Coastal forest and Miombo woodland history of the Vilankulo region, Mozambique

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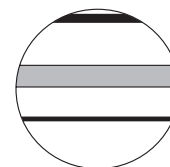
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What is This?

Coastal forest and Miombo woodland history of the Vilankulo region, Mozambique

Anneli Ekblom,[1] Jan Risberg[2] and Karin Holmgren[2]

Abstract
The present day distribution of Miombo savanna-woodland in Mozambique has been attributed to an expansion due to the clearing of original coastal forests through agriculture and use of fire. Here, we test this hypothesis using palaeoecological data from Lake Nhauhache, situated in the Vilankulo region. Our analysis shows that *Brachystegia*, one of the main constituents of the Miombo, has varied over time, and its variability seems to be driven by hydrological changes related to climatic variability rather than by land-use changes. The analyses show that *Brachystegia* was most common during AD 200–700 when a marshy forest/shrub community was dominant. After AD 700, this community changes to a dominance of *Syzygium* and *Fagara* linked to gradually rising water levels. *Brachystegia* remains in low abundance and fluctuating over time. From AD 1000, a general decline in trees/shrubs in favour of grasses concurs with an increase in grass pollen (possibly cereal) and charcoal, most probably as a result of farming activities. The decline in tree taxa was probably exacerbated by periodic droughts after *c.* AD 1200 as indicated by the diatom assemblage. In the period AD 1700 to late 1800, arboreal pollen is well represented, and this is concurrent with the diatom record suggesting high lake levels.

Introduction

The coastal lowlands of southern Mozambique and the Vilankulo area are commonly reported as a forest or forest transition region (White, 1983) or as a Miombo savanna-woodland with a coastal ticket or forest along the sea stretch (Wild and Grandvaux Barbosa, 1967). The forest or forest transition region, the Indian Ocean coastal belt, is described as a mosaic of semi-deciduous forest, thickets, woodland, savannas and edaphic grasslands (Moll and White, 1978; Werger, 1978). Despite representation in vegetation maps, islands of semi-deciduous forests, are, however, only present in the Inhambane region and by the Save River (Wild and Fernandes, 1967). *Miombo* is a colloquial term of savanna-woodland dominated by the genera *Brachystegia, Julbernardia* and/or *Isoberlinia* (Frost, 1996). In the phytogeographies of Werger (1978), the Miombo savanna-woodland was suggested to be invasive on the coast with its original centre of endemism in the south-central Africa (hence the name Zambesian phytochorion). The expansion of the Miombo savanna-woodland has been attributed to the use of fire and farming in the coastal regions. In previous discussions on landscape dynamics (e.g. Hall, 1981; Morais, 1988), it has been assumed that the coastal regions were forested prior to the arrival of farmers in southern Africa *c.* AD 300. Presently, the seaward-facing coastal slopes in the Vilankulo region carry coastal thickets, but the landscape is dominated by *Julbernardia globiflora* and *Strychnos spinosa* savannas, but *Brachystegia spiciformis* is actually very rare (Massinga in Ekblom, 2004; Telford and De Castro, 2001, see section 'Discussion'). As in the case of the absence of coastal forests, the absence of *B. spiciformis* in the Vilankulo region has also been attributed to intensive farming and use of

fire and swidden agriculture (Telford and De Castro, 2001); however, none of these hypotheses have been tested using historic data or palaeoecology. This paper sets out to test this hypotheses using historical sources or palaeoecology. The aim of this paper is therefore to explore the dynamics between forests and Miombo savanna-woodlands in the Vilankulo region.

Earlier palaeoenvironmental investigations in the Vilankulo region have shown that the coastal area in AD 400 consisted of a mosaic of forests, *B. spiciformis* savanna-woodlands, challenging the idea of the Miombo as an invasive type of vegetation (Ekblom, 2008; Ekblom et al., 2013). *B. spiciformis* is underrepresented in pollen diagrams, as it is pollinated by insects. Despite this, it is relatively well represented in the pollen diagrams from southern Africa (Scott, 1982). Meanwhile, *Julbernardia* is rarely reported in pollen diagrams. *B. spiciformis* will thus be used here as a sole indicator of Miombo, even though it should include also other species.

Here, we present a new vegetation record from the Vilankulo region to explore the Miombo/forest dynamics. The analysis is

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based on stratigraphic occurrences of pollen, spores and micro-fossil charcoal from Lake Nhauhache and combined with the diatom assemblage presented previously (Holmgren et al., 2012). The results are discussed in relation to changes in land use, and in regional vegetation and hydrological changes, with a specific focus on the long-term ecology of the Miombo.

There are several processes that can be responsible for the hypothesised transition from forests to a Miombo savanna-woodland. One process is land-use change and swidden agriculture, whereby farmers converted coastal forests into agricultural lands and fallow periods were too short to allow forests to return. Another process that would have promoted Miombo constituents on the cost of forest species is a possible shift in fire regimes (e.g. seasonality, intensity and frequency). As the Miombo constituents are well adjusted to the influence of fire, they sprout from the root, and Miombo woodlands in the African interior have also been reported to burn approximately in four cycles (Chidumayo, 1997). These two processes are likely to be interlinked as forest fires usually tend to spread mainly on the forests floor, for example, not affecting trees once they are matured. A third possibility that will be tested here is that the presence of Miombo constituents can be explained as a long-term constituent of the coastal landscape and as unrelated or weakly related to land use. Indirect evidence of farming communities in southern Mozambique is recorded from AD 300 (see below), but the earliest material evidence of farmers in the Vilankulo region only dates from AD 600. The record presented here dates from AD 200 and will be used to reconstruct the landscape prior to the onset of farming. We also set out to discuss the long-term dynamics of the Miombo/forest ecology and possible causes when it comes to ecological transformations.

Vilankulo region and research background

The Vilankulo region is marked by the presence of several lake systems, most of which are closed lakes with a characteristic circular or semi-circular shape. The Pleistocene dune system of the region forms an aquifer independent from the interior that is fed mainly by rainfall (Coetsee and Hartley, 2001). Vilankulo receives most of its rainfall (832 mm/yr) between November and March, when temperatures are the highest. The region experiences a *c.* 20-year rainfall cyclicity (Tyson and Preston-Whyte, 2000), in addition to high inter-annual rainfall variability. The dune system of the coastal plain is characterised by weakly developed soils with a low organic content and moderate weathering (Fränzle, 1984; Wood, 2001). These soils support a savanna and woodland savanna where *J. globiflora* and *S. spinosa* are well represented, interspersed with grasses. *B. spiciformis* is rarely found in the Vilankulo region (Massinga in Ekblom, 2004; Telford and De Castro, 2001). In some parts, the coastal dunes support a dense shrub characterised by *Commiphora zanzibarica, Phyllanthus reticulatus* and *Turrea nilotica*. These occur with *Grewia monticola, Deinbollia oblongifolia, Clerodendrum glabrum* and *Acalypha glabrata* and also climbers such as *Cocculus hirta* (Massinga in Ekblom, 2004). Coastal forests, constituted by species such as *Chlorophora excelsa, Ficus* spp., *Morus mesozygia, Celtis africana, Afzelia quanzensis, Dialium schlechteri* and *Brachyleana discolor*, are absent in the Vilankulo region today (Ekblom, 2004; Wild and Fernandes, 1968). However, patches of closed canopies sometimes occur and are characterised by species, such as *Millettia stuhlmanni, Alchornea laxiflora, Euclea natalensis* and *A. quanzensis*. Along streams, species such as *Ficus trichopoda* and *Myrica* cf. *pilulifera* are recorded together with *J. globiflora* and, occasionally, *B. spiciformis* (Telford and De Castro, 2001).

The earliest date of farming communities in Mozambique comes from south of Maputo, where early farming community-style pottery (Matola) was found in layers dated to AD 300. Hunter and gatherer communities were active in the area at this time and probably used fire to renew the grass and provide good grazing for game, although there is no direct evidence of this. Hunter and gatherer groups producing late Stone Age lithics are attested to the Bazaruto Archipelago, northeast of Vilankulo town. The Vilankulo area is not well surveyed archaeologically, with the exception of Chibuene, situated 7 km south of Vilankulo. From AD 600–900, this was an important regional hub of trade (Sinclair et al., 2012). An earlier period of settlement before AD 600 is suggested by the presence of Matola-type pottery, but the presence of ceramic producing groups and, possibly, farmers in the early first millennium is yet to be confirmed. The finds of early domesticates, for example, bones and cereals, remain sparse (Badenhorst et al., 2011; Ekblom et al., 2013; Sinclair, 1987).

Palaeoecological investigations have been carried out in Lake Nhaucati and Lake Xiroche in the Chibuene area (Ekblom, 2008). These records span from AD 400 and 600 to the present, respectively. They are both small lakes fed by the same aquifer as Lake Nhauhache. The pollen records of Chibuene indicated a mosaic of forests, Miombo savanna-woodlands and grasslands at AD 400, but with extensive forests constituted by species such as Moraceae, *Celtis* and *Trema*. A progressive decrease of forests occurred after AD 1400, which was tentatively linked to droughts associated with the cold and dry periods sometimes referred to as the 'Little Ice Age' (AD 1400/1600–1800, Ekblom, 2008; Holmgren et al., 2012). The original intention of Lake Nhauhache investigation presented here was to investigate whether the same pattern as in Chibuene could also be found here; however, the research question was reformulated in course of this study to focus on the Miombo (see section 'Discussion'). The pollen records in Chibuene also suggested phases of cultivation decline and expansion. An expansion of cultivation and cattle herding took place after AD 1000 followed by a decline after AD 1400 (e.g. contemporary with the decline of forests in the area). An additional expansion of farming might have occurred in the 20th century as indicated by a decline in *Brachystegia* (Ekblom et al., 2013). There are few other studies of present-to-historic vegetation dynamics available from the coastal lowlands that can provide a comparison to this Miombo/forest controversy. The closest analogue to this study is the work carried out in the coastal KwaZulu-Natal region in Lake Eteza (Neumann et al., 2010; Scott and Steenkamp, 1996) and in Lake Sibaya (Neumann et al., 2008). The Lake Sibaya record does not indicate any marked human influence on the vegetation before the last 200 years (Neumann et al., 2008), while in Lake Eteza marked changes are indicated from AD 700, but whether this is due to human influence, climate variability or the combination is inconclusive (Neumann et al., 2010).

Lake Nhauhache

Lake Nhauhache is situated at 21°58′50″S, 35°17′39″E (at 6 m a.s.l.), about 3 km northwest of Vilankulo town (Figure 1). Nhauhache is uppermost in a system of smaller coastal lakes linked to the Inhamalene River, which feeds into the Indian Ocean. The lake varies in size depending on regional rainfall. In July 2008, at the time of coring, it measured 150 m in diameter and was 2.2 m deep. The lake is characteristic of other lakes in this region, circular with steep surrounding slopes. In the southeast, the flatter topography allows for drainage of the lake during high lake levels.

The surroundings of the lake are today densely populated and cultivated, and the biological production within the lake is high. Hydrophilous plants, such as *Nymphaea lotus, Hyparrhenia* sp. and *Phragmites* sp., are found in the limnic and telmatic zones. Local residents reported that the lake was dry from AD 1990 to 2000 but retained water during the prolonged droughts in the 1980s when other lakes in the area were reported to be almost, or
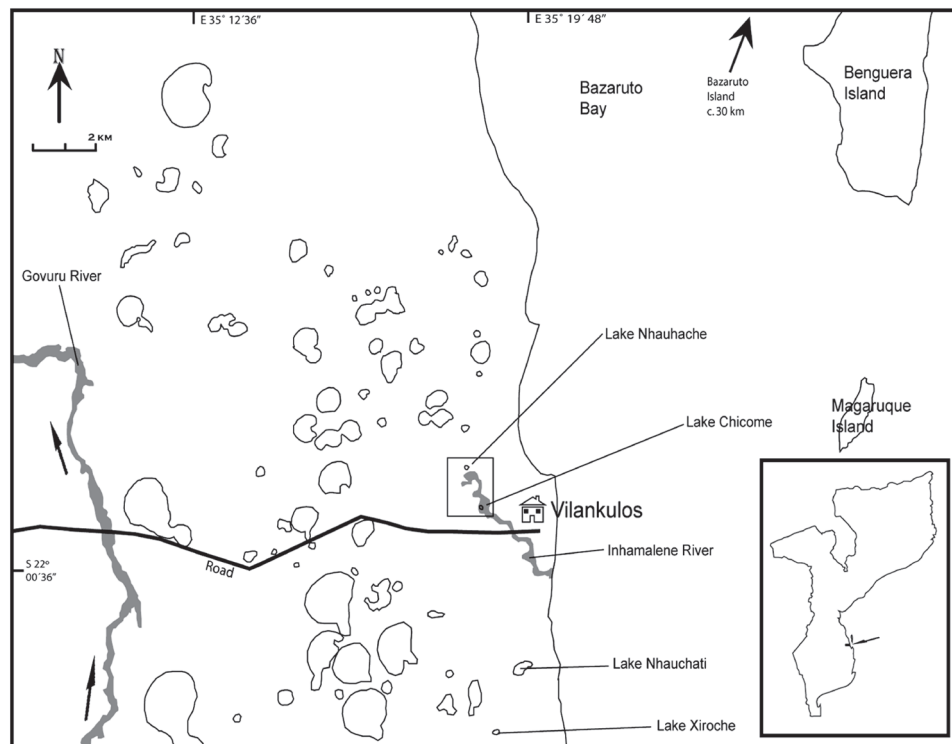
Figure 1. Location of the Vilankulo region; (inset) Vilankulo town, Lake Nhauhache and other investigated lakes in the vicinity.

completely, dry (Holmgren et al., 2012). The diatom assemblages of the Lake Nhauhache record, previously presented (Holmgren et al., 2012) and also used here, were inferred to indicate wetter conditions from *c.* 300 BC to AD 800, fluctuating conditions at AD 800–1150 and dry conditions at AD 1150–1700, followed by more humid conditions until the present.

Methodology

Lake Nhauhache was sampled in July 2008 using a dinghy and a Russian coring device. The bathymetry was examined using a handheld echo-sounder, and a sediment core was subsequently collected in the deepest part of the lake, at *c.* 2.2 m water depth. Lacustrine sediment with a thickness of 2.3 m was cored before it reached a layer of pure dune sand. All sediment depths in this paper are referred to in terms of centimetre from the bottom of the lake. The lithology of the lake sediment is homogeneous and composed of reddish to grey sandy gyttja. In the lower portion of the core, nodules of iron are observed, and a 1-cm-thick layer of rootlets appears at 355 cm depth. There are no clear signs of erosion horizons or palaeosoil surfaces. As the lake is small, we expect it to reflect local conditions of vegetation change (Jacobsen and Bradshaw, 1981; Prentice, 1985).

Pollen

Pollen and microscopic charcoal were extracted through digestion of cellulose with NaOH and concentration of pollen through acetolysis (Faegri and Iversen, 1992; Moore et al., 1991). A known amount of exotic *Lycopodium* marker spores to the sediment to calculate total concentration of pollen grains per square centimetre of sediment. Every 8 cm (or more) was sampled in the upper part of the core. As the original focus of this investigation was on the period AD 1200–1800, the lower part was sampled at larger intervals (4–45 cm spaced, depending on observed changes in the record). Glycerol was used as an embedding medium, and samples were analysed in 250× to 1000× magnification. Counts were made until the sum of trees, shrubs, herbs and grass amounted between

450 and 500 grains. Sedges (Cyperaceae) were not included in the pollen sum, although they may include both dry grassland species and limnic communities. Aquatics and eroded grains were also excluded from the pollen sum. Pollen identification was carried out using the African Pollen Database (http://apd.sedoo.fr/apd/accueil.htm) together with photographs from the reference collections available at the Palynology Laboratory (Department of Plant Sciences, University of the Free State, Bloemfontein) and from Oxford Long-term Ecology Laboratory (Oxford University) together with published references (Bonnefille and Riollet, 1980; El Ghazali, 1993; Scott, 1982; Van Zinderen-Bakker, 1953, 1956; Van Zinderen-Bakker and Coetzee, 1959). Ecological interpretations are based on Coates Palgrave (2002). Pollen diagrams were plotted using Tilia and Tilia Graph (Grimm, 1991).

The pollen of indigenous African cereal grasses (*Pennisetum americanum, Sorghum bicolor* and *Eleusine coracana*) overlap in size and are morphologically similar to wild grass pollen (Tomlinson, 1973). It has been noted in pollen analyses from the Mozambique interior (Ekblom and Gillson, 2010) that larger grass pollen (e.g. <40 μm) tend to occur in greater numbers together with maize pollen; thus, it is likely that the grass pollen >40 μm represent indigenous cereal grasses. We have therefore used a tentative size separation of grasses of <40 μm here. Glycerol tends to swell pollen grains to some extent (Cushing, 1961). There may therefore be an overrepresentation of grains in the <40 μm size class due to the effect of glycerol. We have only included pollen grains that are decisively >40 μm in size, and we did not note any significant changes in sizes in other taxa.

Charcoal

The area of charcoal, that is, black opaque angular particles, was estimated in relation to sediment volume (cm^2/cm^3) and added *Lycopodium* spores, using the point count method, with counting minimum of in total of 50 items (Clark, 1982, 1988). This gives a rough estimate of the amount of charcoal in the sample, although a larger count, of 200 *Lycopodium*/charcoal, would be ideal for higher statistical reliability (Finsinger and Tinner, 2005). We also

Table 1. Calibration dates for Lake Nhauhache. Probability at 1σ and 2σ. Calibration curve for the southern hemisphere used (McCormac et al., 2004). New dates are marked in bold.

Depth from lake surface/sample name	Depth from bottom (cm)	Laboratory number	Age ¹⁴C yr BP	Cal. 68.2% (ranges AD/BC)	Cal. 95.4% (ranges AD/BC)	Material
N1°230	10–11	Poz-27386	180 ± 30	AD 1674 (19.5%) 1710 AD 1720 (10.3%) 1740 AD 1798 (7.4%) 1812 AD 1837 (5.6%) 1849 AD 1854 (12.2%) 1880 AD 1924 (13.2%) 1952	AD 1668 (44.7%) 1785 AD 1794 (9.6%) 1818 AD 1827 (25.3%) 1894 AD 1909 (15.9%) 1954	Sandy gyttja
N1°240–241	**20–21**	**Poz-50380**	**135 ± 30**	**AD 1700 (12.1%)1722** **AD 1810 (16.2%) 1838** **AD 1847 (11.6%) 1867** **AD 1879 (28.3%) 1928**	**AD 1687 (19.0%) 1729** **AD 1804 (76.4%) 1952**	**Sandy gyttja**
N1°261	**41–42**	**Poz-27387**	**415 ± 30**	**AD 1456 (48.3%) 1504** **AD 1591 (19.9%) 1615**	**AD 1448 (56.7%) 1515** **AD 1540 (38.7%) 1625**	**Sandy gyttja**
N1°264–265	**44–45**	**Poz-50381**	**460 ± 30**	**AD 1441 (68.2%) 1483**	**AD 1429 (88.0%) 1503** **AD 1593 (7.4%) 1614**	**Sandy gyttja**
N1°283	63	Poz-27389	750 ± 30	AD 1274 (56.1%) 1302 AD 1365 (12.1%) 1365	AD 1231 (2.9%) 1247 AD 1263 (68.8%) 1320 AD 1351 (23.7%) 1385	Sandy gyttja
N1°283 shell	63	Poz-27447	845 ± 35	AD 1216 (68.2%) 1269	AD 1180 (95.4%) 1280	Fossil shell
N1°303–304	**83–84**	**Poz-50383**	**970 ± 30**	**AD 1045 (33.2%) 1087** **AD 1106 (35.0%) 1157**	**AD 1032 (95.4%) 1181**	**Sandy gyttja**
N1°313	93	Poz-27408	1020 ± 30	AD 1025 (22.6%) 1047 AD 1085 (45.6%) 1133	AD 1016 (95.4%) 1152	Sandy gyttja
N1°356	136	Poz-27409	1370 ± 30	AD 681 (50.7%) 708 AD 748 (17.5%) 766	AD 654 (95.4%) 772	Sandy gyttja
N1°380	160	Poz-27390	1800 ± 30	AD 245 (68.2%) 338	AD 215 (95.4%) 402	Sandy gyttja
N1°403	183	Poz-27391	1565 ± 30	AD 535 (68.2%) 607	AD 434 (17.1%) 492 AD 508 (2.1%) 519 AD 527 (76.3%) 635	Sandy gyttja
N1°411–412	191–192	Poz-50384	1755 ± 30	AD 261 (12.6%) 280 AD 325 (55.6%) 399	AD 255 (95.%) 415	Sandy gyttja
N1°425	205	Poz-27392	1775 ± 30	AD 258 (28.6%) 299 AD 319 (27.7%) 359 AD 364 (12 %) 382	AD 243 (95.4%) 404	Sandy gyttja
N1°447	227	Poz-27393	2285 ± 30	375 (13.9%) 351 BC 301 (54.3%) 201 BC	387 (95.4%) 203 BC	Sandy gyttja

separated two main classes of charcoal: 10–100 μm interpreted as linked to local–regional fires (here referred to as 'regional charcoal') and above 100 μm (here referred to as 'local charcoal') interpreted as linked to local fires (see review in Pitkänen et al., 1999).

Spores

All spores were counted in relation to the added *Lycopodium* spores and presented as concentrations. Most types were identified or grouped together into main type groups (Graf and Chmura, 2006; Jarzen and Elsik, 1986; Prager et al., 2006; Van Geel and Aptroot, 2006; Van Geel et al., 1983, 1986, 2003). Here, we will focus on the coprophilous fungi, mainly Sordariaceae, but also *Coniochaeta lignaria* (Marinova and Atanassova, 2006; Van Geel and Aptroot, 2006; Van Geel et al., 2003). Algal spores from *Spirogyra* spores and *Glomus* (only found in very low numbers and not shown here) were also distinguished. *Botryococcus*, most probably *Botryococcus braunii*, occurred in large numbers throughout the core but was not quantified as they occur as mass material.
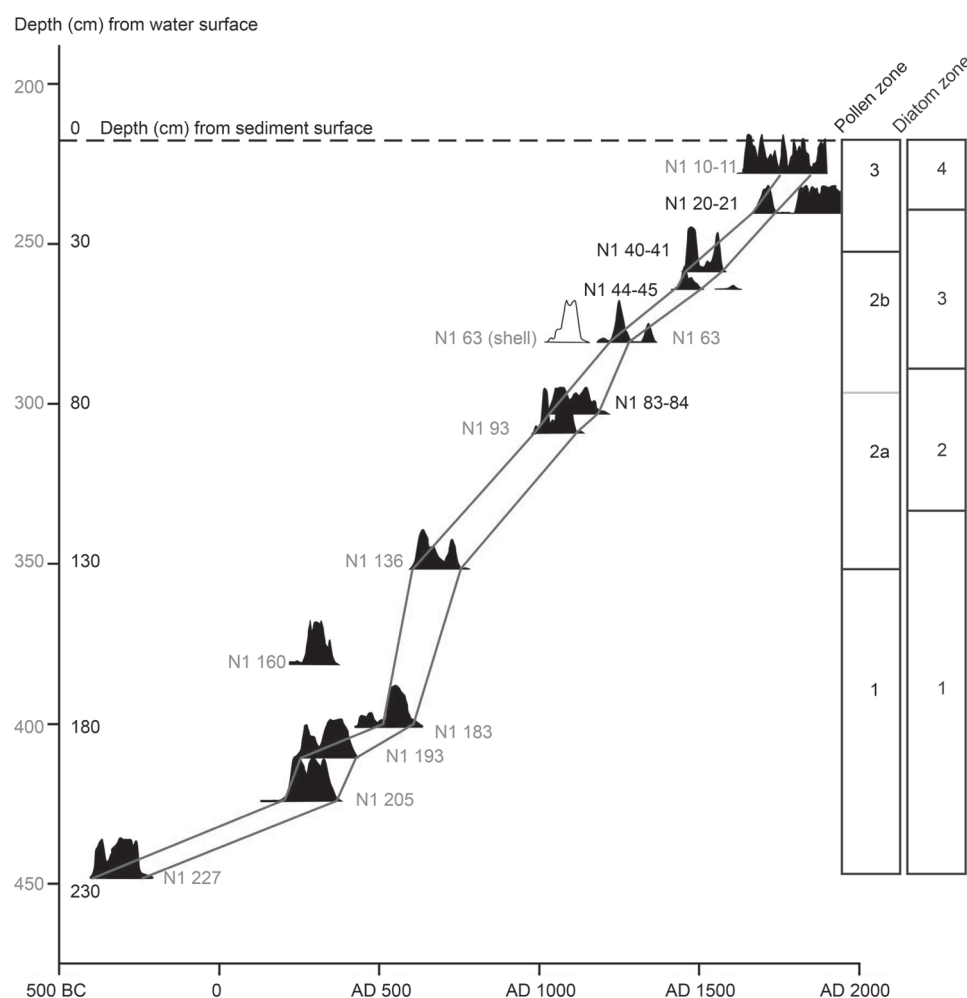
Diatoms

The diatom assemblage has been presented in detail elsewhere (Holmgren et al., 2012). Only the ecological groups are presented here, that is, planktonic, benthic, halophilous, aerophilous and ungrouped taxa. Every 3–4 cm intervals were sampled for diatoms, and the samples were oxidised with 17% H_2O_2. Clay particles were removed by decanting from 100 mL beakers in 2-h intervals (Battarbee, 1986). The remaining samples were mounted on glass slides using Naphrax and studied under a light microscope using oil immersion. Approximately 500 diatom frustules were counted per level using standard references (Cleve-Euler, 1953, 1955; Gasse, 1986; Krammer and Lange-Bertalot, 1986, 1988, 1991a, 1991b; Tynni, 1979).

Dating

Four samples were accelerator mass spectroscopy (AMS) ¹⁴C dated at the Radiocarbon Laboratory in Poznan, Poland, to complement the 10 samples presented by Holmgren et al. (2012; Table 1). Due to the lack of macrofossils in the sediments, bulk sediments (1 cm thickness each) were used for dating. OxCal 4.0 (Bronk Ramsey, 1995) was used for calibration to calendar scale with the calibration curve for the southern hemisphere (McCormac et al., 2004; Figure 2). The new ¹⁴C dates strongly support the previously proposed age model (Holmgren et al., 2012). The record spans the period from *c.* 2300 BC to AD 1800, but here, we have focused on the time period from AD 200 to 1800, as our original focus was to investigate vegetation change in this period (see section 'Discussion'). Sediment accumulation is relatively slow in the lower part of the sequence (*c.* 0.05 cm/yr) but increases between AD 500 and 1000 (*c.* 0.2 cm/yr). From AD 1000 sediment, accumulation again slows down (*c.* 0.1 cm/yr).

Figure 2. Age–depth diagram with the range of dates published in Holmgren et al. (2012, grey) and additional dates (black). The probability distribution (2σ) of each date is shown in the respective graph. The pollen and diatom zones are shown to the right.

Results

The pollen assemblage has been divided into three zones through cluster analysis. The analysis is based on unweighted paired group average and Euclidean similarity index using the software PAST (Hammer et al., 2001). This method is unconstrained by depth and more suitable for cores with possible temporal gaps (Figure 3). The most commonly represented species is presented here (Figures 4 and 5). The tree/shrub group has been divided into two main ecological groupings to assist interpretation, a riverine forest/forest group and a savanna/generalist group (Table 2).

Nhauhache 1: 210–135 cm depth (AD 200–700)

Total pollen concentrations are generally low in this zone. Trees and shrubs are well represented, particularly *Stereospermum*, Combretaceae, *Myrsine Africana, Alchornea* (well represented throughout the core), Moraceae and *Trema*, are here combined into one curve as their representation is low, and they have similar ecological requirements. The identification of *Stereospermum* remains provisional (see Table 2). *Brachystegia* shows its highest values in this zone compared with other parts of the core. There are high values of *Nymphaea* throughout the zone together with *Laurembergia* and Hydrocharitaceae. Poaceae and Cyperaceae show moderate levels. The herbs (Chenopodiaceae, Asteraceae and Acanthaceae) are relatively well represented. Charcoal particles and Poaceae >40 μm are few in this zone. Spores are represented in low numbers and represented mainly by fern spores.
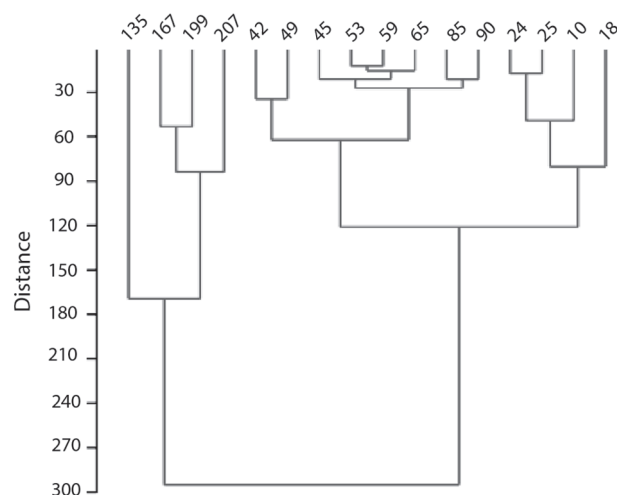

Figure 3. Cluster analyses of analysed levels, the analysis that is unconstrained by depth is based on unweighted paired group average and Euclidean similarity index using the software PAST (Hammer et al., 2001).

Nhauhache 2: 135–42.5 cm depth (AD 700–1500)

This zone could possibly be divided into two subzones 135–90 cm and 90–42.5 cm (AD 700–1100 and AD 1100–1500) on the basis of a decline of trees/shrubs in the upper part of the zone. As there is only one pollen level in the lower part, they are not statistically separated.

Nhauhache pollen diagram
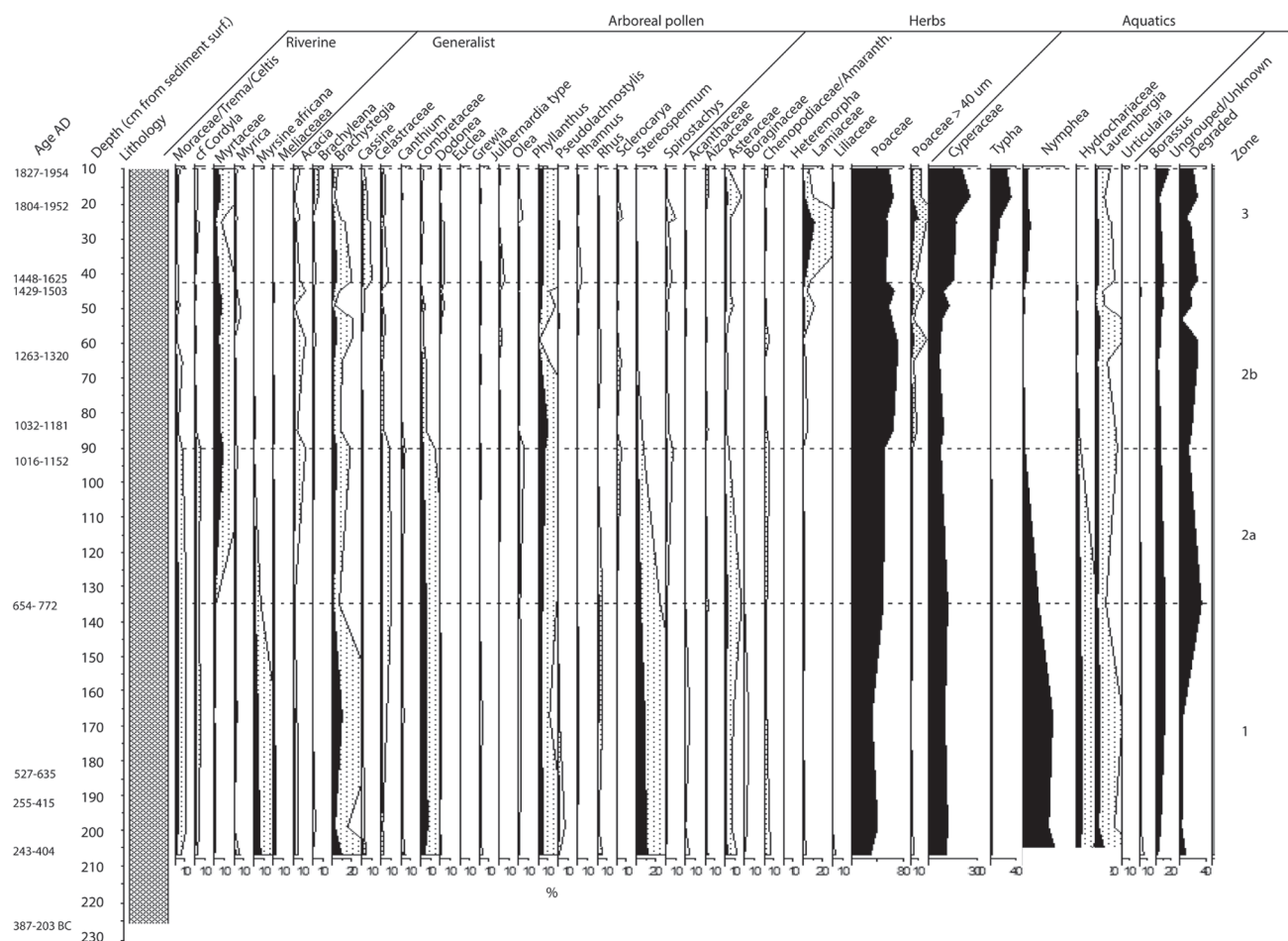
Figure 4. Pollen diagram, with terrestrial pollen percentages grouped into arboreal types and savanna and generalist types. The lithology consists of sandy gyttja. Herbs and aquatics are also shown. The pollen types with a low representation have been exaggerated (hatched silhouette) with a factor of 5.

Total pollen concentrations increase in the whole zone as does the number of degraded grains. Trees and shrubs are still well represented but decrease in relation to previous zone and particularly in the upper part of the zone from 90 cm depth (AD 1100). *M. africana* declines markedly together with Moraceae/*Trema, Stereospermum* and Combretaceae. *Brachystegia* is represented in low numbers throughout the zone. Myrtaceae, mainly represented by *Syzygium* with some contribution of *Eugenia*, is well represented. *Phyllanthus* is more common in this zone than before. *Alchornea* shows a small increase in the upper part. Poaceae increases while the Cyperaceae curve remains stable. *Nymphaea* decreases progressively to low numbers in the upper part of the zone. The herbs decrease slightly, but Asteraceae is better represented than in previous zone. Poaceae >40 μm remains low in numbers until 90 cm depth (*c.* AD 1100), when they increase significantly together with both local and regional charcoal particles. Spore numbers continue to be low, but there is a slight increase in spores associated with coprophilous fungi (*C. lignaria*) from 90 cm depth. Fern spores decline from the beginning of the zone but increases together with trilete fern/moss spores.

Nhauhache 3: 42.5–10 cm depth (AD 1500–1800)

The uppermost zone is of short duration and is distinguished by an increase in trees/shrubs and in Cyperaceae and the aquatics *Nymphaea* and most markedly of *Typha*. Among the trees/shrubs, *Alchornea* remains well represented together with Myrtaceae and *Phyllanthus. Stereospermum* and *Brachystegia* occur only in low

numbers, and the latter is absent in the upper part of the zone. *Dodonaea* is common (as also in the upper part of the previous zone). The herbs show a significant increase, particularly the Lamiaceae group. Fern and fern/moss spores occur in moderate numbers, and there is an overall increase in spores, particularly spores associated with coprophilous fungi *C. lignaria* and Sordariaceae that are very common in the uppermost part of the core. Local and regionally transported charcoal remains well represented together with grasses >40 μm. Pollen concentrations in this zone are higher than in previous zone, and the amount of degraded grains remains high.

Discussion

Summarising the changes in vegetation communities

The results of the Lake Nhauhache pollen analysis show that *Brachystegia* was most common in the beginning of the sequence. At AD 200, a vegetation community with *Brachystegia, Stereospermum, M. africana* and Combretaceae was present near Lake Nhauhache. These occurred with a few representatives of typical forest vegetation. The forest taxa (Moraceae, *Trema, Celtis*) that represented 20–40% of the pollen sum nearby Chibuene (Ekblom, 2008; Ekblom et al., 2013) are not well represented in Lake Nhauhache (forest taxa here represent only *c.* 2% of the pollen sum). Thus, the pollen diagram from Lake Nhauhache does not indicate the presence of a large forest community at AD 200 or later in the pollen diagram, which is also why we rephrased our research question in course of this study. The *Stereospermum, M. africana*

Nhauhache summary pollen, spores, charcoal and diatom diagram
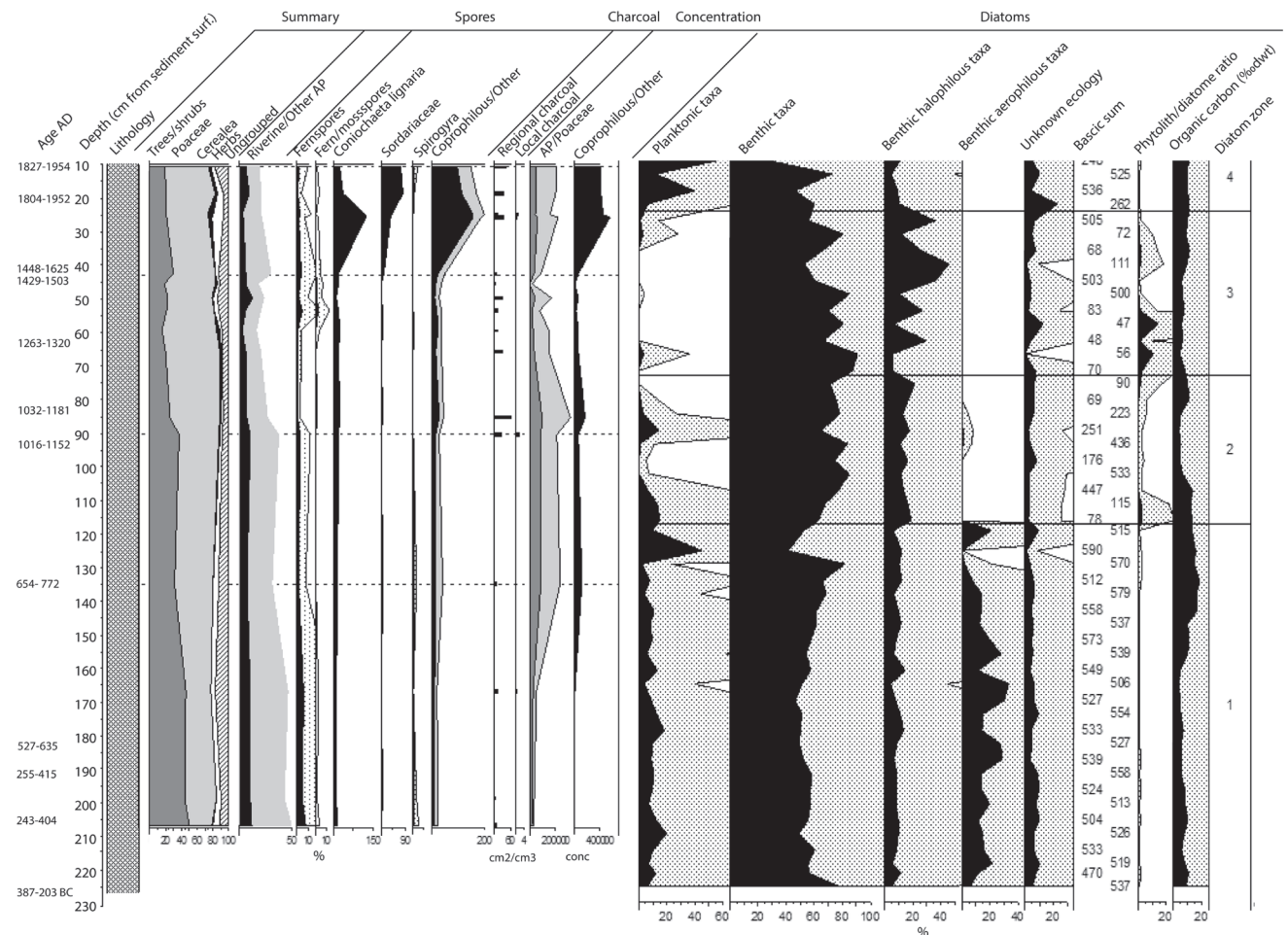
Figure 5. Summary pollen diagrams with the main ecological groups shown in percentages. The lithology consists of sandy gyttja. Distribution of spores (number/cm²), regional and local charcoal (number/cm²) and total pollen and spore concentrations (left). The pollen diagram has been divided into three zones based on the pollen assemblage. A summary diatom diagram is shown to the right with the four zones based on the diatom assemblage indicated for comparison. The sparse representation of charcoal in the lower part of the diagram is due to the low sampling resolution here.

and Combretaceae community was dominant until around *c.* AD 700 (135–136 cm depth), probably as a marshy forest/shrub community with *Brachystegia* common in the well-drained areas. The palm tree *Borassus* also occurs sporadically during this phase, and this is normally associated with temporarily flooded areas. The diatom assemblage (Holmgren et al., 2012) indicates a marshy lake environment with variably high values of aerophilous taxa, suggesting, perhaps, that the area was only temporarily waterlogged. High values of *Nymphaea* parallels the results from Chibuene, which also displays a peak in *Nymphaea* at the beginning of the lake phase when areas high in organic matter were flooded by rising water tables. *Spirogyra* is common in this period, and it usually grows as macroalgal mats in shallow standing waters (Joska and Bolton, 1996). The abundance of *Botryococcus* suggests oligotrophic conditions at the base of the core as well as in the upper part.

In the period AD 700–1000 (135–136 cm depth), there is a change in species composition with *Syzygium* and *Fagara* being more dominant. This is most likely linked to gradually rising water levels and exacerbated conditions for a marshy forest community. The diatom assemblage continues to display high values of aerophilous taxa until 120 cm depth (*c.* AD 840) when there is a peak in planktonic taxa at 125 cm depth (Figure 5), which has been interpreted as a flooding event (Holmgren et al., 2012). Higher lake levels in this period are also supported by high pollen concentrations and the fast accumulation of sediment. Thus, the

change in species representation is probably best explained by a change in hydrology and/or an increase in rainfall. The high lake levels are likely to have drenched the swamp forest community and other species were favoured on the steeper slopes around the lake. *Brachystegia* is still represented with 2–4% after AD 700, but other taxa, as *M. africana* and *Stereospermum*, only occur sporadically after AD 700. The transition is somewhat obscure, however, due to a low sample resolution in this part, something which can hopefully be amended in the future.

From AD 1000 (90 cm depth), there is a general decline of trees/shrubs in favour of grasses. This is contemporary with evidence of an agricultural expansion (see below). Pollen concentrations in this period are moderate. The decline of trees/shrubs in this phase may initially be linked with the agricultural expansion, later exacerbated by periodic droughts. The diatom assemblage indicates overall dry conditions in the whole period from AD 1180 to 1700. Within this period, there were periods of desiccation and re-flooding such as for instance at *c.* AD 1250. Despite these reoccurring dry periods, after AD 1500, the trees/shrubs increase, particularly Myrtaceae and *Phyllanthus*, suggesting an expansion of a riparian forest. This is somewhat surprising since the 18th century was reportedly marked by the most severe periods of droughts (Holmgren et al., 2003; Lee-Thorp et al., 2001; Scott and Lee-Thorp, 2005), but a lack of vegetation change has also been recorded in other regions in southern Africa in this time period (see section 'Discussion' in Ekblom et al., 2012).

Table 2. Represented pollen taxa and ecological groupings in the Lake Nhauhache sediment core.

Pollen included in the terrestrial pollen sum

Trees and shrubs associated with forest/riverine forests

Alchornea	*Eugenia*	*Myrica*
Acalypha	Meliaceae	*Olea*
Celtis	*Millettia*-type	*Syzygium*
Dialium-type	*Mimusops*	*Trema*
Diospyros	Moraceae	*Myrsine*
		Stereospermum-type

Generalist trees and bush

Acacia	Combretaceae	*Julbernardia*
Brachystegia	*Cordia*	Rhamnaceae
Canthium-type	*Dichrostachys*	*Rhus*-type
Capparaceae	*Dodonaea*	*Sclerocarya*
Cassia-type	*Euclea*	*Sterculia*
Cassine-type	*Euphorbia*-type	*Spirostachys*
Commiphora-type	*Fagara*-type	*Uapaca*
Celastraceae	*Grewia*	Vitaceae

Herbs

Acanthaceae	Liliaceae	*Tribulus*
Asteraceae	*Heteromorpha*-type	Poaceae
Boraginaceae	Lamiaceae	*Polygonum*-type
Chenopodiaceae (Chen/Am)	Malvaceae	Ranunculaceae
Apiaceae-type	*Oxygonum*	Solanaceae
Commelina		
Ericaceae		

Ungrouped types (included in the terrestrial pollen sum)

cf. *Vitex*	cf. *Caesaria* spp.	*Borassus/Hyphaene*
cf. Meliaceae	cf. *Peltophorum*	*Podocarpus*
cf. Scrophulariaceae	Borreria-type	Unknown

Pollen excluded from the terrestrial pollen sum

Limnic plants

Cyperaceae	*Borassus* (note this is included in pollen sum)

Herbaceous vegetation associated with damp and marshy vegetation

Apiaceae-type	*Heliotropium*-type	Onagraceae
Commelina	*Heteromorpha*-type	*Polygonum*-type
Dissotis-type	*Ipomoea*-type	Ranunculaceae
Ericaceae	Liliaceae	Solanaceae
Gentianaceae	*Menthe*-type	

Submerged or partially submerged aquatic plants

Equisetaceae	*Nymphaea*	*Typha*
Hydrocharitaceae	*Potamogeton*	*Utricularia*
Laurembergia		

The period from AD 1700 to late 1800 is suggested by the diatom record to have had high lake levels throughout (Holmgren et al., 2012). Arboreal pollen is well represented in this period, but the species composition is slightly different from other periods (*Alchornea*, Myrtaceae, *Phyllanthus*). Herbs and aquatics increase while grasses decline slightly. *Brachystegia* declines and disappears in the upper part of the zone.

Testing the hypothesis of Miombo expansion

Brachystegia is the only species of the Miombo that frequently occurs in the pollen diagram, *Julbernardia* type has been identified but very rarely, and this is a pattern also in other pollen analyses as discussed in section 'Introduction'. Therefore, *Brachystegia* is here treated as a representative of the Miombo. *Brachystegia* is underrepresented in the pollen diagram, and even a low presence is therefore interpreted to indicate considerable coverage. It is unlikely that the low representation of forest taxa throughout the diagram can be explained as the result of land use and/or shift in fire regime as was posited in section 'Introduction'. It cannot be excluded that farmers were active in the area from AD 300, or that hunter and gather communities may have had an impact on vegetation patterns before that, but this would have been on a small scale and not sufficient to reshape vegetation patterns. The material evidence of farming communities only dates from AD 600 in nearby Chibuene. This area probably supported a large population, but there is no evidence of an expansion/intensification of farming until AD 1000–1400. Thus, we argue that the Lake Nhauhache record, notwithstanding a low resolution in the bottom of the core, supports the third hypothesis posed in the introduction, namely, that *Brachystegia* and by extension – the Miombo – is a long-term constituent of the coastal landscape in southern Mozambique.

Our results indicate that *Brachystegia* has varied over time, with the highest representation at AD 200–700. The similarity between the appearance of *Brachystegia* and the diatom record from the same lake indicates that the presence of Miombo has been driven mainly by hydrological changes related to climatic variability.

Grass pollen <40 μm that may represent cereal grasses is represented throughout the core, and in the base of the diagram, this is most likely wild grasses. An increase in grass pollen <40 μm can be seen in the transition between zones 2a and 2b at AD 1000 (90 cm depth). At the same time, there are also high values of charcoal, which is here interpreted as linked with clearing and swidden agriculture taking place in the vicinity of Lake Nhauhache. However, there is no significant increase in coprophilous spores at this time. Charcoal and possible cereal grain pollen remain high throughout zone 2b until AD 1500. Farming and use of fire kept the landscape relatively open as arboreal pollen is represented by less than 20% in this period. The decline in riparian taxa at *c.* AD 1500 may be linked with this agricultural expansion that is also seen in Chibuene. It may also be linked with the repeated droughts occurring from AD 1150 onwards. *Brachystegia* remains represented in lower numbers and fluctuates over time with small peaks at AD 1000 and *c.* AD 1450. Possibly, this can also be related to land use, but it cannot be excluded that this is related to edaphic or hydrological changes. At AD 1500, there appears to be a decline in agricultural activities with a grass pollen <40 μm and charcoal. However, from AD 1700, there is an increase in grass pollen <40 μm, charcoal and most significantly in coprophilous spores. The latter are most probably linked with an increase of domestic stock in the area.

Brachystegia disappears at the top of the record, from AD 1700. As the resolution is low in the upper part and as we are missing the last 200 years of the record, it is unclear whether this is a temporary decline or whether this decline can be linked with the near absence of this species today in the Vilankulo region.

Conclusion

The Lake Nhauhache sequence shows that *Brachystegia* was most common at AD 200–700 years ago. At AD 200, a marshy forest/shrub community consisting of *Stereospermum, M. africana* and Combretaceae was dominant with *Brachystegia* common in the well-drained areas. After AD 700, this community changes to a dominance of *Syzygium* and *Fagara* linked with gradually rising water levels at the same time as *Brachystegia* decreases. From AD 1000, there was a general decline of trees/shrubs in favour of grasses. This was most probably linked with the opening of the landscape for farming as it is concurrent with increase in possible cereal grass pollen and charcoal. The further opening of the landscape was probably exacerbated by periodic droughts after *c.* AD 1200 as suggested from the diatom assemblage in the period of AD 1180–1700. *Brachystegia* remains represented in lower numbers after AD 700 and fluctuates over time over. The small peaks at AD 1000 and *c.* AD 1450 can possibly be related to land use, but it can also be related to edaphic or hydrological changes. The period from AD 1700 to late 1800 is suggested by the diatom record to have had high lake levels throughout, and arboreal pollen is well represented in this period, but the species composition is slightly different from other periods. It is clear from the analysis that *Brachystegia* has varied naturally over time, and its variability seems to be driven mainly by hydrological changes related to climatic variability. The hypothesis that the Miombo savanna-woodland appeared as a result of human-induced land-use changes is thus not supported by this study. The reasons behind the observed decline of *Brachystegia* in the last centuries can, however, not be explained without more detailed studies.

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