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Environmental and vegetation dynamics in the forest of Orile-Owu, southwest Nigeria, from the last ~ 1,4 k cal yr BP

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ABSTRACT - (Environmental and vegetation dynamics in the forest of Orile-Owu, southwest Nigeria, from the last ~ 1,4 k cal yr BP). Vegetation history of southwestern Nigerian forest during the past ~1,416 cal yr BP (534 – 644 AD) is reconstructed based on palynological data from a core from Awerele, wetland in Orile-Owu. Six palynological zones were stablished. Zone I (195-175 cm; ~1,416 cal yr BP) was a period marked by low value of charcoal particles associated with low frequency of *Elaeis guineensis* pollen. In Zone II (175-135 cm), the environment experienced wet conditions depicted by high percentage mainly of Cyperaceae and fern spores. Further, the arable weeds and *E. guineensis* increased values, showing the higher frequency of *Margaritaria discoidea* pollen grains, coupled with a low charcoal amount. Zone III (135-105 cm) to Zone VI (50-0 cm) were characterised by the increase of *E. guineensis* and raising of charcoal particles, followed by the presence of plants exploited for food and medicinal purposes, which may indicate enlarged local landscape disturbance, probably associated with humans' activities. Archaeological evidence suggest that humans occupied the Orile-Owu area from ~ 412 cal yr BP (AD 1,538 - 1,635). The pollen data displayed the persistence of a forest-savanna mosaic, associated with ecological perturbations, which were also noticed in other parts of sub-saharan Africa on the same period.
Keywords: arable weeds, Late Holocene, Nigerian rainforest, paleoenvironmental reconstruction, Palynology

RESUMO - (Dinâmica ambiental e da vegetação na floresta de Orile-Owu, sudoeste da Nigéria, nos últimos ~ 1.4 k cal anos AP). A história da vegetação florestal do sudoeste da Nigéria durante os últimos ~ 1.416 cal anos AP (534 - 644 AD) é reconstruída com base em dados palinológicos de um testemunho retirado em Awerele, de uma área pantanosa em Orile-Owu. Seis palinozonas foram estabelecidas. Zona I (195-175 cm; ~ 1.416 cal anos AP) foi um período marcado por baixos valores de partículas de carvão associado à baixa frequência de pólen de *Elaeis guineensis*. Na Zona II (175-135 cm), o ambiente experimentou condições úmidas representadas principalmente pela alta porcentagem de Cyperaceae e esporos de samambaias. Além disso, os valores de ervas daninhas aráveis e de *E. guineensis* aumentaram, evidenciando a maior frequência de grãos de pólen de Margaritaria discoidea, associada a uma baixa quantidade de carvão. Da Zona III (135-105 cm) à Zona VI (50-0 cm) caracterizou-se pelo aumento de *E. guineensis* e de partículas de carvão, seguidos pela presença de plantas exploradas para fins alimentares e medicinais, que podem indicar maior perturbação na paisagem local, provavelmente associada às atividades humanas. Evidências arqueológicas sugerem que os humanos ocuparam a área de Orile-Owu a partir de ~ 412 cal anos AP (AD 1.538 – 1.635). Os dados polínicos exibiram a persistência de um mosaico floresta-savana, associado a perturbações ecológicas, que foram também notadas em outras partes da África subsaariana no mesmo período.
Palavras-chave: ervas daninhas aráveis, Holoceno Superior, Floresta Tropical Nigeriana, Palinologia, reconstrução paleoambiental

Introduction

Over the last five decades, there has been considerable progress in palaeoenvironmental studies in the tropics of sub-Saharan Africa from different fields of research. Data from such studies revealed the various palaeoenvironmental conditions that prevailed (Maley & Brenac 1998, Ngomanda *et al.* 2005, Adeonipekun *et al.* 2017, Maley *et al.* 2018, Orijemie 2018). It has also been noted that such variations in climate were not uniform globally. For example, as recounted in the Late Quaternary with special focus on vegetation changes and fluctuating dry and wet conditions (Burke *et al.* 1971, Pastouret *et al.* 1978, Sowunmi 1981a, b), the period of maximum aridity was noted globally between 22,000 and 12,500 yr BP, whereas the widespread aridity according to Sowunmi (1981b)

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was between 30-20,000 yr BP. However, based on Burke *et al*. (1971) account, this intense dry phase started earlier and was longer in the region of Lake Bosumtwi in Ghana which spanned 24,000 to 15,000 yr BP (Maley 1996). But the Lake Bosumtwi dry phase fits perfectly within the time frame given by Sowunmi. No doubt this disparity in data presentation of global aridity is as a result of high complex and variable changes in the locals where these studies were conducted. Consequently, there is the need to pay due attention and apply caution while extrapolating results from one area to another.

Variations in the extent of the African rainforest dates as far back as the Late Miocene (Maley 1996). Similarly, the Late Holocene was marked by major climatic crises which affected the Central African rainforests characterized by forest disturbance and fragmentation with expansion of pioneer vegetation and conspicuous erosional activity (Maley *et al.* 2018). After 2,800 yr BP, increase in pollen of grasses, vegetation opening associated with increased pioneer taxa (*Alchornea* and *Elaeis guineensis*) and forest retreat, accompanied by erosion was noted (Maley & Brenac 1998). Nevertheless, after 2,000 yr BP, reduction in grasses associated with marked increase in trees suggested forest recovery but not to its former extent in the early and middle Holocene (Maley & Brenac 1998). In the same way, elsewhere in the coastal Niger Delta region of Nigeria, Sowunmi (1981a, b) reported that from 2,800 yr BP, oil palm pollen (*Elaeis guineensis*) was recorded in noticeable quantities coupled with reduction in forest pollen and increase in weeds of cultivated land. Arguably, this phenomenon was interpreted to suggest opening of the vegetation caused by human interference (Sowunmi 1981a, b). The present study, based on palynological, sedimentological and archaeological data, provides insight into the environmental conditions and vegetation dynamics within the forest region in southwest Nigeria.

Putting into consideration the ambiguity associated with interpreting African rainforest dynamics in terms of climatic and/or anthropogenic disturbance in the last 2,000 years (Ngomanda *et al.* 2005); and the unevenness in global environmental conditions in different regions, this paper is aimed at understanding local variations that occurred in Orile-Owu, a local community within the forest region of southwest Nigeria. Attempts are made at correlating these local climatic variations with those observed in other parts of Africa. By so doing, this paper contributes to data on global palaeoenvironmental conditions.

Material and methods

Study area - Orile-Owu (Lat. 7°14´N and 7°15´N; Long. 4°18´E and 4°22´E) is a Yoruba community in Osun State, southwestern Nigeria**.** It has an average annual temperature of 26.5 °C and 1,405 mm of rainfall annually with double maxima in June and September (https://en.climate-data.org/location/371279/). Orile-Owu constitutes one of the most important historical sites in the area. This is due to its association with ancestral Owu, a major community in the region which was sacked during an internecine war between the allied forces of Ife, Oyo and Ijebu communities at the wake of the nineteenth century (Mabogunje & Omer-Cooper 1971, Akintoye 2010). It is situated in the Guineo-Congolian rain forest (White 1979, 1983).

The natural vegetation of the area is similar to the drier type of the Guineo-Congolian rain forest described by Lebamba *et al.* (2009). Some trees and shrubs similar to Keay's (1959) drier northern part of the lowland rainforest and savanna zone also occur in the area; components include: *Ficus exasperata* Vahl, *Milicia excelsa* (Welw.) C.C. Berg, *Triplochiton scleroxylon* K. Schum, *Cola gigantea* A. Chev., *Acacia ataxacantha* DC., *Anthocleista d'jalonensis* A. Chev. and the weed *Achyranthes aspera* Linn. The present vegetation is dominated by secondary forests of different ages with pioneers [e.g. *Elaeis guineensis* Jacq., *Alchornea cordifolia* (Schum. & Thonn.) Müll. Arg., *Ceiba pentandra* (Linn.) Gaertn., and *Musanga cecropioides* R. Br.]. Relicts of dense vegetation of rainforest [*Blighia sapida* Konig, *Samanea saman* (Jacq.) Merrill, *Dracaena mannii* Bak, *Morinda lucida* Benth., *Pterygota macrocarpa* K. Schum. and *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.] are noted in the area with abrupt boundaries between them. These boundaries are initiated by open spaces with erected buildings and scanty vegetation, and a mixture of farmland and woody plants typical of abandoned farmlands or unfarmed areas.

Cultivated plants dot the landscape such as *Musa paradisiaca* L., *Musa sapientum* L., *Chrysophyllum albidum* G. Don., *Citrus sinensis* L., *Zea mays* Linn., *Dioscorea* sp. Linn., *Capsicum frutescens* Linn. and *Colocasia esculenta* (Linn.) Schott. Cultivated plots of land are characterized by trees some of which may have been preserved from the original woodland or intentionally planted or tended by the farmers for the sake of their fruit, shade or economic significance. Such trees include *Elaeis guineensis, Theobroma cacao* Linn., *Ceiba pentandra, Mangifera indica* Linn., *Milicia excelsa* and *Cola gigantea.* Cocoa plantations are established by felling secondary forest trees and planting cocoa seedlings along with a food crop on the newly cleared land (Clayton 1958). Weeds common in this area included *Ageratum conyzoides* Linn., *Talinum triangulare* (Jacq.) Willd. *Amaranthus* sp. Linn., *Aspilia africana* (Pers.) C. D. Adams, *Euphorbia hirta* Linn., *Urena lobata,* Linn., *Solanum torvum* Sw., *Acanthospermum hispidum* DC., *Sida rhombifolia* Linn., *Chromolaena odorata* (L.) R. M. King & H. Rob., *Achyranthes aspera* and *Boerhavia diffusa* Linn. and weed of cultivated/disturbed land such as *Commelina erecta* Linn. and *Bidens pilosa* Linn. Other vegetation types identified on the landscape include freshwater swamp forest: *Raphia vinifera* P. Beauv., *Alstonia boonei* De Wild. and *Cissus* sp. Linn.; savanna species: *Acacia ataxacantha, Ipomoea asarifolia* (Desr.) Roem. & Schult., *Cleome viscosa* Linn., *Boerhavia diffusa* L. and *Panicum maximum* Jacq.; riparian/fringing forest: *Raphia vinifera*, *Cola gigantea, Mimosa invisa* Mart. and *Albizia zygia* (DC.) J. F. Macbr.; and montane forest such as *Indigofera tinctoria* Linn.

Coring and sampling - A 200 cm sediment core was drilled with the aid of a Hiller sampler at Awerele, a marshy area in Orile Owu, located inside the Ayedaade local government area of Osun State, southwest Nigeria (7°14´12.6´´N, 4°19´43.9´´E) (figures 1-2). Sediment samples (10 g of fresh weight) were collected at 5 cm intervals for sedimentological and palynological analysis. The physical characteristics of the sediment core samples such as texture of the inorganic component, grain sizes and soil colour were determined through visual examination using grain size chart and Munsell soil colour chart (Munsell 1975, FAO 2007).

^{14}C age dating - For a proper understanding of the chronology of the site, radiocarbon date was obtained for a sediment sample from the basal layer (195-190 cm) of the Awerele core. Also, charred palm kernels (*Elaeis guineensis*) from layer 70-60 cm, below surface of an excavated trench, were radiocarbon dated. Archaeological and palynological investigations on the trench, 500 m southwest from the coring site, were published in Daraojimba (2016). The samples were analysed by

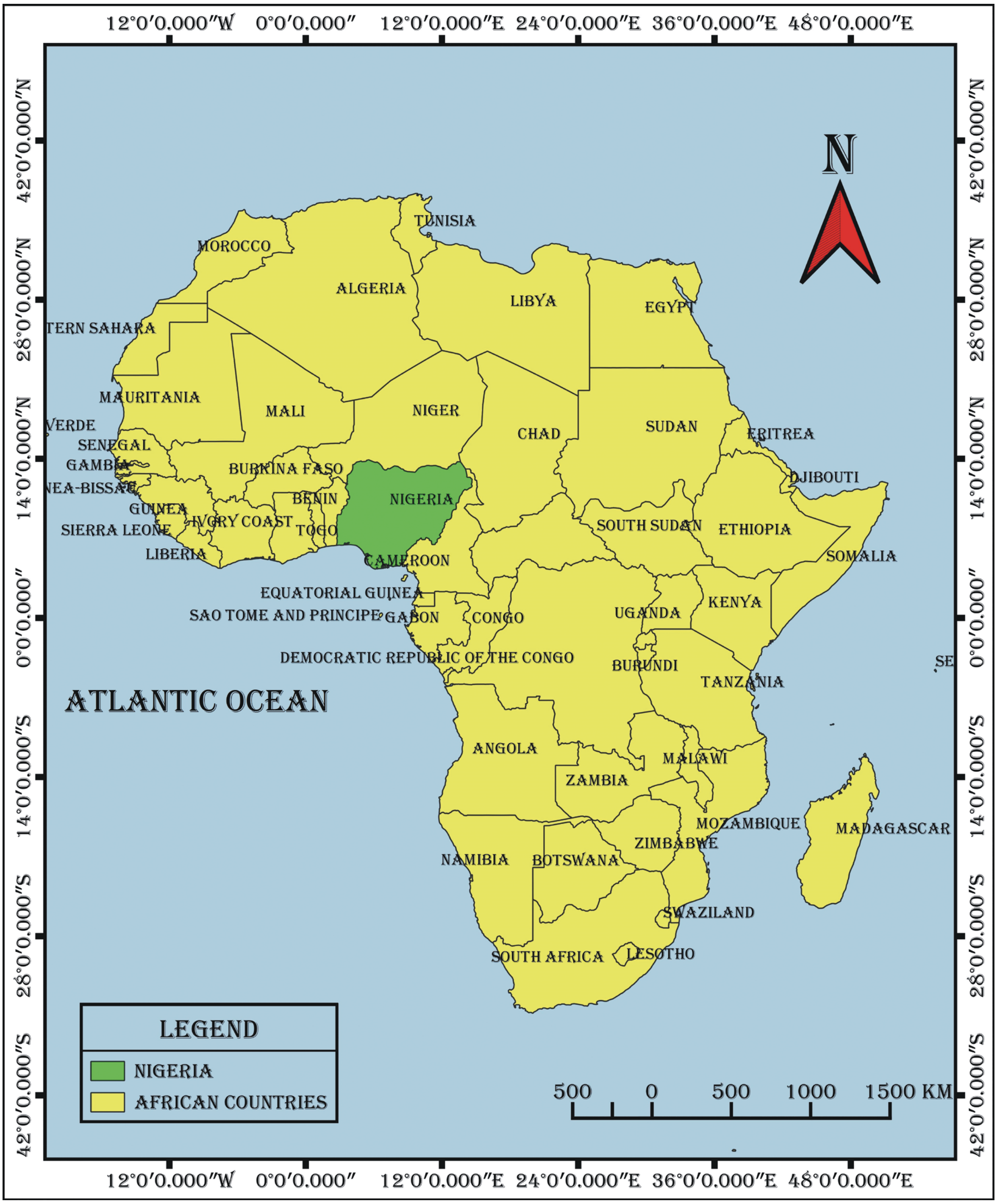

Figure 1. Map of Africa showing Nigeria (in green).

Figura 1. Mapa da África mostrando a Nigeria (em verde).

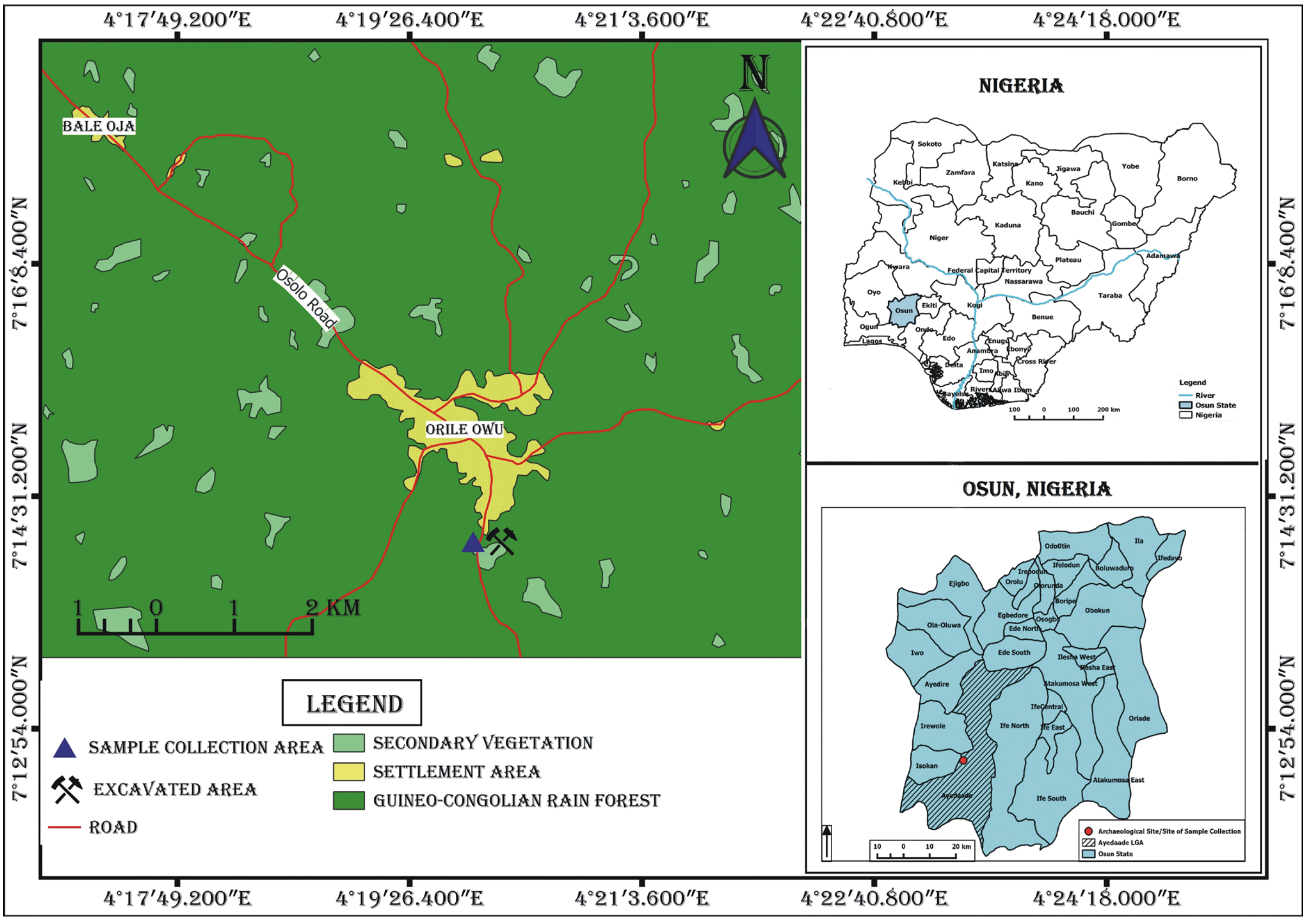

Figure 2. Map of modern vegetation and sediment core collection site in Awerele, a marshy area in Orile Owu, located inside the Ayedaade local government area of Osun State, southwest Nigeria.

Figure 2. Mapa da vegetação moderna e local de coleta do testemunho em Awerele, uma área pantanosa em Orile Owu, localizada na área governamental de Ayedaade do Estado de Osun, sudoeste da Nigeria.

Accelerated Mass Spectrometry (AMS) radiocarbon dating at Beta Analytic, Florida, United States of America. Radiocarbon dates reported in this study were converted to calendar years (calibrated ^{14}C ages) with the international calibration curve IntCal 13 data set from Reimer *et al.* (2013) using the High Probability Density (HPD) range method (Bronk Ramsey 2009).

Pollen sample preparation and analysis - Sub-samples from 65-50 cm (25 g) were merged to one sample, to make up the required weight for pollen analysis due to the low quantity of sediments contained within those levels. Therefore, a total of thirty-seven sub-samples were analysed for palynomorph content using Faegri & Iversen (1989) procedure.

Pollen slides were studied using an Olympus CH30, AmScope MU1000 and Fisher research microscopes. The Olympus and AmScope MU1000 digital compound microscopes (in the palynology unit of the Department of Archaeology and Anthropology, University of Ibadan and Microbiology unit of International Institute for Tropical Agriculture (IITA), respectively, also in Ibadan) were used for photographing the palynomorphs. Palynomorphs were identified and counted under x40 and x100 objectives. Identifications of the palynomorphs were based on comparison with the pollen reference collection (Palynotheca) and photomicrographs available at the Palynology unit, University of Ibadan. The pollen/spore type names follow the concept of Joosten & De Klerk (2002). The term 'pollen-spore type' means a single plant species or a group of species, or higher taxa, presenting similar pollen-spore morphology, i.e., the names indicated in the palynological diagrams are not plant taxon names (De Klerk & Joosten 2007). Pollen identification was also done in reference to photomicrographs in publications such as APLF (1974), Gosling *et al.* (2013) and Sowunmi (1973, 1995).

Identified palynomorphs were classified into eight phytoecological groups. The classification was done based on the present-day natural distribution of vegetation zones of the taxa to which they belong in Nigeria (Lézine *et al.* 2009): Freshwater swamp forest, freshwater swamp/hydro-hygrophyte taxa (sedges, riverine vegetation), lowland rainforest, montane forest, savanna, secondary/open forest, weeds and ubiquitous vegetation.

Certain identified palynomorphs taxa were treated separately due to their peculiarity as indicators of opening of the vegetation, perhaps caused by humans or a reflection of the conditions of the environment. These taxa include Poaceae (grasses), *Elaeis guineensis*, *Alchornea* sp, weeds and fern spores.

Those palynomorphs that could not be identified due to the uncertainty of their taxonomical classification were tagged 'unidentified' while those that could not be identified due to their poor state of preservation were classified as 'unidentifiable'. Some pollen grain types were classified as 'Ubiquitous' since they have the potential of being widely distributed.

Statistical analysis - Generally, we attempted to count a sum higher than 300 pollen grains per sample, however, the pollen sums were smaller in those less rich or sterile, obtaining an average total land pollen sum (TLP) of ~100 terrestrial pollen grains per sample. Taxa included in the TLP are considered indicators of regional vegetation. Pollen and fern spores were counted alongside microcharcoal particles (Kangur 2002). Fern spores were excluded from the TLP but expressed separately as a percentage of it. Stratigraphically constrained cluster analysis (total sum of squares method - CONISS, Grimm 1987) was applied to pollen and fern spore data to define palynological zones. TILIA and TILIAGRAPH software were used for illustration of the pollen and spore data calculations (Grimm 1987).

Results and Discussion

Sedimentology - Two sedimentological units (sand and silty clay) were recognized from the sampled column based on texture and grain size. However, fourteen informal sedimentological units were identified, displayed by six alternating colour types (brown, very dark gray, grayish brown, gray, olive, olive gray) (table 1).

Palynology - Thirty-seven sediment core samples were analysed which revealed a total of 100 identified pollen and spore types (table 2). The total counts of pollen grains, fern spores and charcoal particles are presented in Figure 3. Whilst level 200-195 cm was sterile and had no palynomorph content, others (180-175 cm and 145-140 cm) were less rich within the stratigraphic profile. Charcoal frequency increased to the top of the profile. The palynological diagram (figures 4 a-c) was divided into six zones (I-VI) with the aid of stratigraphically constrained cluster analysis based on marked changes in the palynomorph assemblage. Zone I (195-175 cm: 4 samples), Zone II (175-135 cm: 8 samples), Zone III (135-105 cm: 6 samples), Zone IV (105-80 cm: 5 samples), Zone V (80-50 cm: 4 samples) and Zone VI (50-0 cm: 10 samples). Data obtained showed appreciable representations of *Alchornea,* Amaranthaceae, Asteraceae, *Elaeis guineensis* and Poaceae in the studied samples.

Chronology of environmental changes - Two AMS-generated ^{14}C dates (table 3). The dates were obtained from the basal layer of the Awerele core and from the archaeological excavated unit Orile-Owu TP1.

Sedimentological and palynological analysis of Awerele sediment core revealed the sedimentological characterization of the sediment and palaeovegetation of the study area, respectively, with inferences on palaeoenvironmental conditions and human interactions with the environment after ~1,416 cal yr BP. The sampled column was basically two distinct lithofacies: silty clay lithofacies I (200 – 45 cm) and sand lithofacies II (45 – 0 cm) (table 1). The sediment profile displayed slight increase in siltation of the sediment and decrease in the level of sorting towards the top of the profile. Improved seasonality in rainfall that took place during the Late Holocene (Maley *et al.* 2018, Bayon *et al.* 2019). However, human actions may have also contributed to increasing sedimentation rates (Daraojimba 2016). In addition, lithostratigraphic observations suggest that the sediment was formed under reducing and poor drainage conditions based on the greyish and brownish colours identified for most of the units (Hassan 1978). At lithofacies II where siltation was greater, sediments were more greyish in colour, an attestation to the increasing poor drainage conditions. These phenomena also had an implication for good pollen preservation and representation as lithofacies II registered a higher frequency of pollen than lithofacies I. Similarly, upsurge in the representation of pioneer pollen types (*Alchornea, Antidesma, Bridelia, Cissus, Elaeis guineensis* and *Tetrorchidium*) and weeds associated with cultivated fields (Amaranthaceae and Asteraceae) were noted in lithofacies II. The appearance of weed types associated with cultivated

Table 1. Sedimentological characteristics of sediment core from Awerele, Orile-Owu, Nigeria.

Depth (cm)	Lithology	Lithofacies	Colour
10-0	Silty clay	I	Brown
15-10	Silty clay		Very dark gray
20-15	Silty clay		Grayish brown
40-20	Silty clay		Gray
45-40	Silty clay		Grayish brown
110-45	Clay	II	Gray
125-110	Clay		Olive
130-125	Clay		Brown
135-130	Clay		Olive gray
140-135	Clay		Brown
170-140	Clay		Olive gray
175-170	Clay		Brown
180-175	Clay		Gray
200-180	Clay		Brown

Table 2. Phytoecological groups and identified pollen-spore types for Awerele core, Nigeria. H= herb; T= tree; S= shrub; C= climber.

Main occurring environment	Pollen and spore types and their respective habit
Savanna	*Bombax costatum* (T), *Bridelia ferruginea* (S/T), *Keetia hispida* (S), *Hymenocardia acida* (S/T), *Lannea* cf. *microcarpa* (T), *Gymnosporia senegalensis* (S/T), *Maranthes kerstingii* (T), *Margaritaria discoidea* (S/T), *Phyllanthus reticulatus* (H), *Protea elliottii* (S), *Polygala* sp. (H), *Tapinanthus* sp. (C), *Uapaca heudelotti* (ST)
Lowland rainforest	*Alstonia boonei* (T), *Antidesma* cf. *vogelianum* (S/T), *Berlinia grandiflora* (T), *Berlinia confusa* (T), *Berlinia craibiana* (T), *Bombax buonopozense* (T), *Bosqueia angolensis* (T), *Canthium subcordatum* (T), *Canthium* cf. *vulgare* (S/T), *Ceiba pentandra* (T), *Celtis brownii* (T), *Celtis* sp. (T), *Chrysophyllum cainito* (T), *Cola acuminata* (T), *Daniellia pynaertii* (T), *Delonix* sp. (T), *Funtumia elastica* (T), *Holarrhena floribunda* (S/T), *Hymenocardia heudelotii* (S/T), *Irvingia* cf. *gabonensis* (T), *Jasminum* cf. *dichotomum* (S), *Lannea* cf. *welwitschii* (T), *Lonchocarpus sericeus* (T), *Mansonia altissima* (T), *Milicia excelsa* (T), *Morus* cf. *mesozygia* (T), *Peltophorum pterocarpum* (T), *Sherbournia bignoniiflora* (S), *Tetrapleura tetraptera* (T), *Tetrorchidium oppositifolium* (S), *Triplochiton scleroxylon* (T)
Weeds	*Ageratum conyzoides* (H), *Alternanthera* sp. (H), Amaranthaceae (H), *Aspilia africana* (H), Asteraceae (H/S), *Bidens pilosa* (H), *Chromolaena odorata* (S), *Emilia* sp. (H), *Euphorbia hirta* (H), *Lepistemon owariense* (C), *Oldenlandia corymbosa* (H), *Polydora serratuloides* (S), *Sida* sp. (H/S), *Sida* cf. *stipulata* (H), *Solanum* cf. *indicum* (H), *Tridax procumbens* (H)
Appear separately on pollen diagram	*Alchornea* sp. (S/T), *Elaeis guineensis* (T), Poaceae (H), Unidentifiable, Unidentified
Ubiquitous	*Berlinia* sp. (S/T), *Canthium* sp. (S/T), *Cassia* sp. (S/T), *Cissus* sp. (C/S), Combretaceae/Melastomataceae (S/C/T), *Commelina* sp. (H), *Euphorbia* sp. (S/T), Euphorbiaceae (H/S/T/C), Caesalpiniaceae (H/S/T/C), *Grewia* sp. (S/C/T), *Ixora* cf. *brachypoda* (S), *Lophira* sp. (T), Loranthaceae (S/T), Meliaceae (S/T), Mimosaceae (H/S/T/C), *Myrcia* sp. (S/T), Myrtaceae (S/T), Papilionaceae (H/S/T/C), *Prosopis* sp. (S/T), Salicaceae (S/T), Sterculiaceae (S/T), *Striga* sp. (H), Tiliaceae (H/S/T), *Triumfetta* sp. (S)
Secondary forest	*Adenia cissampeloides* (C), *Glyphaea brevis* (T), *Paullinia pinnata* (C), *Rauvolfia caffra* (T), *Spondias mombin* (T), *Tetrorchidium didymostemon* (S/T)
Fern spores	Monolete spores, Trilete spores
Freshwater swamp (Hydro-hygrophyte taxa)	*Ceratopteris* cf. *pteridoides* (H), Cyperaceae (H), *Ludwigia repens* (H), *Lygodium microphyllum* (H)
Freshwater swamp forest	*Leea guineensis* (S), *Spondianthus preussii* (T)
Montane forest	*Podocarpus* (T)

fields and pioneering forest pollen types, which colonize disturbed forest habitat (Maley & Chepstow 2001), suggest opening of the vegetation. The increasing erosion activity and pollen indicators of human activity noted in lithofacies II can be explained to have been initiated by a combination of natural and human induced factors.

Vegetation history and human interactions in Orile-Owu - Information on past vegetation patterns in Orile-Owu as inferred from pollen assemblages of the 200 cm core (figures 5-7). After ~1,416 cal yr BP, high proportions of tree pollen dominate the spectra of the Orile-Owu sequence. The tree pollen types mainly represent dry forest woodland taxa (*C. brownii, C. subcordatum* and *M. discoidea*). This is in accordance with increased proportion of dry woodland representatives after the mid-Holocene in the pollen diagram Lake Tilla, NE Nigeria (Salzmann 2000, Bayon *et al.* 2019). However, this pattern of occurrence of tree pollen in the mid-Holocene was not significant from the pollen data of this study, which spans the Late Holocene period. Although the pollen record gives no clear information on long term vegetational changes, it should be stressed that the vegetation was mostly forested with a mosaic of savanna pollen types during the period. The pollen assemblage was characterized by higher frequency of forest trees pollen relative to woodland savanna, coupled with pioneer pollen/ spore types, which suggested opening of the vegetation. The palynological zones identified are discussed below.

Zone I (195-175 cm; 1,416 to 1,306 cal yr BP; 1,490 ± 30 yr BP) - This zone is generally characterized by very low palynomorph content. The zone is marked by an initial period with the presence of a montane forest pollen type (*Podocarpus*). Lowland rainforest [*Canthium* cf. *vulgare*

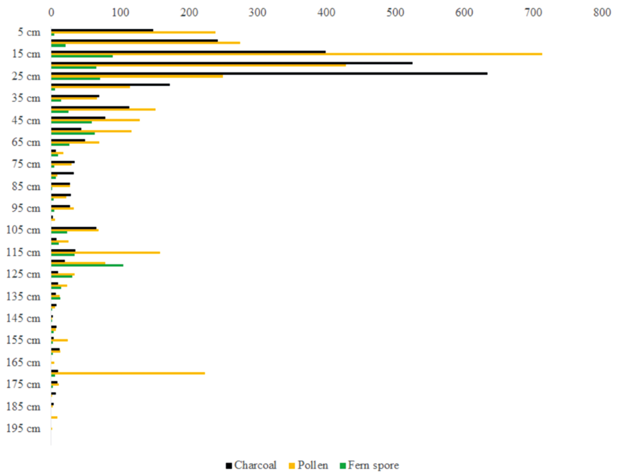

Figure 3. Total amount of pollen grains, fern spores and charcoal particles by stratigraphic level of sediment core from Awerele, Orile-Owu, Nigeria.

Figura 3. Quantidade total de grãos de pólen, esporos de samambaias e partículas de carvão por nível estratigráfico do testemunho de Awerele, Orile-Owu, Nigéria.

(50% at 185cm)], few ubiquitous pollen types [mainly *Cassia* (50% at 185cm), Combretaceae/Melastomataceae (11.1%, Caesalpiniaceae (33.3%) and *Prosopis* type (44.4%)], and low frequency of *Elaeis guineensis* (11.1%) (lower part of the zone) were identified coupled with very poor frequency of charcoal particles. It should be noted that *Podocarpus* moved to higher elevations at the beginning of the Holocene, hence its low values at lowland forests (Lézine *et al.* 2013), currently experienced in the site. Thus, areas where high occurrence of montane *Podocarpus* are recorded usually indicate cool and windy environmental conditions (Adeonipekun *et al.* 2017). Low values of anemophilous *Podocarpus* pollen in this zone and the local absence of the parent tree in the present-day vegetation of the area suggest the distant location of its parent tree and existence of strong air currents enabling pollen transport to the site in that period of time (Daraojimba *et al.* 2018). Re-occurrence of *Podocarpus* and other montane (1.5-3.8%) and dry forest elements just before 802 ± 29 yr BP in Tse Dura, Central Nigeria, revealed an event of cooler and drier conditions (Orijemie 2018). Similarly, low frequency occurrence of *Podocarpus* (0.2-0.4%) in recent sediments (126.5 ± 0.3 pMC) at Motako (Daraojimba *et al.* 2018), located about 6 km north of Orile-Owu, may suggest occurrence of similar climatic conditions that thrived around ~ 1,490 yr BP (AD 534 – 644) in Orile-Owu and the last century at the neighboring site, Motako.

Furthermore, as reported by Williamson (1993) based on linguistic evidence, oil palm (*Elaeis guineensis*) is heavily embedded in the cultural and ritual customs among the people of southern Nigeria just like other old indigenous plants including wine palm (*Raphia hookeri* Mann Wendl.), yams (Aerial yam - *Dioscorea bulbifera* Linn., and Guinea yams - *D. cayenensis* Lam. and *D. rotundata* Poir) and kola nuts (*Cola acuminata* (P. Beauv) Schott and Endl. and *C. nitida* A. Chev.). This suggests that the oil palm constitutes one of the earliest food plants exploited in southern Nigeria which goes back to Proto-Atlantic-Congo (Williamson 1993). Oil palm has been regarded as the second in economic importance to Guinea (Andah 1993) and the antiquity of its occurrence in archaeological deposits and perhaps utilization in the rain forest and woodland savanna zones of west and west central Africa stretches back to at least 5,000 yr BP (Sowunmi 1999, Umeji *et al.* 2012). However, its poor frequency at zone I in Awerele core cannot be argued to be an indicator for its utilization. Ordinarily, it is difficult to tell if the oil palm was cultivated or domesticated in the past from pollen records. This is because, as explained by Sowunmi (1999), oil palm increases also occur either during a dry phase or at the beginning of a wet phase when forests would have naturally cleared creating conditions for the oil palm tree to blossom. It is therefore paramount to put into consideration certain parameters, especially its pattern of occurrence, while interpreting the occurrence of oil palm pollen in sediment deposits. The sudden and appreciable increase in the oil palm pollen associated with decrease in forest trees and appearance of weeds of cultivated land or waste places could suggest opening of the forest due to farming activities (Sowunmi 1985, Daraojimba *et al.* 2018). Pollen data from Ohe pond in Nsukka, southeast Nigeria, suggest drier climatic conditions around 1,470 ±79 yr BP and human activities that may have contributed not only to the increase in *Elaeis guineensis* but also maintained the derived savanna vegetation of the area (Njokuocha & Akaegbobi 2014). On the contrary, as mentioned previously, the occurrence of *E. guineensis* at this zone cannot be associated with human activities as there is no evidence to infer such. Low charcoal values at the upper part of the zone are associated with low representation of rain forest pollen (*Canthium* cf. *vulgare*).

Zone II (175-135 cm; Post 1,416 to 1,306 cal yr BP; After 1,490 ± 30 yr BP) - This zone showed fluctuating frequencies of charcoal particles with percentage increases of *Alchornea* (7.7-33.3%), *E. guineensis* (4.1-28.6%), Poaceae (1.4-28.6%), pollen of some weed plants which made their first appearance in this zone [mainly *Alternanthera* (14.3%), Amaranthaceae (16.7%), *Aspilia africana* (16.7%), Asteraceae (0.9-36.4%) and *Chromolaena odorata* (8.3-14.3%)], secondary forest [mainly *Paullinia pinnata* (4.2%) and *Spondias mombin* (2.3%)] and fern spores (1.4-28.6%). The appearance of weeds of cultivated places or disturbed areas in this zone in appreciable frequencies coupled with increasing frequencies of pioneering forest pollen types (*Alchornea* and *E. guineensis*) and *Canthium subcordatum* (4.2%) which thrives in more open parts of high forest, suggest disturbance of the vegetation perhaps not necessarily by humans, but by some natural disturbance at the local vegetation. Low charcoal values continue to be represented in this zone like the previous zone. Pollen of *E. guineensis* (4.1-38.5%) occurred in fluctuating frequencies but increased in this zone in association with percentage increase of some weed plants. Ubiquitous vegetation was represented in this zone by Combretaceae/Melastomataceae (0.5%), *Striga* type (0.5%), *Myrcia* sp (25%) Myrtaceae (4.2-16.7%) and Euphorbiaceae (4.2%). Increased diversity of weeds and appreciable quantities of freshwater swamp vegetation, mainly Cyperaceae (45.5%) and fern spores were noted in this zone. The sudden appearance of hydro-

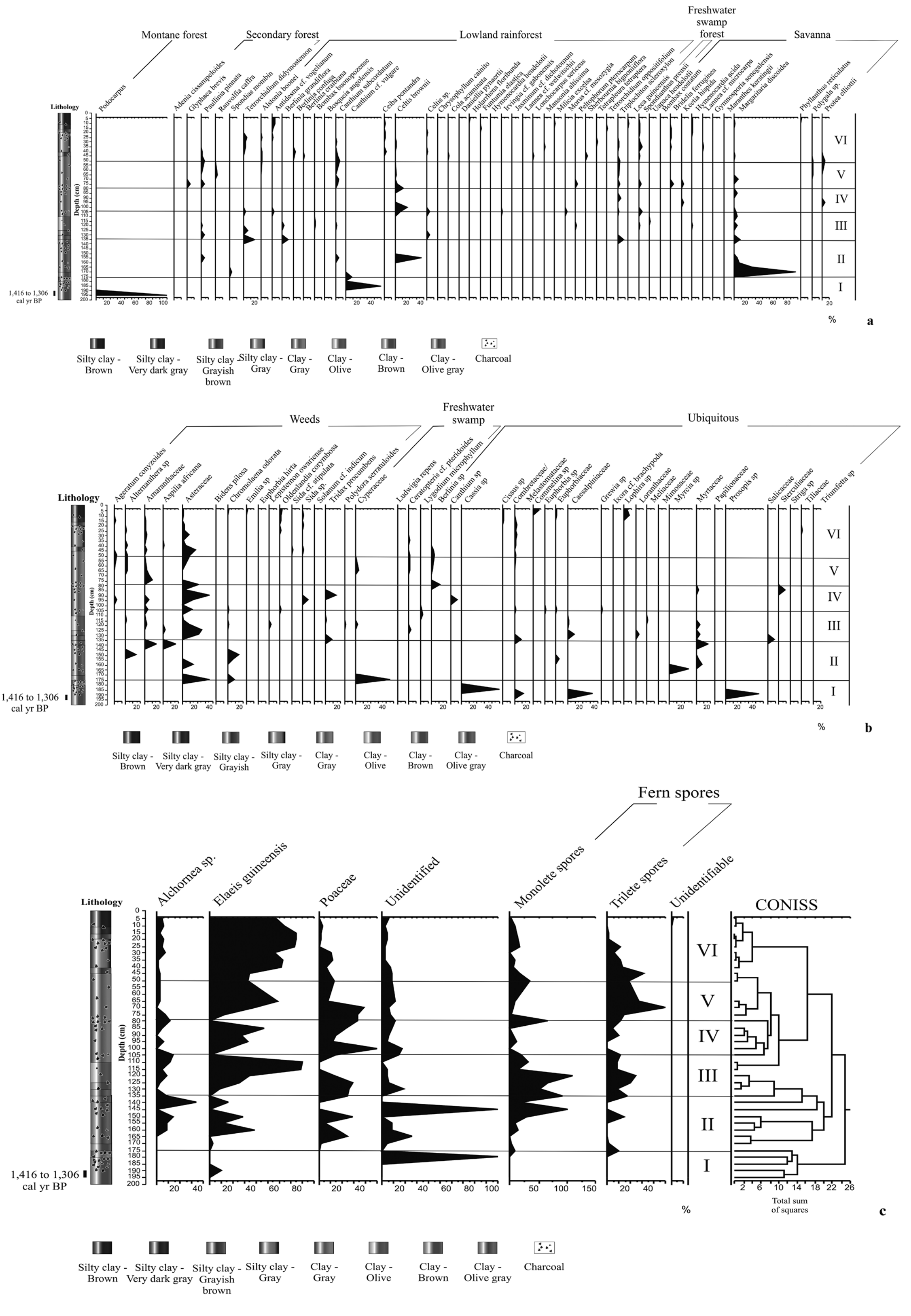

Figure 4. Palynological diagrams with phyto-ecological groups and selected taxa for Awerele core, Orile-Owu, southwest Nigeria. The silhouettes show the percentage curves of the taxa. CONISS cluster analysis together with the six Palynological Zones (separated by solid lines) were plotted. Values are expressed as percentages of the total land pollen sum (TLP). Diagram a. Forest and Savanna vegetation. Diagram b. Weeds, Fresh water and Ubiquitous vegetation. Diagram c. *Alchornea* sp., *Elaeis guineensis*, Poaceae, Unidentified pollen types, Fern spores and Unidentifiable types.

Figura 4. Diagrama palinológico com grupos fitoecológicos e táxons selecionados do testemunho de Awerele, Orile-Owu, sudoeste da Nigéria. As silhuetas mostram as curvas percentuais dos táxons. Análise de cluster CONISS juntamente com as seis zonas palinológicas (separadas por linhas sólidas) foram plotadas. Os valores são expressos como porcentagens da soma total de pólen terrestre (TPT). Diagrama a. Vegetação de floresta e savana. Diagrama b. Ervas daninhas, vegetação de áreas úmidas e vegetação ubíqua. Diagrama c. *Alchornea* sp., *Elaeis guineensis*, Poaceae, Tipos polínicos não Identificados, Esporos de samambaias e Tipos Não Identificáveis.

Table 3. Results of AMS (Accelerator Mass Spectrometry) radiocarbon ages for Awerele core (Orile-Owu, Nigeria), showing conventional age in yrs BP and calibrated ages (2σ) in cal yrs BP. BP: before present; AD: Anno Domini; AD 1950; cal: Calibrated.

Source	Sample depth (cm)	Dated material	Lab. code	14C age year BP	Calendar age range (cal year BP) [a]	Calibrated AD range	$^{13}C/^{12}C$ (‰)
Sediment core	195-190	Organic sediment	Beta-415569	1,490 ± 30	1,416 to 1,306	534 to 644	- 27.5
Archaeological excavation unit - Orile-Owu TP1	70-60	Charred palm kernel endocarp	Beta-403755	350 ± 30	412 to 315	1,538 to 1,635	- 22.9

[a] Calibrated ages are calculated from IntCal 13 (Reimer et al. 2013), which assumes a two-sigma error on radiocarbon measurements with an error multiplier of 1.0.

hygrophyte taxa (Cyperaceae), fern spores and high percentage of weeds suggest wet conditions at this point in time. However, Fern spores and weeds decreased at level 170 cm and there was disappearance of hydro-hygrophyte pollen (Cyperaceae) coupled with a preponderance of the pollen of *Margaritaria discoidea* (86.5%) (a natural forage plant used nowadays to feed sheep) which thrives in moister parts of savanna and drier parts of the forest, especially on old farmlands (Hutchinson & Dalziel 1958). This swift transition from short wet period to dry conditions may have been climatically influenced. Drier conditions may have encouraged the proliferation of *M. discoidea* because *Celtis brownii* (37.5%), which thrive in drier parts of the forest regions, was also noted in high frequency in this zone. In Africa, *Margaritaria discoidea,* which is a protein-rich leafy feed, could serve as a supplement to poor quality grass to small ruminants during dry season (Osakwe *et al.* 2000, Duku *et al.* 2010). This post-fifth to seventh century AD period (after 1,300 yr BP) perhaps corresponds to the earlier Volta period drought phase in Banda, Ghana lasting from about AD 1,000 to 1,300 (Logan & Stahl 2017). Although no ^{14}C date was obtained for this level, it is believed that this 11th to 14th century AD (approximately 1,000-700 yr BP) drought period noticed in Ghana appears to correspond to this zone. Pollen evidence from Central Gabon suggested that the dry season recorded between 8th to 15th century AD period (1,240 and 550 cal yr BP) was more prolonged and severe than today (Ngomanda *et al.* 2005).

Zone III (135-105 cm) - This zone is characterized by continued high Poaceae proportions (12.7-28.6%), an increase in fern spores (7.7-108.9%) and pioneering types, and maximum values of *Elaeis guineensis* (8.7-80.8%). Savanna pollen types (1.3-8.3%) and hydro-hygrophyte taxa (2.5-2.9%) were generally poorly represented in this zone. On the contrary, there was increased diversity of lowland forest represented by *Berlinia grandifolia* (2.5-8.3%), *Bombax buonopozense* (1.3%), *Canthium subcordatum* (2.5%), *Celtis* sp. (4.4%), *Irvingia gabonensis* (0.6%), *Mansonia altissima* (1.3%), *Peltophorum pterocarpum* (1.3%) and *Triplochiton scleroxylon* (8.33%), secondary forest represented by *Paullinia pinnata* (1.3-4.4%) and *Tetrorchidium didymostemon* (0.6-16.7%) and weeds represented by *Ageratum conyzoides* (0.6%), *Alternanthera* sp. (0.6%), Amaranthaceae (2.5%), *Aspilia* (2.9%), Asteraceae (1.3-25.7%), *Chromolaena* (2.5%), *Lepistemon owariense* (1.3-2.5%), *Tridax procumbens* (0.6-8.3%) and *Polydora serratuloides* (1.3%). *Alchornea* (2.9-11.5%) occurred in relatively lower values and freshwater swamp forest (0.6-1.3%) made its first presence in this zone. The continuous appearance of weed types associated with cultivated fields and pioneering forest pollen types (*Alchornea, E. guinensis,* and *Tetrorchidium*), which colonize disturbed forest habitat, suggest opening of closed canopy forests. Meanwhile, some elements of canopy close forest (*Berlinia*, *Canthium* and *Celtis*) (Ngomanda *et al.* 2005) were also noted in this zone, perhaps indicating relict of these forests. Low charcoal values were also recorded in the earlier part of the zone but there was a slight increase at the upper part corresponding to the increase of *E. guineensis* pollen. It is common that native vegetation areas were burnt to foster *Elaeis guineensis*.

Zone IV (105-80 cm) - This zone showed the increase in Poaceae (12.2-50%) and diversity of weeds was maintained as in the previous zone represented by *A. conyzoides* (3%), Amaranthaceae (4.3-6.1%), Asteraceae (3.7-36.4%), *C. odorata* (1.4%), *Oldenlandia corymbosa* (1.4%), *Sida* sp. (6.1%) and *Tridax* (13.6%). *Elaeis guineensis* (16.7-48.2%) and fern spores (3.7-12.1%) occurred in lower frequencies compared to zone III. Lowland forest pollen [*Antidesma vogelianum* (2.9%), *Celtis brownii* (7.1%-16.7%), *Celtis* sp. (4.3%), *Irvingia* cf. *gabonensis* (1.4%), *Morus* cf. *mesozygia* (2.9%) and *Triplochiton scleroxylon* (1.4-4.6%)] declined at the upper part of the zone after an initial relatively higher representation of *Celtis brownii* (16.7%) at the lower part of the zone. There was a slight further increase in *Alchornea* (3.7-14.3%) and the frequency of charcoal occurrence compared to the previous zone. The dominance of pollen types representing taxa of drier forest types such as *Celtis*, *Margaritaria discoidea* and *Morus* cf. *mesozygia* (2.9-16.7%) in the lower part of the zone suggest drier conditions during that period. This drier period, assumed to date to the 16th century (or younger), may be correlated to an interval of droughts about 1,450-1,650 AD, documented in Banda, Western Central Ghana. This so-called Kuulo and Atlantic period was distinctly drier than the recent Sahel droughts in the late 1960s and early 1970s (Logan 2016, Logan & Stahl 2017). Also, as noted by Maley & Venet (2015) a similar drying phase of the Lake Chad (Sahelian zone of West-Central Africa) occurred within the same period dating to the middle of the fifteenth century (AD 1,450)

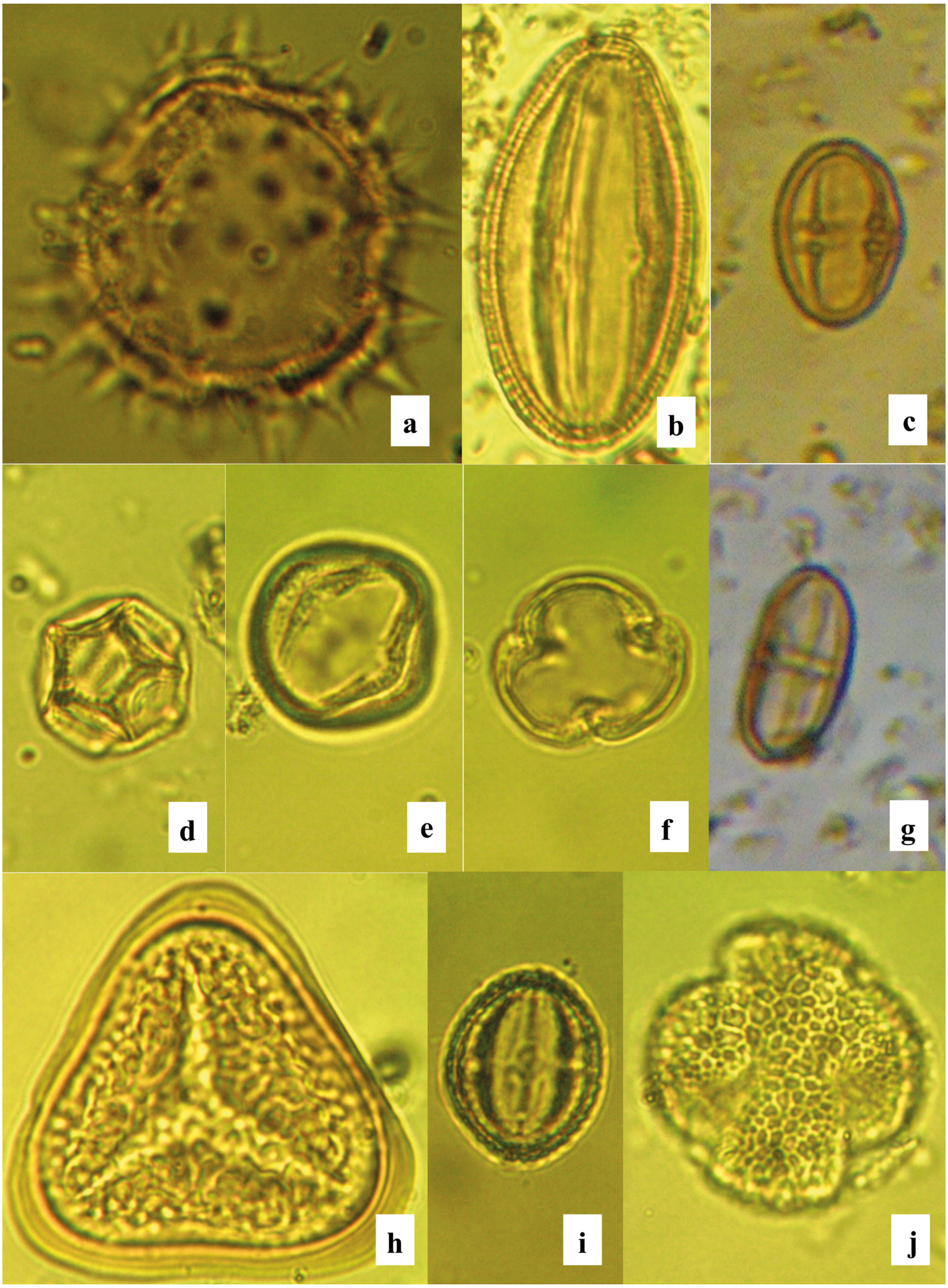

Figure 5. Pollen and spores from Awerele core, Orile-Owu, southwest Nigeria. a. *Tridax procumbens* (Asteraceae). b. *Cissus* sp. (Vitaceae). c. *Spondianthus preusii* Euphorbiaceae). d. *Alternanthera* sp (Amaranthaceae). e-f. *Alchornea* sp. (Euphorbiaceae). g. *Antidesma* cf. *vogelianum* (Euphorbiaceae). h. Fern spore/Trilete i. *Margaritaria discoidea* (Phyllanthaceae). j. *Citrus* cf. *sinensis* (Rutaceae). Magnification x1000 (a-j).

Figura 5. Pólen e esporos do testemunho de Awerele, Orile-Owu, sudoeste da Nigéria. a. *Tridax procumbens* (Asteraceae). b. *Cissus* sp. (Vitaceae). c. *Spondianthus preusii* Euphorbiaceae). d. *Alternanthera* sp. (Amaranthaceae). e-f. *Alchornea* sp (Euphorbiaceae). g. *Antidesma* cf. *vogelianum* (Euphorbiaceae). h. Esporo de samambaia/Trilete. i. *Margaritaria discoidea* (Phyllanthaceae). j. *Citrus* cf. *sinensis* (Rutaceae). Magnificação x1000 (a-j).

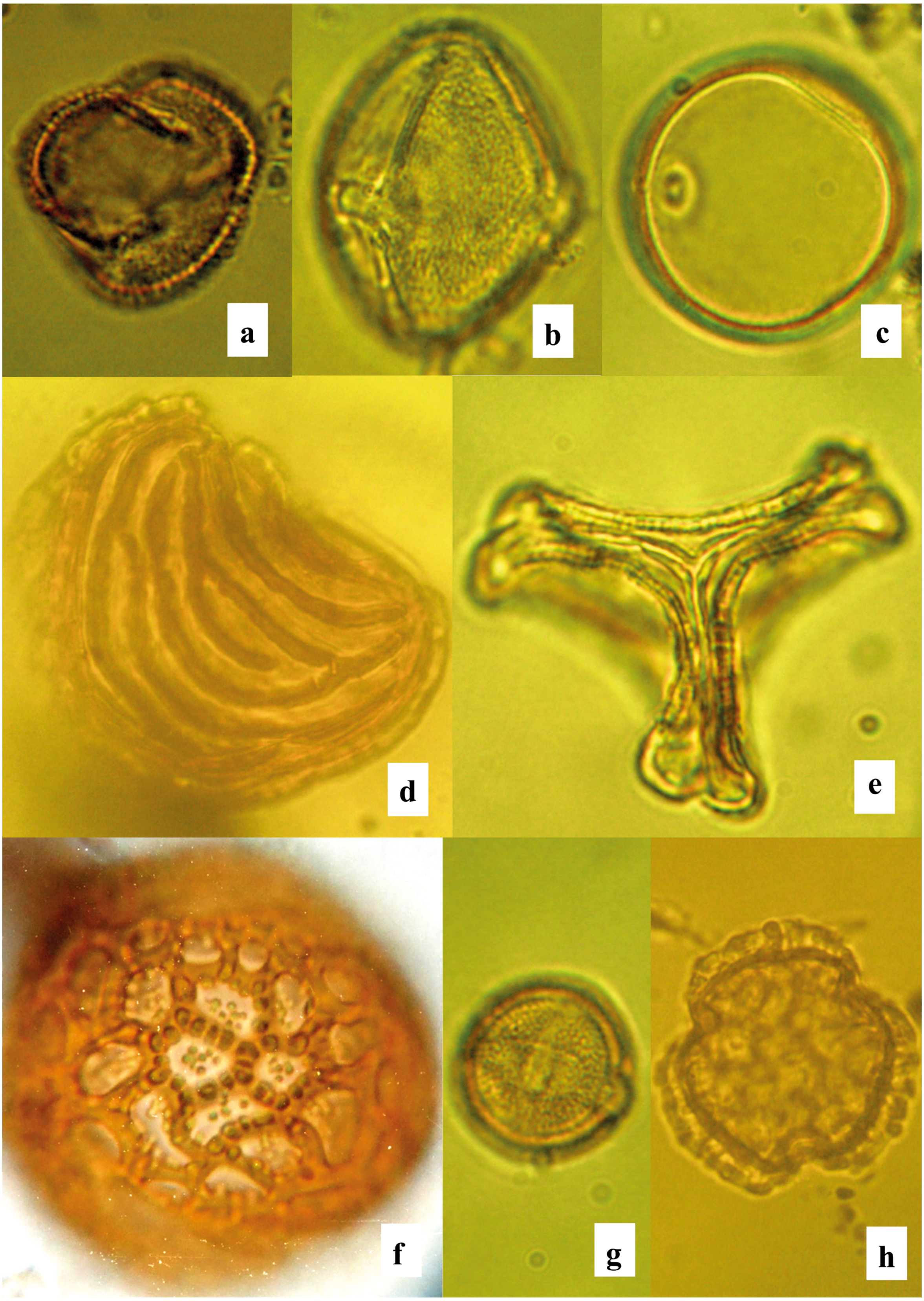

Figure 6. Pollen and spores from Awerele core, Orile-Owu, southwest Nigeria. a. *Tetrorchidium didymostemon* (Euphorbiaceae). b. *Spondias mombin* (Anacardiaceae). c. Poaceae. d. *Ceratopteris pteridoides* (Pteridaceae). e. *Tapinanthus* sp (Loranthaceae). f. *Delonix* sp (Fabaceae). g. *Ixora* cf. *brachypoda* (Rubiaceae). h. *Peltophorum pterocarpum* (Fabaceae). Magnification x1000 (a-c, e-g), x400 (d, h).

Figura 6. Pólen e esporos do testemunho de Awerele, Orile-Owu, sudoeste da Nigéria. a. *Tetrorchidium didymostemon* (Euphorbiaceae). b. *Spondias mombin* (Anacardiaceae). c. Poaceae. d. *Ceratopteris pteridoides* (Pteridaceae). e. *Tapinanthus* sp. (Loranthaceae). f. *Delonix* sp. (Fabaceae). g. *Ixora* cf. *brachypoda* (Rubiaceae). h. *Peltophorum pterocarpum* (Fabaceae). Magnificação x1000 (a-c, e-g), x400 (d, h).

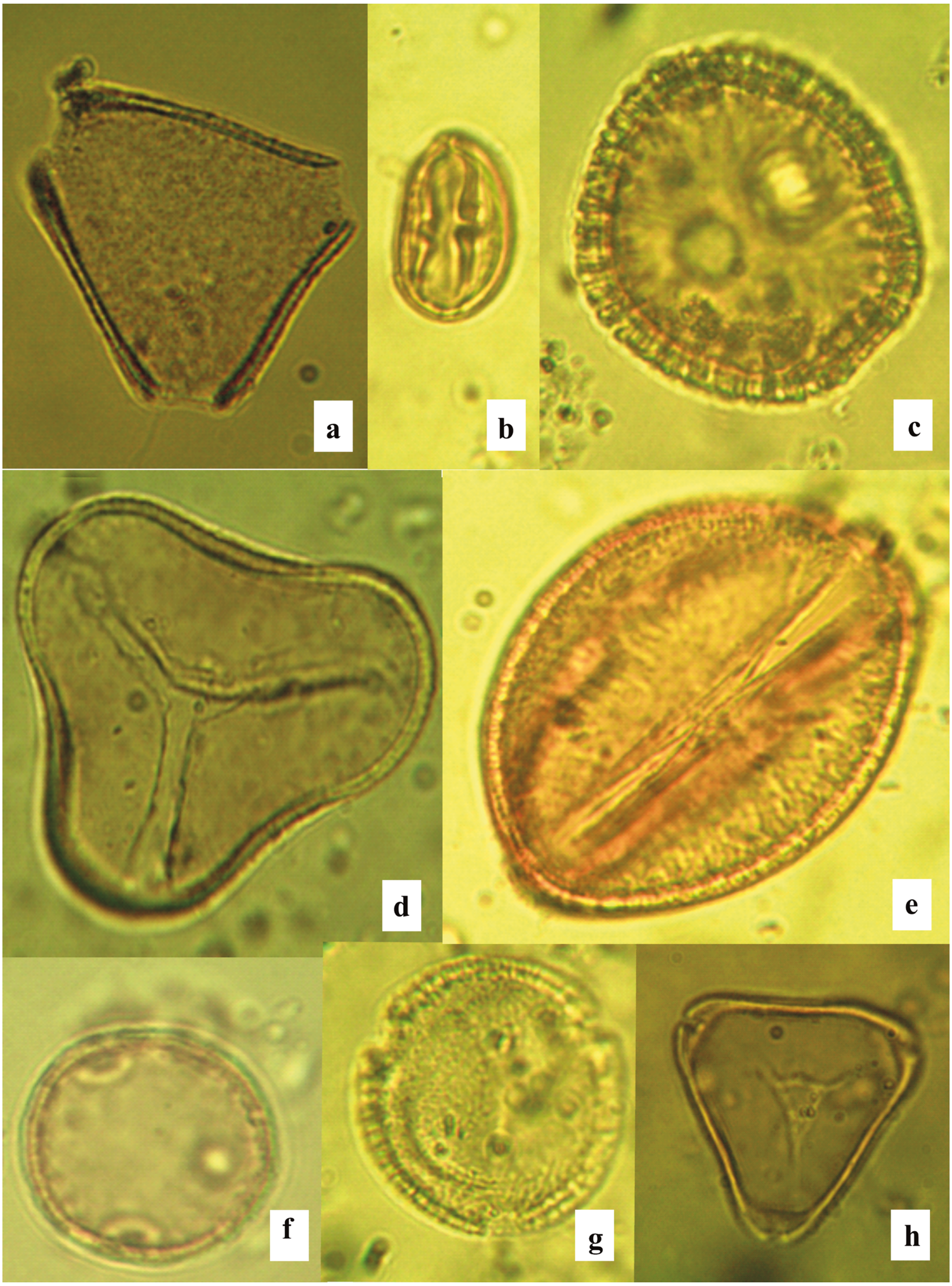

Figure 7. Pollen and spores from Awerele core, Orile-Owu, southwest Nigeria. a. *Paullinia pinnata* (Sapindaceae). b. Salicaceae. c. *Canthium* sp (Rubiaceae). d. *Elaeis guineensis* (Arecaceae). e. Caesalpiniaceae. f. *Celtis* sp (Cannabaceae). g. *Triplochiton scleroxylon* (Malvaceae). h. Myrtaceae. Magnification x1000 (a-h).

Figura 7. Pólen e esporos do testemunho de Awerele, Orile-Owu, sudoeste da Nigéria. a. *Paullinia pinnata* (Sapindaceae). b. Salicaceae. c. *Canthium* sp (Rubiaceae). d. *Elaeis guineensis* (Arecaceae). e. Caesalpiniaceae. f. *Celtis* sp (Cannabaceae). g. *Triplochiton scleroxylon* (Malvaceae). h. Myrtaceae. Magnificação x1000 (a-h).

leading to abandonment of the area and declining population. Correspondingly, the Little Ice Age (AD 1,400-1,750) drought of central Africa coincides with this time period for the western Africa drought in contrast to wet conditions in eastern equatorial Africa (Russell & Johnson 2007). Savanna pollen types (*Keetia hispida*, *Margaritaria discoidea* and *Protea elliottii*) continue to be represented in low quantities (2.9-3.7%), likewise freshwater swamp forest (4.3%) which also was less diverse.

Zone V (80-50 cm) - This phase represents a lot of climatic instability or a periodically flooded environment. There was increase in the pollen of *E. guineensis* (13.3-59.2%) towards the top of the zone coupled with appreciable representation of fern spores (3.3-66.7%) and presence of weeds of cultivated fields (2.8-22.2%) alongside some secondary forest elements, mainly *Glyphaea brevis*, *Paullinia pinnata* and *Rauvolfia caffra* (2.8-3.3%). This zone may not have been as dry as the previous zone due to low micro carbons and good representation of fern spores (*Lygodium* and *Ceratopteris*) which are characteristic of swamp or flooded environments. Lowland rainforest pollen types decreased in diversity in this zone, a possible effect of the aftermath of the dry phase recorded in the previous zone which may have led to the opening of the forest. This is supported by the presence of open and dry forest elements, mainly *C. brownii, C. subcordatum* and *M. discoidea* (1.4-11.1%). *Alchornea* sp. (2.8-11.1%) decreased from the bottom to the top of the zone, while Poaceae occurred in fluctuating frequencies (7-38.9%). Savanna pollen types (*Bridelia ferruginea* 3.3%, *Keetia hispida* 3.3%, *Margaritaria discoidea* 5.6% and *Polygala* 1.4%) were poorly represented, in a similar way as freshwater swamp forest (3.33%) and hydro-hygrophyte taxa (1.4-4.2%).

Zone VI (50-0 cm) - *Elaeis guineensis* frequencies increase to about 75.6%. Together with increased charcoal proportions and reduced records of weedy plant taxa, these vegetation changes suggest intense burning activities for subsequent cultivation. This zone can be associated with a period when human settlement would have been fully established in the Orile-Owu area and human activities would have become conspicuous on the cultural landscape of the region. Reduction in Poaceae (grasses) and hydro-hygrophyte taxa (sedges) coupled with peak in pioneer pollen type (*E. guineensis*) is a possible indication of natural response of forest species regrowth (Sowunmi 1999). The increased diversity of pioneer pollen taxa was similarly noted in this zone, mainly *Alchornea*, *Antidesma, Bridelia*, *Cissus, Lophira*, *Tetrorchidium* and *Triumfetta,* occurring within a range of 0.4-7.0%. *Cissus*, *Lophira* and *Triumfetta* pollen types occurred for the first time in the sediment profile, an indication of increasing colonization by forest pioneer species. The increasing activity of pioneer forest taxa in this zone is corroborated by the identification of *Lophira* (2.1%) and *Elaeis guineensis* (44%) pollen grains at the topmost (0-2cm) layer of the excavated unit (Daraojimba 2016).

In addition, there was a remarkable increase in diversity of lowland rainforest pollen (0.1-5.9%) characterized by the presence of tree pollen belonging to closed canopy forest mainly *Bosqueia, Celtis, Daniella* and *Lannea*, a reflection of significant change in forest dynamics. Pollen of Poaceae (0.4-12.7%), secondary forest (0.3-4.2%), hydro-hygrophyte taxa vegetation (0.2-1.5%) and fern spores (1.4-34.8%) decreased. Multiple reappearance of *Ceratopteris* in this zone, after a single initial appearance at zone III (125-120 cm), in association with *Ludwigia repens* and freshwater swamp forest pollen types (*Leea guineensis* and *Spondianthus preusii*) may indicate wet conditions. This is corroborated by the increased siltation noted in the sedimentological profile of the sediment.

Due to the association of this zone to a phase that correlates with when humans would have fully settled in the area, the identification of certain plant taxa in the pollen record was interpreted to signify the possibility of being exploited by humans for various purposes. The plants ethnobotanical significance was determined based on anecdotal evidence from oral sources (Daraojimba *et al.* 2018). In this zone was identified pollen of *Tetrorchidium oppositifolium*, a shrub or small tree harvested from the wild for local use as medicine (Burkill, 1985). Other pollen of plants with medicinal properties represented in this zone included *Alstonia boonei, Cola acuminata* (ritual), *Hymenocardia acida, Spondianthus preusii* (for ringworm treatment) and *Bridelia ferruginea* (for skin infection treatment). *Aspilia* (for asthma and diabetes treatment), *Chromolaena* for malaria treatment (Idu & Onvibe 2007), *Leea guineensis, Oldenlandia corymbosa* (for fever treatment in children) and *Tetrapleura tetraptera* (for typhoid treatment and for food seasoning).

Conclusions

This study provides evidence for palaeoenvironmental conditions and vegetational dynamics that existed in Orile-Owu over the past ~1,416 cal yr BP (1,490 ± 30 yr BP, 534 to 644 AD). Local vegetation changes at Orile-Owu fit into regional, sub-saharan Africa vegetation fluctuations. The Awerele palynological data show the persistence of a forest-savanna mosaic during the period, with dry phases during the 11th-14th centuries AD and 15th-17th centuries AD. Archaeological data presently available indicate that humans occupied the Orile-Owu area from 300 to 500 years ago. This period of human occupation may correspond to Zone III (135-105 cm) of the sediment core where weeds of cultivated fields, remarkable increase in the pollen of *Elaeis guineensis*, and increasing charcoal frequency were noted. Increased sedimentation rates towards the top (45-0 cm) corroborates the opening of the vegetation documented by means of pollen analysis. It may however be difficult to rule out the contribution of enhanced climatic seasonality for the increased erosional activity at the top of the sediment profile. However, pollen types indicating human impact on the vegetation are numerous. Pioneer taxa (represented by *Alchornea*, *Antidesma*, *Bridelia*, *Cissus*, *Elaeis guineensis* and *Tetrorchidium*), weeds and taxa with ethnobotanical significance, may indicate increased human interference in the Orile-Owu vegetation, especially after the last five hundred years.

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Author contributions

Kingsley Chinedu Daraojimba: Substantial contribution in the concept and design of the study; contribution to data collection; contribution to data analysis and interpretation; contribution to manuscript preparation.

Cynthia Fernandes Pinto da Luz: Contribution to data analysis and interpretation; contribution to critical revision, adding intellectual content; contribution to manuscript preparation.

Marcia Aguiar de Barros: Contribution to data analysis and interpretation; contribution to critical revision, adding intellectual content.

Conflicts of interest

There is no conflict of interest.

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