]
MYRTACEAE	<i>Nymphaea lotus</i> -type [4]
NYMPHAEACEAE	<i>Strombosia</i> -type <i>scheffleri</i> [2]
OLACACEAE	<i>Jasminum abyssinicum</i> -type [2]
OLEACEAE	<b><i>Olea capensis</i></b> [1] <b><i>Olea europaea</i></b> -type [1] <i>Borassus</i> -type <i>aethiopus</i> [2] <i>Phoenix reclinata</i> -type [2] <i>Sesamum</i> [3]
PALMAE	<i>Plantago africana</i> -type [3]
PEDALIACEAE	Poaceae undiff. [3]
PLANTAGINACEAE	<b><i>Podocarpus</i></b> [1]
POACEAE	<i>Polygonum senegalense</i> -type [4] <b><i>Rumex</i></b> [3]
PODOCARPACEAE	<i>Potamogeton thunbergii</i> -type [4]
POLYGONACEAE	<b><i>Protea</i></b> -type [2] <i>Clematis</i> -type [5] <i>Ranunculus oreophytus</i> -type [3]
POTAMOGETONACEAE	Resedaceae undiff. [2]
PROTEACEAE	Rhamnaceae undiff. [2]
RANUNCULACEAE	<i>Alchemilla</i> [3] <i>Hagenia abyssinica</i> [1] <b><i>Prunus africana</i></b> -type [1] <i>Rubus pinnatus</i> -type [1] <i>Anthospermum</i> [3] <i>Hymenodictyon</i> -type <i>floribundum</i> [2] <i>Keetia</i> -type <i>gueinzii</i> [2] <i>Kohautia</i> -type <i>caespitosa</i> [5] <i>Oligocodon</i> -type <i>cunliffeae</i> [2] <i>Rubia</i> -type [3] Rubiaceae undiff. [5] <i>Spermacoce</i> -type [3] <i>Uncaria</i> -type <i>africana</i> [5]
RESEDACEAE	<i>Teclea</i> -type [2] <i>Toddalia</i> -type <i>asiatica</i> [2] <i>Zanthoxylum</i> -type <i>usambarensis</i> [2]
RHAMNACEAE	
ROSACEAE	
RUBIACEAE	
RUTACEAE	
SAPINDACEAE	<b><i>Allophylus</i></b> [2] <i>Aphania</i> -type <i>senegalensis</i> [2] <i>Cardiospermum halicacabum</i> -type [5]

Table 2 (Continued).

	<b><i>Dodonaea viscosa</i></b> [2] Sapindaceae undiff. [2] <i>Zanha golungensis</i> -type [2]
SAPOTACEAE	Sapotaceae undiff. [2]
SOLANACEAE	<i>Solanum</i> -type [3]
STERCULIACEAE	<i>Dombeya</i> -type [2] <i>Sterculia</i> -type [2] <i>Gnidia</i> -type <i>chrysantha</i> [5]
THYMELAEACEAE	Tiliaceae undiff. [5]
TILIACEAE	<i>Tribulus</i> [3]
TRIBULACEAE	<i>Typha</i> [4]
TYPHACEAE	<i>Celtis</i> [2] <i>Trema-type orientalis</i> [2]
ULMACEAE	Urticaceae undiff. [3]
URTICACEAE	Verbenaceae undiff. [5]
VERBENACEAE	<i>Cyphostemma</i> -type [5]
VITACEAE	<b><i>Monoletes undiff.</i></b>
PTERIDOPHYTA	<b><i>Triletes undiff.</i></b>
ANTHOCEROTACEAE	<b><i>Anthocerotaceae undiff.</i></b>

Taxa in bold are shown in the pollen diagram of Fig. 3. [1], Afromontane trees and shrubs; [2], Zambezi trees and shrubs; [3], herbs; [4], aquatics; [5], climbers or undifferentiated taxa.

(AP: arboreal pollen; NAP: non-arboreal pollen) and, for the AP, to their phytogeographical affinities (Afromontane or Zambezi) (Fig. 4). Considering that any taxon is over-represented throughout the lacustrine MM8 pollen record, for the calculation of the percentages only indeterminate grains have been excluded from the pollen sum.

Pollen preservation is good in all the samples and the microflora is rich and well diversified, with a total of 179 taxa identified (Table 2). Seven main zones, clearly reflecting seven steps in the development of Lake Masoko area vegetation during the last 4200 years, have been distinguished. The boundaries between these zones were established on the basis of significant changes in the proportion of the major taxa. From the bottom to the top of the sequence, they are:

*Pollen zone 7 (269–237 cm; 4200–3450 cal yr BP)*

This zone is characterised by an increase of Zambezi AP, mainly represented by *Acalypha*, Moraceae, *Uapaca* (*Uapaca nitida*-type), Ulmaceae (*Celtis*), *Macaranga*, associated with some Caesalpiniaceae (*Brachystegia*, *Isoberlinia*-type), Anacardiaceae and *Euclea*. At the same time, a



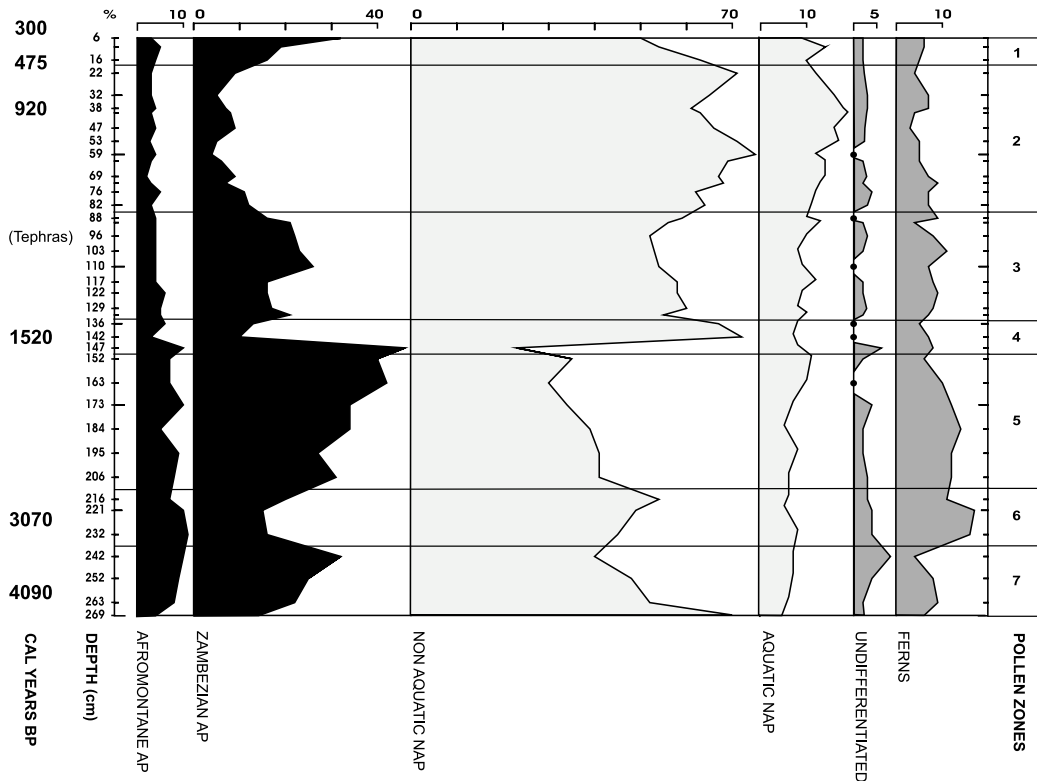


Fig. 4. The MM8 synthetic pollen diagram from Lake Masoko (southern Tanzania), showing the main groups of taxa lumped according to the physiognomy or the ecology of the producing plants (the pollen sum includes all identified pollen and spore taxa, excluding indeterminable grains).

decrease of herbaceous taxa (NAP, mostly Poaceae) is registered. Urticaceae are present in significant percentages. In the regional vegetation, *Olea* (mainly *Olea capensis*-type) is the dominant element of the Afromontane formations associated with some *Apodytes dimidiata*, *Prunus africana* and *Myrica*.

*Pollen zone 6 (237–211 cm; 3450–2800 cal yr BP)*

During the deposition of this sediment, a slight decrease in local Zambezan AP affecting all the taxa except *Acalypha* is observed. It is contemporaneous with an increase in Poaceae and ferns (trilete-type).

*Pollen zone 5 (211–150 cm; 2800–1650 cal yr BP)*

This zone shows an increase of Zambezan arboreal taxa, dominated by *Uapaca* (mainly *Uapaca nitida*-type), at the expense of the grass pollen. Also significant percentages of the Moraceae, Ulmaceae and *Acalypha*, and of *Olea*, an Afromon-

tane element, are registered. Ferns (trilete-type) are always abundant.

*Pollen zone 4 (150–132 cm; 1650–1450 cal yr BP)*

A marked change is observed in this zone. After a peak of *Macaranga*, a decrease in local (*Uapaca*) and regional AP is registered, synchronous with a sharp increase in Poaceae. For the first time in the sequence, Asteraceae and *Ricinus communis* are present in significant percentages.

*Pollen zone 3 (132–85 cm; 1450–1200 cal yr BP)*

In this zone, a further increase in Zambezan AP is observed, but it is not as pronounced as in zone 5. The main taxon is still *Uapaca* (mainly *Uapaca nitida*-type), associated with *Acalypha*, and for the first time in regular and significant percentages, *Allophylus*. In the regional environment, *Olea* progressively declines, as do the other main Afromontane elements.

*Pollen zone 2 (85–19 cm; 1200–500 cal yr BP)*

The minimum frequencies of Zambezi AP are recorded in this zone. Poaceae associated with Asteraceae and *Ricinus communis*, reach high percentages. Among aquatic taxa, Cyperaceae show their highest representation in the sequence.

*Pollen zone 1 (19–6 cm; 500–300 cal yr BP)*

This most recent zone is characterised by a renewed increase in Zambezi arboreal taxa such as *Uapaca*, *Acalypha*, Moraceae, *Allophylus*, *Dodonaea viscosa*, and, for the first time with more than 1%, *Protea*-type. Poaceae pollen decreases.

## 5. Interpretation and discussion

Throughout the Masoko pollen record, the dominance of Zambezi arboreal components associated with abundant Poaceae is striking. This is indicative of the permanence of wetter miombo woodlands in the basin of the lake and in its close neighbourhood during the last 4200 cal yr BP. On the surrounding hills and highlands, Afromontane forests with *Olea* (mainly *Olea capensis*) as a dominant element were present until 1650 cal yr BP. The low frequencies of *Podocarpus*, a tree that produces much well-dispersed pollen (Hamilton, 1972), indicate that it is unlikely that this montane element was abundantly present nearby.

However, during the last four millennia, the pollen sequence registered fluctuations in the representation of arboreal taxa versus non-arboreal ones and in the composition of the microflora, indicative of changes affecting both the physiognomy (density of the canopy cover versus herbaceous layer) and the floristic composition of the local Zambezi woodlands. Following an expansion of the arboreal canopy between 4200 and 1650 cal yr BP (pollen zones 7–5), with a high representation of *Uapaca* from 2800 to 1650 cal yr BP (pollen zone 5), interrupted by a slight episode of regression between 3450 and 2800 cal yr BP (pollen zone 6), a first major replacement of dense Zambezi woodlands by a more open vegetation is registered between 1650 and 1450 cal yr BP (pollen zone 4). First, *Macaranga* became more abundant, then the grass cover increased at the expense of trees. This change took place

in less than 200 years, affecting particularly *Uapaca* (mainly *Uapaca nitida*-type). At the same time, on the surrounding highlands, montane forests, dominated by *Olea*, decline. Then, a new expansion of woodlands with *Uapaca* and *Allophylus* as dominant components is observed between 1450 and 1200 cal yr BP (pollen zone 3), but less important than during pollen zone 5. A final episode of opening of the local arboreal cover associated with a large increase of the grass layer and of swampy formations is registered between 1200 and 500 cal yr BP (pollen zone 2) followed, from 500 to 300 cal yr BP, by a slight new development of trees, mainly *Uapaca* and *Protea*-type.

In south tropical East Africa, late Holocene forest and woodland changes have been registered in numerous pollen records (e.g. Hamilton, 1982; Vincens, 1989, 1993; Bonnefille et al., 1991; Jolly et al., 1997; DeBusk, 1998; Marchant and Taylor, 1998; Taylor et al., 1999). However, the timing of these changes appears to be asynchronous from site to site, and their interpretation, mainly concerning declines, in terms of ecological change and/or human interference is not clear (e.g. Hamilton et al., 1986; Perrott, 1987). For our pollen sequence, these two hypotheses are assessed independently, and discussed in the light of other data from the same core and/or more regionally from tropical Africa.

On the African continent, the main ecological factor influencing vegetation during the late Holocene is climate, and especially rainfall (total annual amount and seasonal distribution). Today, in southern Tanzania, the precipitation is strongly controlled by the intensity of the southeast summer monsoon, the pluviometric regime being driven by the yearly oscillation of the Intertropical Convergence Zone (Nicholson, 1996). The vegetational changes registered in the Masoko pollen record during the last 4200 years seem likely to strongly depend on the monsoon intensity, since the permanence of typical deciduous woodlands indicates that climate was always seasonal. Our pollen data show that the Masoko catchment and adjacent areas were dominated by dense Zambezi woodlands between c. 4200 and 1650 cal yr BP, with a large extension be-

tween 2800 and 1650 cal yr BP, indicating that summer monsoon strength probably reached its late Holocene maximum at this time. A first opening of these woodlands between 3450 and 2800 cal yr BP, synchronous with a short expansion of *Olea* on the surrounding highlands, suggests a first slight decrease in monsoon strength, probably associated with a slight cooling. A new opening of the woodlands is registered between 1650 and 1450 cal yr BP, which could indicate a second episode of decrease in monsoon intensity, followed, from 1650 to 1200 cal yr BP, by a new increasing phase as indicated by a new extension of the canopy cover. But the greatest reduction of the canopy cover occurs in the pollen sequence between 1200 and 500 cal yr BP, synchronously with an extension of herbaceous swampy formations which likely colonised the borders of the lake during a lowstand. Such a large degradation of the woodlands would indicate that monsoon strength was probably reduced to its late Holocene minimum during this period. Between 500 and 300 cal yr BP, a last new expansion of the tree cover could be indicative of a recent increase in annual rainfall.

However, some changes in the environment of Lake Masoko, mainly opening episodes, may also be associated with human activities. In central East Africa, the late Holocene human-induced clearance of mainly forested areas from interlacustrine highlands of Burundi, Rwanda and Uganda was locally correlated with political-economic changes, such as the entry of Bantu-speaking people and the onset of the Early Iron Age some 2300 years ago (Jolly et al., 1997; Taylor et al., 1999). The beginning of clearance was site-specific, related to local topography and soils depending on their suitability to human practices. But the most severe level of tree cover degradation seems to be associated with the beginning of the Late Iron Age, some 1500 years ago (Marchant and Taylor, 1998). Anthropogenic clearance of lower montane forest and woodland during the late Holocene has been related to multiple purposes: agriculture, pastoralism and hunting, these three practices being generally associated with burning, ore smelting or timber, or more locally for medicinal values and dye production

(Kikula, 1986; Ngulube et al., 1995; Clark et al., 1996; Chidumayo, 1999).

In the Masoko pollen record, only the presence of *Ricinus communis* pollen in significant frequencies from 1550 cal yr BP onwards, associated with an increase of Asteraceae, can be considered a marker supportive of a local opening of the woodland canopy. Therefore, it may indicate human disturbance of the vegetation for agricultural and/or pastoral activities. Unfortunately, as is the case all over East Africa, most indigenous crop plants do not leave identifiable traces in the pollen records (e.g. cereals), so direct palynological evidence of early agriculture is limited. But taking into consideration the morphology of the Lake Masoko catchment, with abrupt slopes ( $> 30^\circ$ ; Fig. 2), the prevalence of poor soils, few available timber trees and the presence of the tsetse fly making this region poorly productive and attractive for early dense settlements during the late Holocene (Pratt and Gwynne, 1977; Lawton, 1982; Chidumayo, 1999), agricultural practices seem unlikely and this interpretation must be viewed here with caution. According to the Wanyakyusa local tribe memory, the summit of the crater rim and adjacent areas of Lake Masoko were locally cleared then cropped, mainly with exotic plants such as bananas, sweet potatoes, manioc, coffee, in the very recent past, the last century, under the German occupation (L. Mwanjakeli, personal communication). Moreover, the fringing part of the lake actually supports some oil palms, but their cultivation is also probably recent, no pollen of *Elaeis guineensis* being found at the top of the core dated 300 cal yr BP. Local pastoralism may, however, have occurred, and this activity cannot be excluded during the last two millennia.

Changes affecting the physiognomy and the floristic composition of the local woodlands can also have been affected by fire. Although most fires from the Miombo area are anthropogenic, their occurrence is strongly controlled by climate through the mean annual rainfall and the length of the dry season (Frost, 1996). Charcoal countings of core MM8 indicate a sudden increase in fine, elongated charcoal concentration at 1750 cal yr BP, pointing to a change in the fire regime and

intensity at this time (Thevenon et al., 2003). This change takes place c. 200 years before the major physiognomic vegetation change in our pollen record at 1550 cal yr BP, and c. 100 years before the major change in the floristic composition of the local woodland at c. 1650 cal yr BP. At that time, *Uapaca* abruptly decreased in abundance and was partly replaced by *Macaranga*, a pioneer tree on bare soils, sometimes locally abundant after burning and a marker of vegetation opening (Jolly and Bonnefille, 1992).

Like many previous works carried out in central East Africa, this pollen study illustrates the difficulties of directly concluding whether the perturbations affecting the vegetation in the Masoko catchment and adjacent areas during the late Holocene are natural or linked to human impact. However, some more precise indications can be inferred by comparison with other data obtained on the same MM8 core and/or more regionally in tropical Africa.

Synchronously with the first episode of woodland decline detected between 3450 and 2800 cal yr BP, a major change in intertropical African vegetation communities has been registered in most pollen sites (e.g. Lake Victoria: Kendall, 1969; Lake Tanganyika: Vincens, 1993; Lake Albert: Ssemmanda and Vincens, 1993; central African interlacustrine highlands: Jolly et al., 1997; Lake Malawi: DeBusk, 1998; central Atlantic Africa: Vincens et al., 1999). It seems clear today that this change, in so far as at the same time many lakes reduced in level or dried up completely, is linked to increased aridity (e.g. Lake Naivasha: Richardson and Richardson, 1972; Lake Manyara: Holdship, 1976; Lake Bogoria: Tiercelin and Vincens, 1987; Lake Cheshi: Stager, 1988; Lake Tanganyika: Casanova and Hillaire-Marcel, 1992; Lake Sinnda: Vincens et al., 1998). This evidence supports the exclusion of human interference as a primary reason explaining why woodlands opened around Lake Masoko during this episode.

In contrast, the interpretation of the woodland opening at 1650–1550 cal yr BP is less clear considering that the record of *Ricinus communis* pollen can be interpreted as a local signal of human practices associated with intensification of burn-

ing as shown by charcoal analyses (Thevenon et al., 2003). Nevertheless, a synchronous decline of montane forests on the highlands suggests a much more regional event, drier conditions and/or increase in seasonality, rather than a primarily anthropogenic one. It seems difficult to imagine that, at this time, southern Tanzanian human populations were sufficiently large and dense to have had an impact at such a geographical scale. In addition, the morphology of the lake catchment, the gradual change in erosion proxies and the associated decrease in surface soil components (Williamson et al., 1999) are not consistent with an abrupt onset of agriculture in the basin at 1650 cal yr BP.

Concerning the third episode of woodland decline dated between 1200 and 500 cal yr BP, the climatic deterioration evidenced by pollen toward dry conditions is consistent with previous rock-magnetic and diatom assemblages studies, respectively suggesting reduced runoff (Williamson et al., 1999) and regression in water level (Barker et al., 2000) between 1500 and 350 cal yr BP. For this last episode, a deterioration of climate seems also to be the main driving factor for the opening of woodlands. However, a hypothesis of anthropogenic influences cannot be completely excluded, as evidenced by the presence of Late Iron Age settlements in the northern part of Lake Malawi since at least 1200 yr BP (Mapunda and Burg, 1991). However, the impact was probably local and not significant enough, or too selective, to lead to a vegetational change such as the one recorded at Masoko.

In conclusion, a climatic interpretation is preferentially advanced to explain the vegetational changes registered in the Masoko pollen sequence, mainly fluctuations in the southeast summer monsoon strength. Meanwhile, it is possible that the most likely explanation could be a combination of climatic and anthropogenic factors, although climate can be considered to have exerted the major control in the development of human activities, as observed elsewhere in Africa (e.g. Schwartz, 1992; Kershaw et al., 1997). So, it remains clear that more late Holocene high-resolution pollen and charcoal sequences, associated with numerous archaeological investigations, are still needed to im-

prove our knowledge of human/climate impacts on the history of southern Tanzanian vegetation, a region where very few palaeoenvironmental data are today available.

### Acknowledgements

This work was supported by the European Community through the EEC Program Rukwa, the INSU-Variante and Eclipse (CLEHA) programs. After publication, the pollen data will be stored in the African Pollen Database (APD) managed by the INCO CEE project and the UNESCO PICG 431, and in the CLEHA Multi-proxy-Database managed by the INSU-Eclipse and RESOLVE programs. Thanks to H. Hooghiemstra and M. Meadows who made helpful comments and language revision in reviewing the manuscript.

### References

- Barker, P., Telford, R., Merdaci, O., Williamson, D., Taieb, M., Vincens, A., Gibert, E., 2000. The sensitivity of a Tanzanian crater lake to catastrophic tephra input and four millennia of climate change. *Holocene* 10, 303–310.
- Bergonzini, L., Gibert, E., Winckel, A., Merdaci, O., 2001. Bilans hydrologique et isotopique ( $^{18}\text{O}$  et  $^2\text{H}$ ) du lac Massoko, Tanzanie. Quantification des échanges lac-eaux souterraines. *C.R. Acad. Sci. Paris* 333, 617–623.
- Bonnefille, R., 1971a. Atlas des pollens d’Ethiopie. Principales espèces des forêts de montagne. *Pollen Spores* 13, 15–72.
- Bonnefille, R., 1971b. Atlas des pollens d’Ethiopie: pollens actuels de la basse vallée de l’Omo (Ethiopie). *Récoltes botaniques* 1968. *Adansonia* 2 (11/3), 463–518.
- Bonnefille, R., Riollet, G., 1980. Pollens des savanes d’Afrique orientale. CNRS, Paris, 140 pp.
- Bonnefille, R., Riollet, G., Buchet, G., 1991. Nouvelle séquence pollinique d’une tourbière de la crête Zaire-Nil (Burundi). *Rev. Palaeobot. Palynol.* 67, 315–330.
- Campbell, B., 1996. The Miombo in Transition: Woodlands and Welfare in Africa. CIFOR, Indonesia, 266 pp.
- Casanova, J., Hillaire-Marcel, C., 1992. Late Holocene hydrological history of Lake Tanganyika, East Africa, from isotopic data on fossil stromatolites. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 91, 35–48.
- Chidumayo, E., 1999. Using natural and fertilizers in Miombo woodlands. *Afr. Biodivers.* 2.
- Clark, J., Cavendish, W., Coote, C., 1996. Rural households and miombo woodlands: use, value and management. In: Campbell, B. (Ed.), *The Miombo in Transition: Woodlands and Welfare in Africa*. CIFOR, Indonesia, pp. 101–136.
- Cribb, P.J., Leedal, G.P., 1982. *The Mountain Flowers of Southern Tanzania*. Balkema, Rotterdam, 244 pp.
- DeBusk, G.H., 1998. A 37,500-year pollen record from Lake Malawi and implications for the biogeography of afro-montane forests. *J. Biogeogr.* 25, 479–500.
- Delvaux, D., Kervyn, F., Vittori, E., Kajara, R.S.A., Kilembe, E., 1998. Late Quaternary tectonic activity and lake level change in the Rukwa Rift basin. *J. Afr. Earth Sci.* 26, 397–421.
- Faegri, K., Iversen, J., 1975. *Textbook of Pollen Analysis*, 3rd edn. Blackwell, Oxford, 295 pp.
- Frost, P., 1996. The ecology of miombo woodlands. In: Campbell, B. (Ed.), *The Miombo in Transition: Woodlands and Welfare in Africa*. CIFOR, Indonesia, pp. 11–56.
- Gibert, E., Bergonzini, L., Massault, M., Williamson, D., 2002. AMS  $^{14}\text{C}$  chronology of 40.0 cal ka BP continuous deposits from a crater lake (Lake Massoko, Tanzania); Modern water balance and environmental implications. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 187, 307–322.
- Goery, C., 1988. Acquisition, gestion et représentation des données de l’analyse pollinique sur micro-ordinateur. *Inst. Fr. Pondichéry Trav. Sect. Sci. Techniques* 25, 405–416.
- Hamilton, A.C., 1972. The interpretation of pollen diagrams from Highland Uganda. In: *Palaeoecology of Africa and Surrounding Islands*, vol. 7. Balkema, Rotterdam, pp. 45–149.
- Hamilton, A.C., 1982. *Environmental History of East Africa. A Study of the Quaternary*. Academic Press, London, 328 pp.
- Hamilton, A.C., Taylor, D., Vogel, J.C., 1986. Early forest clearance and environmental degradation in south-west Uganda. *Nature* 320, 164–167.
- Holdship, S.A., 1976. *The Palaeolimnology of Lake Manyara, Tanzania: A Diatom Analysis of a 56 Meter Sediment Core*. Unpublished Thesis, Duke University, Durham, NC, 120 pp.
- Jolly, D., Bonnefille, R., 1992. Histoire et dynamique du marécage de Ndurumu (Burundi), données polliniques. *Rev. Palaeobot. Palynol.* 75, 133–151.
- Jolly, D., Taylor, D., Marchant, R., Hamilton, A., Bonnefille, R., Buchet, G., Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr B.P.: pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. *J. Biogeogr.* 24, 495–512.
- Kendall, R.L., 1969. An ecological history of the Lake Victoria Basin. *Ecol. Monogr.* 39, 121–176.
- Kerfoot, O., 1964. A preliminary account of the vegetation of the Mbeya Range, Tanganyika. *Kirkia* 4, 191–205.
- Kershaw, A.P., Bush, M.B., Hope, G.S., Weiss, K.F., Goldammer, J.G., Sanford, R., 1997. The contribution of humans to past biomass burning in the tropics. In: Clark, J.S. et al. (Eds.), *Sediment Records of Biomass Burning and Global Change*. NATO ASI Series, 151, Springer-Verlag, Berlin, pp. 413–442.

- Kikula, I.S., 1986. The influence of fire on the composition of Miombo woodland of SW Tanzania. *Oikos* 46, 317–324.
- Lawton, R.M., 1959. A pollen analysis of the Lake Bangweulu peat deposits. *North Rhod. J.* 4, 33–43.
- Lawton, R.M., 1963. Palaeoecological and ecological studies in the Northern Province of Northern Rhodesia. *Kirkia* 3, 46–77.
- Lawton, R.M., 1978. A study of the dynamic ecology of Zambian vegetation. *J. Ecol.* 66, 175–198.
- Lawton, R.M., 1982. Natural resources of miombo woodland and recent changes in agricultural and land-use practices. *For. Ecol. Manage.* 4, 287–297.
- Lind, E.M., Morrison, M.E.S., 1974. *East African Vegetation*. Longman, London, 257 pp.
- Livingstone, D.A., 1971. A 22,000 year old pollen record from the Plateau of Zambia. *Limnol. Oceanogr.* 16, 349–356.
- Mackereth, F.J.H., 1969. A short core sampler for subaqueous deposits. *Limnol. Oceanogr.* 14, 145–151.
- Mackereth, F.J.H., 1979. Modifications to the Mackereth corer. *Limnol. Oceanogr.* 24, 607–610.
- Malaisse, F., 1978. The Miombo ecosystem. In: *Tropical Forest Ecosystems. A state of Knowledge Report*. Natural Resources Research XIV, UNESCO, Paris, pp. 589–606.
- Mapunda, B., Burg, S., 1991. Preliminary report on archaeological reconnaissance along the Ruhuhu River Basin, southern Tanzania. *Nyame Akuma* 36, 32–40.
- Marchant, R., Taylor, D., 1998. Dynamics of montane forest in Central Africa during the late Holocene: a pollen-based record from western Uganda. *Holocene* 8, 375–381.
- M'Benza-Muaka, Roche, E., 1980. Exemple d'évolution paléoclimatique au Pléistocène terminal et à l'Holocène au Shaba (Zaire). *Mém. Mus. Natl. Hist. Nat. Paris, Sér. Bot.* 27, 137–148.
- M'Benza-Muaka, Roche, E., Doutrelepont, H., 1984. Note sur les apports de la palynologie et de l'étude des bois fossiles aux recherches géomorphologiques sur la vallée de la Lumpembashi. *Rev. Paléobiol. Genève, Vol. Spec.*, pp. 149–154.
- McKone, D., Walzem, V., 1994. A brief survey of Mbeya region catchment forest reserves. Government of Tanzania/EEC Agroforestry, Soil and Water Conservation Project/Regional Natural Resources Office, Mbeya.
- Meadows, M.E., 1984a. Past and present environments on the Nyika Plateau, Malawi. In: *Palaeoecology of Africa and Surrounding Islands*, vol. 16. Balkema, Rotterdam, pp. 353–390.
- Meadows, M.E., 1984b. Late Quaternary vegetation history of the Nyika Plateau, Malawi. *J. Biogeogr.* 11, 209–222.
- Merdaci, O., 1998. Changements climatiques au cours des derniers 30 000 ans en Afrique Sud-Equatoriale (Tanzanie) par l'étude des pigments et phénols lacustres. Unpublished Thesis, Univ. Aix-Marseille III, 208 pp.
- Ngulube, M.R., Hall, J.B., Maghembe, J.A., 1995. Ecology of a miombo fruit tree: *Uapaca kirkiana* (Euphorbiaceae). *For. Ecol. Manage.* 77, 107–117.
- Nicholson, S.E., 1996. A review of climate dynamics and climate variability in eastern Africa. In: Johnson, T., Odada, E.O. (Eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*. Gordon and Breach, Toronto, ON, pp. 25–56.
- Nicholson, S.E., Kim, J., Hoopingarner, J., 1988. *Atlas of African Rainfall and Its Interannual Variability*. Florida State University, Tallahassee, FL, 252 pp.
- Perrott, R.A., 1987. Early forest clearance and the environment in south-west Uganda. *Nature* 325, 89–90.
- Pratt, D.J., Gwynne, M.D., 1977. *Rangeland Management and Ecology in East Africa*. Hodder and Stoughton, London, 310 pp.
- Richardson, J.L., Richardson, A.E., 1972. History of an African Rift Lake and its climatic implications. *Ecol. Monogr.* 42, 499–534.
- Roche, E., 1975. Analyse palynologique du site archéologique de la Kamoia. *Ann. Mus. R. Afr. Cent., Sér.* 8, 84, 331–337.
- Schwartz, D., 1992. Assèchement climatique vers 3000 B.P. et expansion Bantu en Afrique centrale atlantique quelques réflexions. *Bull. Soc. Géol. Fr.* 163, 353–361.
- Ssemmanda, I., Vincens, A., 1993. Végétation et climat dans le bassin du lac Albert (Ouganda, Zaire) depuis 13 000 ans B.P.: apport de la palynologie. *C.R. Acad. Sci. Paris* 316, 561–567.
- Stager, J.C., 1988. Environmental changes at Lake Cheshi, Zambia since 40,000 years B.P. *Quat. Res.* 29, 54–65.
- Stuiver, M., Reimer, P.J., 1993. Extended  $^{14}\text{C}$  database and revised CALIB 3.0  $^{14}\text{C}$  age calibration program. *Radiocarbon* 35, 215–230.
- Taylor, D., Marchant, R.A., Robertshaw, P., 1999. A sediment-based history of medium altitude forest in central Africa: a record from Kabata Swamp, Ndale volcanic field, Uganda. *J. Ecol.* 87, 303–315.
- Thevenon, F., Williamson, D., Bard, E., Vincens, A., Buchet, G., Taieb, M., Decobert, M., 2003. Late Holocene charcoal analysis from a tropical crater lake (Lake Masoko, SW Tanzania). Climatic and human implications. *Holocene* 13.
- Tiercelin, J.J., Vincens, A. (coords), 1987. Le demi-graben de Baringo-Bogoria, Rift Gregory, Kenya. 30 000 ans d'histoire hydrologique et sédimentaire. *Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine* 11, 249–540.
- Tomlinson, R.W., 1973. The Inyanga Area, An Essay in Regional Biogeography. Univ. Rhodesia Occid. Pap. 1, 67 pp.
- Tomlinson, R.W., 1974. Preliminary biogeographical studies on the Inyanga Mountains, Rhodesia. *South Afr. Geogr. J.* 56, 15–26.
- Van Zinderen Bakker, E.M., Clark, J.D., 1962. Pleistocene climates and cultures in North-Eastern Angola. *Nature* 196, 639–642.
- Van Zinderen Bakker, E.M., 1969. The Pleistocene vegetation and climate of the basin. In: Clark, J.D. (Ed.), *Kalambo Falls Prehistoric Site. I: Geology, Palaeoecology and Detailed Stratigraphy of the Excavations*. University Press, Cambridge, pp. 57–84.
- Vincens, A., 1989. Paléoenvironnements du bassin Nord-Tanganyika (Zaire, Burundi, Tanzanie) au cours des 13 derniers mille ans: apport de la palynologie. *Rev. Palaeobot. Palynol.* 61, 69–88.
- Vincens, A., 1991. Late Quaternary vegetation history of the

- South-Tanganyika Basin. Climatic implications for South Central Africa. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 86, 207–226.
- Vincens, A., 1993. Nouvelle séquence pollinique du lac Tanganyika, 30 000 ans d'histoire botanique et climatique du bassin Nord. *Rev. Palaeobot. Palynol.* 78, 381–394.
- Vincens, A., Chalié, F., Bonnefille, R., Guiot, J., Tiercelin, J.J., 1993. Pollen derived rainfall and temperature estimates from Lake Tanganyika and their implication for Late Pleistocene water levels. *Quat. Res.* 40, 343–350.
- Vincens, A., Schwartz, D., Bertaux, J., Elenga, H., de Namur, C., 1998. Late Holocene climatic changes in western equatorial Africa inferred from pollen from lake Sinnda, southern Congo. *Quat. Res.* 50, 34–45.
- Vincens, A., Schwartz, D., Elenga, H., Reynaud-Farrera, I., Alexandre, A., Bertaux, J., Mariotti, A., Martin, L., Meunier, J.D., Nguestop, F., Servant, M., Servant-Vildary, S., Wirmann, D., 1999. Forests response to climate changes in Atlantic Equatorial Africa during the last 4000 years B.P. and inheritance on the modern landscapes. *J. Biogeogr.* 26, 879–885.
- Walter, H., Lieth, H., 1960–1967. *Klimadiagramm-Weltatlas*. Fisher, Jena.
- Werger, M.J.A., Coetzee, B.J., 1978. The Sudano-Zambezian Region. In: Werger, M.J.A. (Ed.), *Biogeography and Ecology of Southern Africa*. Junk, The Hague, pp. 301–462.
- White, F., 1983. *The Vegetation of Africa. A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa*. UNESCO, Paris, 356 pp.
- Williamson, D., Jackson, M.J., Banerjee, S.K., Marvin, J., Merdaci, O., Thouveny, N., Decobert, M., Gibert-Massault, E., Massault, M., Mazaudier, D., Taieb, M., 1999. Magnetic signatures of hydrological change in a tropical maar-lake (Lake Massoko, Tanzania): Preliminary results. *Phys. Chem. Earth A* 24, 799–803.