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Research Article
Palynological Analysis of Late Holocene Sediments and its Paleoenvironmental Interpretations from Lagos Coastal Environment, Southwestern Nigeria

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Abstract
Background and Objective: Information from the distribution of palynomorphs is used to infer past vegetation changes and paleo-climatic settings, characteristic of a particular environment. This palynological studies aimed to assess the distribution of palynomorphs and reconstruct the past vegetation and make inferences on the paleoclimate of a late Holocene core. **Materials and Methods:** Sediments samples were collected at intervals of 3 cm to a depth of 51 cm using a universal peat corer and subjected to standard palynological procedures. Prepared slides were studied with both light and scanning electron microscope. Photomicrograph of some recovered palynomorphs was imaged using Zeiss merlin scanning electron microscope. Lithological analysis and standard accelerated mass spectrometry (AMS) was also carried out to provide a calibrated accurate ratio of ^{14}C and ^{13}C dates. **Results:** Five palynoecological groups were recognized to include mangrove, freshwater swamp, riverine/lowland rainforest and fern spores suggestive of a humid climate. Absolute ages from radiocarbon dating showed the study sediments were deposited around the last 111.8$\pm$0.4 BP indicating the late Holocene. Lithology, pH and salinity analysis revealed a miscellany of sedimentary depositional environment in which the recovered palynomorphs were preserved. **Conclusion:** Significantly the study revealed the disappearance of mangrove vegetation notably *Rhizophora* sp. and *Acrosticum aureum*, while open vegetation dominated recovery indicating an increase in human influence on the study area.

Key words: Late holocene, vegetation, paleoclimate, lagos, palynomorphs

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The knowledge of past vegetation and climatic history is important to evaluate human impact in regions where population growth, agriculture and urbanization are increasing geometrically. Pollen preserved in sediments or peat bogs and wet lands have been used to reconstruct past vegetation and to infer the paleoenvironment with respect to changes in climate over time particularly when integrated with lithological studies[1]. These changes are most evidently reflected in vegetation, which is part of the biological components of an environment. More so, the distribution and composition of tropical west African vegetation is strongly linked to the prevailing climatic conditions[2,3]. Sowunmi[3] reported that a close relationship exists between vegetation and other components of the environment, particularly climate and soil and affirmed that the flora of an area provides a good reflection of the major climatic regime of that area. Booth postulated that there are alternating periods of wet and dry climatic conditions in west Africa in the Quaternary period which consequently influenced the type of vegetation present in the prevalent climatic conditions[4]. While other researchers, from their study of a 2072 cm core, broadened the knowledge of the Holocene vegetation and climate history in KwaZulu-Natal which could be linked to regional and global climate change. They found that there was a marked decrease in *Podocarpus* with a corresponding increase in the mangrove swamp, riverine forest, Chenopodiaceae/Amaranthaceae, Grasses and *Phoenix* during[5] the late Holocene after ca. 3600 cal yrs BP. In Nigeria, most palynological studies are largely concentrated on the tertiary of the Niger Delta oil and gas producing region where stratigraphic data are investigated in the process of searching for oil fossils, to the detriment to other major locations and areas in need of paleovegetation reconstruction and paleoclimatological study. However, Sowunmi[6] studied an 11 m terrestrial core from Ahanve, a village in the western part of the Lagos coastal environment and reported an abrupt decrease and a subsequent disappearance of *Rhizophora* pollen during the late Holocene which was replaced by freshwater vegetation. Orijemie and Sowunmi[7] also carried out some archaeological and palynological works in the same location and reported a changing vegetation setting. Adekanmbi and Ogundipe[8] compared pollen and spore assemblages recovered from the shoreline of the floor of the Lagos lagoon and off coast sediments from the hinterland of the same lagoon. Other palynological studies involve quaternary sediments from University of Lagos but there is no record of the wetland environment[9-11]. Therefore, considering the importance of plants and the emerging drastic changes currently taking place in the environment of Lagos the present study was undertaken to examine the past ecological changes, that prevailed over time, assess the distribution of this necessitated the present study to assess the distribution of palynomorphs and examine changes in the past vegetation and paleoclimate in the late Holocene of the Lagos coastal environment to complement the very few reported palynological studies in southwestern Nigeria especially the Lagos coastal environment.

MATERIALS AND METHODS

Study site: This study was carried out from February, 2016 to April, 2017 with sampling on the 20th, February 2016. Ologun wet land is a coastal environment located along river Oshun in Alakuko town on the boundary between Lagos and Ogun state, Nigeria (Fig. 1). It lies between latitude 6°45'0.30"N and Longitude 4°73'0.55"E. The climate of the area is a tropical wet and dry based on the Köppen climate classification system with mean annual rainfall and temperature of about 1800 mm and 27°C, respectively[12]. The area is dominated by two main seasons (the rainy and dry seasons), the rainy season is characterized by two wet periods. The strongest and the first wet period lasts between April and July while the second and weaker wet period between September and November. In between these wet periods is a relatively dry period in August-September commonly referred to as the "August Break". The main dry season lasts from December-March and is usually characterized by harmattan winds from the North-East Trade Winds and dominated currently by secondary swamp vegetation.

Sample collection: A total of 18 samples were collected at a 3 cm interval from 0.00 to a depth of 51 cm using a Universal peat corer and transferred into sealed sample bags[13]. The samples were then subjected to palynological, lithological and pH analysis. The map of the location (Fig. 1) was developed by using coordinates obtained with a global positioning system GPS in Arc GIS software by the author.

Samples treatment: The sediment samples were treated following standard palynological methods. These include Hydrofluoric acid (HF) treatment for the removal of siliceous materials; Hydrochloric acid (HCl) for the removal of carbonaceous materials, heavy liquid separation (separating palynomorphs from sediments) and acetolysis to destroy cellulosic materials and darken palynomorphs for easy identification[14].

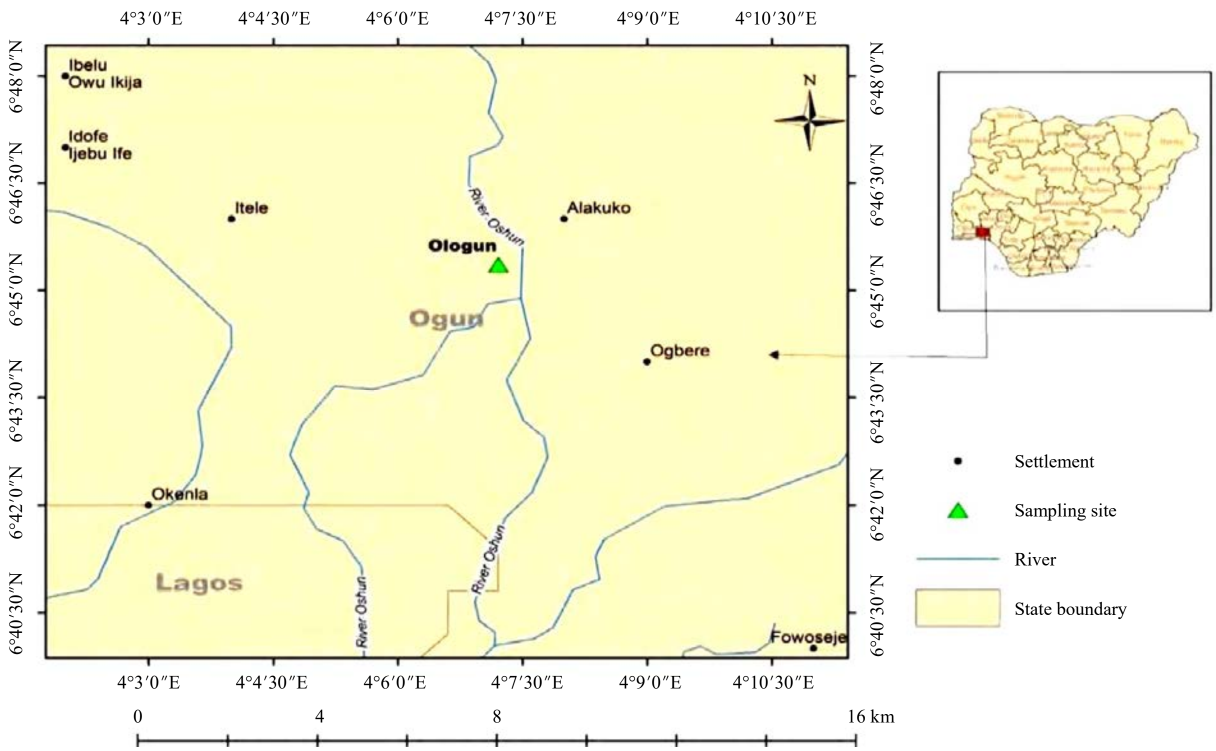

Fig. 1: Map of the study site (designed by author)

Pollen identification: Identification of pollen grains and spores were achieved by comparing the morphological characters with published descriptive keys of African pollen grains and spores pollen albums and other reference collections in the Department of Botany, University of Lagos[15-20]. Imaging of pollen and spores was done by mounting prepared samples onto standard 12 mm aluminum SEM stubs on the scanning electron microscope and sputter-coated with a thin layer of gold to enhance conductivity, then visualized with a Zeiss Merlin Field emission scanning electron microscope using an accelerating voltage of 2-3 kV and Inlens Secondary Electron (SE) and SE2 detection. Images were captured as TIFF using a store resolution of 2048 x 1536 pixels.

pH test and lithology: The pH values of the samples were determined to investigate their acidity or alkalinity with the aid of a digital pH meter. To calibrate the pH meter, standardized pH solutions of 4 and 9 was used. Five grams of each sample was dissolved in distilled water in plastic cups, stirred and shaken vigorously to form a solution. The pH electrode was then inserted into the solution and values were noted and recorded. The lithological analysis was done by washing the sediments with distilled water using a 63 µm sieve. The sediments were oven dried, examined and described with the aid of Grain Size Comparator and Analyzer. Rock Color Chart, stereo binocular microscope and hand-held magnifying lens at X40 magnification.

Radiocarbon dating: Standard Accelerated Mass Spectrometry (AMS) was carried out on the top, middle and bottom sediment samples at Beta Analytic Inc. 4985 S.W. 74 Court Miami, Florida. USA, following a simplified approach to calibrating ^{14}C Dates reported earlier by Stuiver and Robinson[21]. Furthermore, only pollen grains and spores, identified to specific, generic or familial level, as recommended by Moore and Webb[22] were selected to constitute the pollen sum. The pollen diagram was constructed using Tilia graph computer software after Grimm[23].

Statistical analysis: Mean and standard deviation were performed on the different ecological groups.

Pollen zones and phytoecological groupings: Pollen zones were recognized based on the changes in abundance values of the recovered palynomorphs and the use of palynoecological groupings. To construct the pollen zones, phytoecological groupings was done for all the recovered palynomorphs in the study. These palynoecological groups were recognized based on the present day distribution of variously identified plant taxa following[3,24-29].

RESULTS

pH, salinity and lithology: The pH revealed a slightly acidic to alkaline medium with values ranging from 5.20-6.80. The salinity did not show much variation and values range from 0.02-0.10 ppt (Table 1). Also, three sedimentary units were recognized from the lithological analysis (Table 1). The lithologic unit I: Depth 51/48-33/36 dominated by very fine grain sand, micaceous and brownish. Lithologic unit II: Depth 30 to 15/18 very fine grain sand, micaceous and brownish but no plant materials recorded. Lithologic unit III: Depth 12 to 9/3 Light brown, loose very fine grain sand, containing lots of plants materials and capping the surface with a dark brown, silty sand with lots of plant materials.

AMS Radiocarbon ^{14}C dates: Table 2 shows absolute ages from the radiocarbon dating and revealed sediments from the study location were deposited around the last 111.8+/-0.4 BP.

Palynological analysis: A total of 1,453 palynomorphs was recovered from the palynological analysis is recorded in Table 3. Nymphaea lotus, *Cyclosorus* sp., *Acrostichum aureum* and *Alchornea cordifolia* dominated the recovery with 197, 164, 159 and 128 pollen grains, respectively. While Poaceae, Elaeis guineensis, *Symphonia globulifera* and Cyperaceae also have a relatively high occurrence in the pollen assemblage with 94, 68, 62 and 44 palynomorphs (Table 3). Across the studied depths, depth 00 and 42 recorded the highest palynomorphs with 244 and 112 representing 16.8 and 7.7% while depths 12, 15 and 18 had the lowest count of 48 each and 30 representing 3.3 and 2.1%, respectively (Table 3).

Figure 2 showed the three delineated pollen zones and 7 palynoecological associations generated from the percentage composition of the recovered palynomorphs. It was characterized by variation/fluctuation over time of the occurring phytoecological groups which include mangrove, freshwater swamp, rainforest species, fern spores and open forest vegetation/savanna (Fig. 2).

Photomicrograph: Plate 1a-l shows the photomicrographs of selected recovered palynomorphs imaged using the Zeiss Merlin Field Emission Scanning Electron Microscope revealing distinct morphological characters that ensure accurate identification of the fossil pollen grains and spores. Significantly Asteraceae and Malvaceae pollen looks alike under light microscope on light microscope (LM) due to its low power resolution but were properly identified with Scanning Electron Microscope (SEM) with a very high resolution power.

Table 1: The pH, salinity and lithological description of study location

Depths (cm)	pH	Salinity (ppt)	Lithological description
0	6.40	0.10	Dark brown, silty sand with lots of plant materials
3	5.20	0.10	Light brown, loose very fine grain sand, containing lots of plants materials
6	5.60	0.10	Light brown, loose very fine grain sand, containing lots of plants materials
9	5.60	0.10	Light brown, loose very fine grain sand, containing lots of plants materials
12	6.20	0.10	Very fine grain, sandstone, rich in muscovites (loose sand)
15	6.50	0.03	Very fine grain sand, micaceous and brownish but no plant materials recorded
18	6.60	0.03	Very fine grain sand, micaceous and brownish but no plant materials recorded
21	6.40	0.03	Very fine grain sand, micaceous and brownish but no plant materials recorded
24	6.50	0.04	Very fine grain sand, micaceous and brownish but no plant materials recorded
27	6.50	0.04	Very fine grain sand, micaceous and brownish but no plant materials recorded
30	6.50	0.03	Very fine grain sand, micaceous and brownish but contain plant materials with lots of trace fossils
33	5.70	0.03	Very fine grain sand, micaceous and brownish
36	6.70	0.02	Very fine grain sand, micaceous and brownish
39	6.30	0.03	Very fine grain sand, micaceous and brownish
42	6.70	0.02	Very fine grain sand, micaceous and brownish
45	6.30	0.03	Very fine grain sand, micaceous and brownish
48	6.50	0.03	Very fine grain sand, micaceous and brownish
51	6.80	0.03	Very fine grain sand, micaceous and brownish

Table 2: AMS ^{14}C dates of study location

Sample data	Measured radiocarbon dates	Isotope results o/oo	Conventional radiocarbon age
β-456307			
Ologun0-3 cm	102.7±0.4 pMC	d13C = -30.3	103.8±0.4 pMC
β-456308			
Ologun48-51cm	111.8±0.4 pMC	d13C = -25.4	111.9±0.4 pMC

Table 3: Recovered palynomorphs across the studied depths

Palynomorphs/depths	Poaceae	Arecaceae (Palmae)	Sapotaceae	Cyperaceae	*Alchornea cordifolia*	*Elaeis guineensis*	Chenopodaceae-	Am aranthaceae	*Nymphaea lotus*	Rutaceae	*Acrostichum aureum*	Mimosaceae	Ceasalpinceae	*Cyclosorus* sp.	Euphorbiaceae	Microforaminiferal wall	Monosulcate pollen	Meliaceae	Combretaceae/Melastomac	*Symphonia globulifera*	*Rhizophora* sp.	Polypodiaceae	*Tridax pr ocumbens*	*Celtis* sp.	Malvaceae	Pediastrum	Asteraceae	Pollen indeterminate	Fungal spore	Trilete spore	Monolete spore	Spores indeterminate	Laevigatosporites	Total
0	15	11	12	16	30	13	3	34	0	12	0	0	7	0	1	0	0	1	7	1	2	6	7	9	1	7	6	29	8	2	1	3	244	16.79
3	6	9	0	4	5	6	1	18	3	12	5	1	7	3	1	0	0	1	0	0	1	1	1	6	0	1	0	11	0	1	0	0	104	7.158
6	7	7	0	5	11	8	2	11	0	8	3	0	4	2	1	2	0	1	6	0	0	1	0	7	1	1	1	8	0	1	1	3	102	7.020
9	6	4	0	2	3	11	1	10	0	9	0	0	0	0	0	5	2	2	2	1	1	1	0	1	1	1	0	8	0	2	1	2	76	5.231
12	7	0	0	1	5	7	1	0	0	1	0	0	0	1	1	0	0	0	0	0	3	4	0	0	1	1	2	12	0	1	0	0	48	3.304
15	6	0	0	6	0	11	2	0	0	0	0	0	0	0	0	0	0	1	7	2	0	2	1	1	0	0	2	7	0	0	0	0	48	3.304
18	6	0	0	2	0	5	1	0	0	0	0	0	0	0	1	2	0	0	0	0	2	0	1	0	0	3	0	5	1	0	0	1	30	2.065
21	13	0	0	1	0	3	0	0	0	0	0	0	6	0	0	1	4	1	3	1	0	0	4	2	0	0	3	4	0	0	0	0	46	3.166
24	11	0	3	0	5	2	1	6	0	0	0	0	9	1	2	3	3	2	11	0	4	2	0	1	0	1	4	7	0	0	0	0	78	5.368
27	1	0	0	4	5	0	1	2	2	12	0	0	9	0	0	0	2	0	0	1	2	0	1	1	0	3	0	5	2	0	2	2	57	3.923
30	2	0	0	0	0	0	1	6	6	19	0	0	17	3	0	2	1	0	0	1	0	2	0	0	0	1	5	5	0	0	0	1	72	4.955
33	1	0	5	0	6	1	0	9	2	10	5	0	19	1	0	5	2	0	7	0	1	0	0	0	0	5	1	6	0	0	0	0	86	5.919
36	2	0	1	1	2	0	0	14	1	0	2	0	0	0	0	0	2	0	0	3	0	0	0	0	0	2	0	2	0	0	0	1	33	2.271
39	1	0	0	0	7	0	0	22	0	0	0	0	0	0	0	2	3	0	9	2	1	0	0	0	1	1	0	2	1	0	0	0	52	3.579
42	1	0	0	0	9	1	0	25	0	17	3	0	27	0	0	3	0	0	9	5	2	1	0	0	0	2	3	3	0	0	0	1	112	7.708
45	3	0	0	2	11	0	0	11	2	22	0	0	19	0	0	0	0	0	0	2	4	1	0	0	0	0	0	4	0	1	0	0	82	5.643
48	2	0	0	0	14	0	0	24	0	19	0	0	21	0	0	0	0	0	1	3	4	0	0	0	0	0	1	5	0	0	0	2	96	6.607
51	4	0	0	0	15	0	0	5	0	18	0	0	19	0	0	0	0	0	0	5	1	1	0	0	0	0	3	9	1	0	0	6	87	5.988
94	31	21	44	128	68	14	197	16	159	18	1	164	11	7	25	19	9	62	27	28	22	15	28	5	29	31	132	13	8	5	22	1453	100	

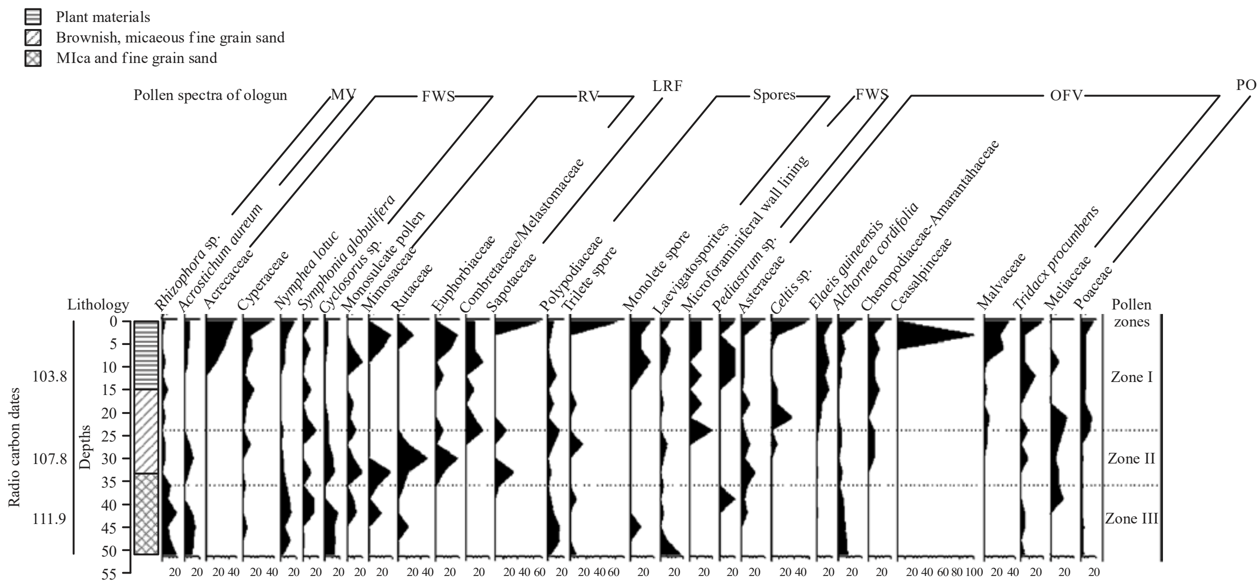

Fig. 2: Pollen diagram showing percentage palynomorphs for each phytoecological group, pollen zones, lithology and radiocarbon dates

MV: Mangrove vegetation, FWS: Freshwater swamp, RV: Rainforest vegetation, LRF: Lowland rainforest, OFV: Open forest vegetation and PO: Poaceae

DISCUSSION

The recovered pollen grains and spores revealed the vegetation pattern of the different ecological zones in Nigeria namely mangrove, freshwater swamp, riverine/lowland rainforest, open forest and savanna which indirectly reflect the paleoclimatic conditions. The lithology of the basal section of the core, 51-36 cm, 111.9 cal B.P, (Wet Phase) was dominantly very fine micaceous and brownish grain sand which may have been deposited during channel over-flooding or overbank deposit agreeing with earlier report by Adeonipekun *et al.*[10]. The occurrence of mangrove, freshwater swamp, riverine, fern spores and spot presence of freshwater algae are indicative of a wet paleoclimatic phase supported[30]. Also, the botanical shreds of evidence are suggestive of a well-established mangrove surrounded by an extension of freshwater swamp and rainforest vegetation confirming the works of other researchers[3,31]. *Rhizophora* pollen is indicative of the presence of minor and short-lived salt-water swamp in the locality and the salinity of 0.2-0.3 ppt. found within the freshwater range, is indicative of likely varied levels of freshwater inundation into the study location at different period of deposition supported earlier[9,32]. The dominance of micaceous and brownish fine grain sand with no recorded plant materials at 36-24 cm 107.8 cal B.P (Transitional Wet/Dry Phase) suggests the long transport of sediments before deposition during over bank deposit confirming the work of Durugbo *et al.*[29]. The occurrence of mangrove, freshwater swamp, riverine, fern spores and open forest/Poaceae is suggestive of a transitional wet/dry paleoclimatic phase. A more dominantly wet type is suggested, relative to the dry for this period, this is evidently supported by the less occurrence in Poaceae and open forest group and agreed with previous study[9]. Also, the occurrence of fern spores, riverine, lowland rainforest, freshwater swamp and mangrove vegetation though duly represented are indicative of yet a wetter condition in prior agreement[6]. This is supported by another researcher[31], who reported that the recovery of fern spores and freshwater swamp from sediments is indicative of a humid condition. This might have been a transitional period between the rainforest and savanna representatives, associated with an apparent establishment of a secondary forest probably influenced by anthropogenic activities.

The period 103.8 cal B.P, 24-0.00 cm (transitional wet/dry phase) recorded the highest recovered and more diverse palynomorphs, the salinity fall within the range generally considered conducive for palynomorph preservation according to previous study by Adeonipekun *et al.*[10] and Poumot[28] and the intercalation of very fine grain sand, micaceous and brownish capped by a thin layer of top soil layer consisting of dark brown, silty sand with lots of plant materials accounts for the high recovery and indicates that, the location was a marginal inland part of an estuary and never freshwater until the present time and

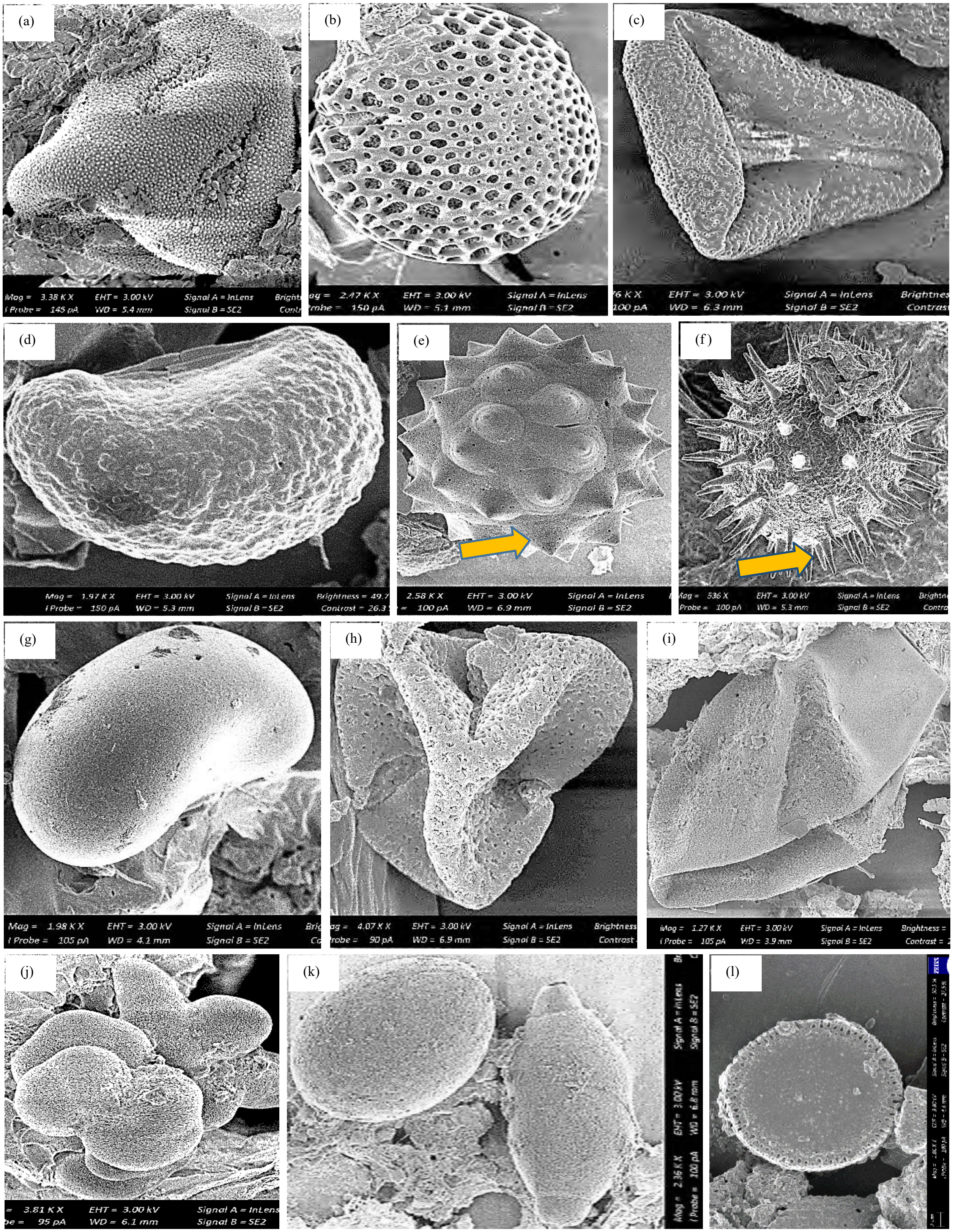

Plate 1(a-l): Scanning electron photomicrographs of some recovered palynomorphs: (a) *Cyperus* sp., (b) Amaranthaceae, (c) *Elaeis guineensis*, (d) *Cyclosorus* sp., (e) Asteraceae, (f) Malvaceae, (g) *Ceratopteris* sp., (h) Trilete spore, (i) Arecaceae, (j) Microforaminiferal wall linings, (k) Fungal spores and (l) Algae cyst agreed with earlier research[29]. The representation of freshwater swamp, riverine, lowland rainforest, fern spores with peak occurrences of freshwater algae, open forest vegetation and Poaceae suggested a transitional wet/dry paleoclimatic cycles, probably caused by an incidence of climatic instability[6,7]. Where it analyzed cored samples from four different communities of the Niger Delta, Nigeria to check changes in vegetation and revealed that, the reduction in forest species and a concomitant expansion of Savanna was due to adverse dry climatic conditions. The peak occurrence of freshwater algae *Pediastrum* sp. and the sea incursion indicator micro foraminiferal wall linings indicate the near shore environment of deposition possibly following a sea level fall in a transitional paleoclimatic phase and is supported by Durugbo *et al.*[29]. Furthermore, significant vegetation changes have occurred in this study site, transiting from a more mangrove and rainforest vegetation to a secondary and savanna setting probably due to human-induced activities over time.

Therefore, it is expedient for active conservation strategies to be employed in order to avoid the absolute extinction of mangroves and rainforests in the environment considering their importance for future generations.

CONCLUSION

The palynological analysis of late Holocene sediments around the coastal environment of Lagos has enabled the reconstruction of changing paleovegetation patterns. The palynoecological groups delineated and documented also indirectly reflected the paleoclimatic conditions which exhibited fluctuations between the wet and dry paleoclimatic cycles.

SIGNIFICANCE STATEMENT

This study discovered changes in vegetation especially the drastic reduction to the almost non-occurrence of the mangrove vegetation and a fluctuating climate considering the benefits derived from them to mankind. This work will help to provide a better understanding of vegetation responses to alternating environmental conditions and contribute to palynological and climatic studies of the late Holocene.

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