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Sedimentological and Paleoecological Research Techniques, with Applications to the Environmental History of Loboi Swamp, Kenya

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Abstract

This research involved sedimentological and paleoecological research techniques, with application to the environmental history of Loboi Swamp (Kenya) in the context of water-resource management and wetland conservation. The analyses included non-destructive scanning of sediment cores (magnetic properties, water content, colour spectroscopy, digital photography), determination of bulk sediment composition (organic matter, carbonate, mineral sediments), grain-size analysis, and aquatic invertebrate remains. This was undertaken at Ghent University, department of Biology in the Limnology research unit.

Keywords: Sedimentology; Paleoecology; Loboi, Swamp; Wetland; Limnology

Introduction

The use of paleolimnological and paleoecological proxies (indicators) has been established to provide important information on past environmental changes in aquatic ecosystems, especially in situations where there is lack of past data, either due to the fact that it was not possible to monitor the focus parameters or because the cost of monitoring was too high to afford at the time. Precisely, this is the situation in many tropical lake ecosystems, resulting in high scarcity of past and present ecological data [1]. This has mostly been as a result of lack of research funding especially on biological indicators of ecosystem health. In addition the remoteness of some of the sites and lack of research facilities hinder accessibility and sound data collection.

The use of the variety of biological and geochemical indicators found preserved in lake sediments have proved vital in reconstruction of past environmental change, and more so past climate patterns [2]. Paleolimnological techniques are powerful also due to the fact that they centralise (integrate) information brought in from a large region of landscape surrounding the wetlands and deeper water bodies. Sediment sources are thus of either autochthonous (aquatic) or allochthonous (terrestrial) origin [3]. The main source of allochthonous materials emanate from rivers and streams, which transport organic and inorganic matter and chemicals into lakes and swamps. In addition, pollen dust and other particulates can also fall into the wetlands from the atmosphere. Autochthonous sources include chemical precipitation and biological remains such as decomposing plant and animal materials that can contribute to the sediment's composition [4]. Hence, information retrieved from the sediments can be used to infer changes that have occurred within and around the water body, which in turn allow the reconstruction of past environments through proper qualitative or quantitative interpretation of sediment materials.

Lake sediments contain a wide range of biological, physical and chemical data that can be used to trace the past history of a wetland and the wetland catchment [5]. With the assumption that very little or no disturbance of the sediments occurred over the years since their original deposition, lake sediments at the bottom can be said to be the oldest in terms of the period of deposition and chronologically followed by successively younger deposits higher up, which leads to formation of a timescale profile of information over tens or hundreds of years.

Most often, so-called multi-proxy studies are implemented that recover information of various proxies from the same sediment record. Some of the most commonly used biological proxies includes shells of snails and ostracods, the head-shields, post-abdomens and claws of cladocerans, the mouthparts of midge larvae, skeletal elements of diverse other aquatic invertebrates and also plant remains [1,5]. These biological components of sediments have proved vital in providing information on the environmental events and perturbations that may have affected a given wetland or lake over the years, such as acidification of water, change in water levels and fire events.

The use of aquatic invertebrates as environmental proxies is supported by the fact that organisms always prefer to inhabit regions or habitats with optimum conditions for their survival and reproduction [6]. Hence, due to this species preferences, the presence of or absence particular species, or the composition of an entire community is expected to change along environmental gradients such as temperature, salinity, pH or nutrient availability. Subsequently, the use of single species to indicate the ecological status of a given ecosystem can prove to be of vital importance as an indicator. Rather than looking at individual species, preference is placed on the information derived from the overall structure and composition of communities and their interactions with environmental variables that dictate the abundance and distribution of each species present.

The use of aquatic invertebrates in paleolimnology as indicator species has been practised for decades to infer changes in aquatic habitats and also on climatic changes. For instance, cladocerans, which fall under class Crustacea, are now widely studied and can generally be grouped into either planktonic (Bosmina or Daphnia) or littoral (Chydorids) water fleas [7]. Both groups are commonly used and mainly well preserved in sediments to facilitate species-level identification and permitting their use as indicators of past environmental events [5].

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Being entirely aquatic organisms, the use of cladocerans in climate reconstruction is pegged on the species' sensitivity to changes in water temperature, salinity and water levels over the years. Studies by Lotter et al. [8] demonstrates that air temperature changes, which in turn affect water temperature, can be correlated to cladoceran species assemblages with a given degree of certainty. In addition, they have also portrayed potential to estimate changes through time in fish populations. This is possible due to the close and well-understood relationship between the size structure of zooplankton communities and the visual predation by fish. The importance of cladocerans in aquatic food webs and the significant cascade effect exerted by fish populations on these food webs make it possible to reconstruct past changes in fish abundance and distribution [9]. For example, Verschuren and Marnell [10] reconstructed changes in abundance of cutthroat trout in Avalanche Lake in the USA. Armed with prior knowledge of the feeding habits of cutthroat trout on Daphnia, the abundance and size of Daphnia ephippia (resting eggs) recovered from lake sediments were used to infer the fish density at the time, and from it the history of fish stocking.

Also aquatic invertebrates from the class Phylactolaemata (Bryozoa) are often retrieved from sediment cores. Bryozoans found in freshwater ecosystems occur as sessile, either individual or colonial organisms and live attached to hard substrates such as leaves, stems of macrophytes, rock surfaces and on large aquatic invertebrates such as clams. The most commonly found remains of bryozoans are the encapsulated resting stages; the adult animals themselves are hardly recovered due to their poor preservation in sediment.

Concerning non-biological sediment properties, magnetic susceptibility (MS) is the level to which a given sediment material can be magnetised. Mostly depending on the amount of mineral inorganic materials within the sediment, it has been applied as a proxy indicator since environmental magnetism was founded in the 1970s [11]. Variations in magnetic susceptibility along a sediment core can be used to infer changes in mineral soil sources and hence aid in recognition of statigraphic changes which are valuable in providing information on changing patterns of sedimentation within a wetland or lake ecosystem. Soil minerals, especially those containing iron (magnetite and maghemite) are more easily magnetised than other sediment constituents [12].

Coupled with other geochemical techniques such as grain-size analysis, which analyses the particle size comprising the sediment material (fine and course soil particles), can be analysed to reveal the possible sources and mode of transportation of the sediments into the sediment beds. For instance, fine sediment material may indicate slow and low energy transportation of material originating from sheet erosion of the upper fine soil component. On the other hand, large-sized materials require higher energy transport mechanisms. Furthermore, the loss-on-ignition technique can provide additional information on the composition of the sediment material, in terms of water content, carbon material and the mineral component.

Problem statement

From the early 1920s, major land-use events occurred within the major catchment areas of Tugen and Lembus forest areas in Baringo County, Kenya. Widespread forest excision and inappropriate land-tenure systems were awarded to timber milling companies. Large-scale deforestation and logging activities took place with little or no substantial conservation efforts, leading to massive degradation of these catchments [13].

With reduced areas of pastureland for local herders and escalating cattle raiding, some local communities opted for agricultural practices; employing fallow irrigation to foster their production. This resulted in extensive degradation due to poor farming systems. These land-use changes are believed to have played a significant role in the strong reduction in water levels in both Lake Bogoria and Lake Baringo in the early 2000s. In Lake Baringo the increased sedimentation combined with shallow depth has created high turbidity and loss of transparency, which affected the aquatic productivity. Consequently, fish catch per unit effort within Lake Baringo greatly dwindled.

However, recently there have been erratic heavy rainfall patterns within the region, thought to be linked to global climate change. Due to loss of ecological function of the catchment in terms of water retention and infiltration, there has been frequent heavy runoff and gully erosion resulting in flash floods. With this increased rainfall and extensive runoff, most of the rift-valley lakes, especially Bogoria and Baringo are experiencing an all-time high in water levels that has left behind severe damage to houses and local livelihoods. The water chemistry of hyper-alkaline Lake Bogoria has drastically changed, affecting the development of the algae that the millions of lesser flamingos are highly dependent upon. On the positive side, in Lake Baringo the high lake level has now greatly diminished bottom resuspension, which increased transparency and benefited both aquatic productivity and fisheries.

The recent increase in water levels has rekindled the debate on what are the major drivers of this event, and lake-level changes in general. With global climate change and local land-use changes at the centre of it all it would be highly valuable to understand and determine the magnitude of long-term dynamics of various aquatic ecosystems located within these regions.

Connecting the climate and human-driven paleohydrological histories of several sites around the wetland (through linking with the sediment records of lakes Bogoria and Baringo), the paleoecological records derived from Loboi swamp will be useful to determine the magnitude of natural long-term dynamics of this particular aquatic ecosystem, and the number of times it may have dried out in the past millennium. This has immediate relevance to long-term wetland and water-resource conservation. In addition, this paleoecological information will provide increased knowledge about what kind of environmental variability the endemic tilapia has lived through.

This research mostly involved sedimentology, basic geochemistry, and analysis of the fossil remains of aquatic insect larvae (e.g., chironomids) in new cores collected within Loboi swamp. This was useful to frame paleoecological variables within the wetland. It also aided in obtaining better dates on the timing of past flooding events.

Study area

Loboi Swamp is a 1.5 km^2 freshwater wetland situated just north of the equator in the central Kenya Rift Valley, on the drainage divide between lakes Bogoria and Baringo within extensive Baringo county. The region has a local semi-arid tropical climate with an estimated four to one ratio between potential evaporation and rainfall. Loboi Swamp serves as an important reservoir of freshwater during regional drought, and a moderator of river flow into Lake Baringo. The swamp is fed by water from three main surface springs: Lake Bogoria spa spring, Chelaba spring and Turtle spring. Due to the consistent seepage and flow of the springs, it is suggested that local aquatic ecosystems may have persisted even during past episodes of severe climatic aridity when Lake Baringo and other Rift lakes stood completely dry [14].

Loboi Swamp serves an important role of habitat provision for a wide range of biodiversity. For instance, the large herds of common zebras, ostrich, wild pigs, hippopotamus, over 300 wetland-dependent bird species, marsh mongoose, tortoise, crocodiles, several snake species. In addition, the wetland is a vital resource to the local community residing within the Loboi, Sandai and Kapkuikui areas. With their main economic activity being small scale-farmers they highly rely on the wetland freshwater for irrigation activities. Several canal channels have been constructed with the help of the government to avail water to individual farms.

Also, a substantial number of livestock are heavily dependent on the wetland flood zone for pasture throughout the years.

Materials and Methods

Three cores were collected in July 2014 from Loboi swamp, Baringo Kenya. The cores were retrieved with a rod-operated single-drive piston corer (Wright, 1980) operated from the mud surface. The core site was selected with proximity to Ashley's et al., [14] previous core site as main reference(Figure 1), however better accessibility aided by reduced water levels within the wetland made it possible to access part of the deepest area on the western side of the wetland. The longest core section, LOB14-1P I, measured 101.8 cm and reached almost to the base of the swamp deposit. The second core section, LOB14-1P II, measured 10.0 cm and was retrieved from the same hole to form a continuous core profile that includes the base of the deposit and the underlying desiccation surface. A third core section LOB14-2P I, measured 22.4 cm and was cored about a meter away from the first core. This core (2P) was meant to act as an overlap between the first and second section of core 1P. This was achieved by driving the corer to a depth of 101 cm below the surface before securing the piston and applying force on the drive rod to penetrate the sediment. All the cores were collected in polycarbonate tubes, sealed by topping the top of the cores with foam and sealed by duct tape. They were transported intact to Ghent University and stored in the cooler.

Reference to the 3 cores

- 1P I: 101.8 cm total length
- 1P II: 10.5 cm total length
- 2P I: 22.4 cm total length

Non-destructive scanning of sediment cores Splitting of cores

Splitting was done longitudinally into two halves using a vibrating electric saw in preparation for scanning, imaging and analysis of the sediment core. One of the core halves to be used for the analysis of LOI, retrieval of plant and aquatic invertebrate remains and grain-size composition was stored in the cooler for later analysis.

Imaging: The best half of all three split cores was selected and cleaned for imaging and scanning. Imaging was done with a digital line-scan camera. Correct resolution was set for best imaging, and the images were processed to obtain a continuous photograph for the entire length of each of the three cores.

Scanning: This involved scanning of the cores using different sensors on the Geotec MSCL (Multi-Sensor Core Logger) to obtain different spectral information values: gamma density, colour spectrophotometry and magnetic susceptibility (MS). The three cores were scanned by all 3 sensors and the data were saved in the Geotec computer for later retrieval and analysis.

Composite construction: Using the data derived frm the MS, density values and the colour photograph for all the three sections, single sediment composite composing all three sections was constructed to form a single depth profile. This was achieved by firstly using the entire depth profile of 1-PI and then joining it with 1-PII to form a continuous profile (since 1PII was retrieved in the same core hole as 1-PI. In order to make a continuous profile with 2-PI, a section from both 1-PII and 2-PI graphs with almost similar MS and density values was objectively identified and an overlap made from this section. The lower section of 1-PII (6.3 cm - 10.5 cm) and the upper section 2-PI (0-7.6 cm) where the overlap was sought to be were deleted and the remaining sections joined to form the continuous composite.

Bulk sediment composition

Grain-size analysis: Samples for grain-size analysis were subsampled from the working half of each core section. Using the information derived from the MS sensor, which indicates probable differences in sediment composition, and from the scanned high-resolution images a sampling interval of every 2 cm was done along the entire length of the 3 sediment cores using the composite depth scale to sample the correct interval in each section. A total of 59 sediment samples were retrieved to represent a continuous depth sediment profile [15] (composite depth).

The sampled sediments were placed in pre-weighed 15 ml vials and the initial weight of the sediments was measured, recorded and the vials labelled. 5 ml of 10% HCl was added to each sample to help in removal of the carbonate components in the soil sediments, they were placed in the oven at 80°C for 5 hours, with shaking intervals every hour. The samples were then retrieved from the stove, centrifuged at 3500 rpm for 8 minutes then HCl was decanted and the samples rinsed 2 times using deionised water. 5 ml of 30% hydrogen peroxide was then added to all the samples to help in destroying the organic matter in the sediments. The samples were then placed for 7 days in the stove at 65°C to catalyse the reaction, and later the samples were left at room temperature for another 2 weeks to ensure complete destruction of the organic matter.

The samples were then rinsed twice with deionised water. 7 ml of 2 M sodium hydroxide was added to the samples to dissolve the biogenic silica and the samples were placed in the stove for 2 hours at 90°C. The samples were then rinsed twice with deionised water, using the shaker to ensure complete removal of the sodium hydroxide. 6 ml of 0.05 M sodium polyphoshate was added to the samples to help in dispersal of coagulating sediment and the samples were left overnight prior to analysis of the grain sizes. The analysis was carried out using the Malvern mastersizer at the Sterre Campus. The sediment grain sizes were grouped according to Wentworth size classification [16] and the results were grouped in the 3 major classes: clay, silt and sand.

Loss on Ignition (LOI) analysis: Sampling was done every 2 cm along the entire composite length of the core. Each of the 59 samples was weighed in a premeasured porcelain crucible. They were then placed in the stove and heated overnight at 105°C: this was important in order to determine the % water content in each of the samples from different depths. The samples were withdrawn from the oven and the resultant weight measured and recorded.

The samples were then placed in the oven (muffle furnace) and heated at 550°C for four hours: this was done to combust all organic materials within the sediment. The remaining residue was measured and recorded. This gives the % organic matter content within the samples. The samples were then returned in the oven and heated at 1000°C for two hours: at this temperature all or most of the carbonate components

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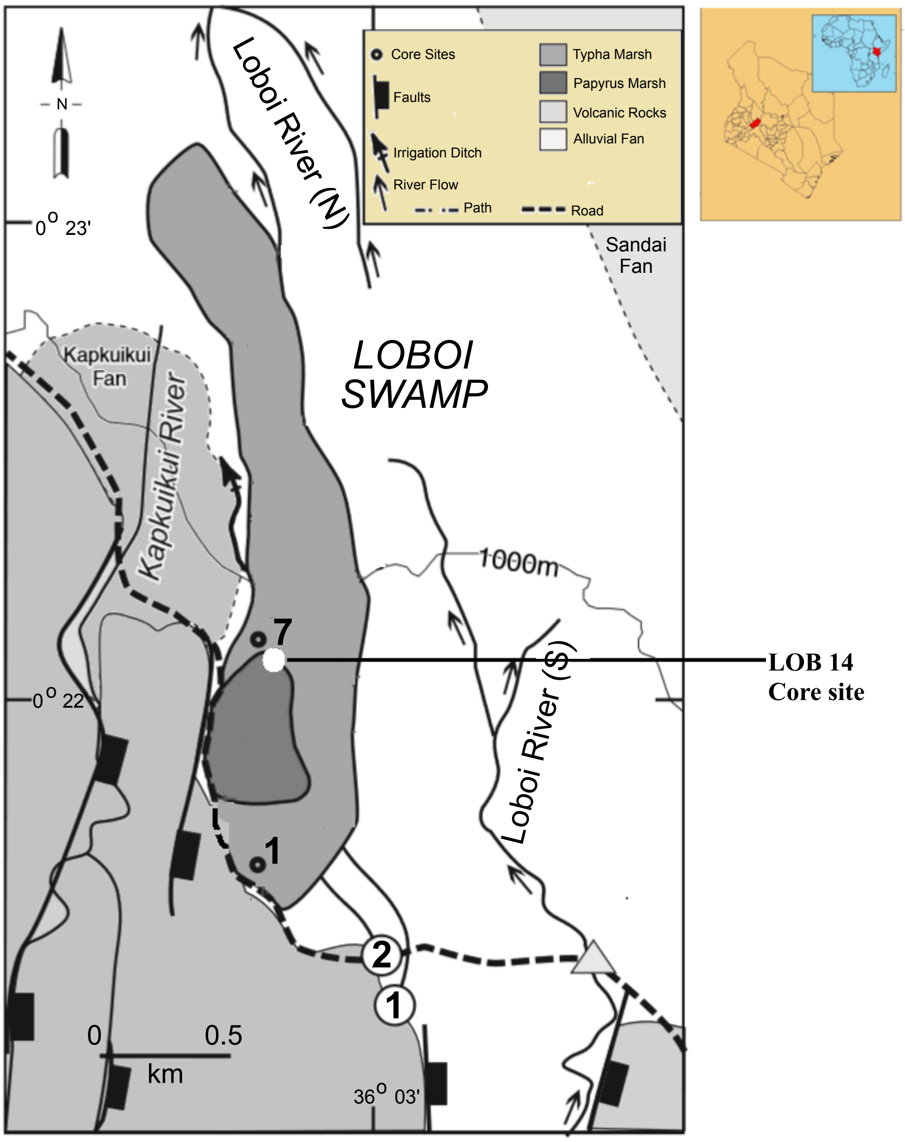

Figure 1: Map of Loboi swamp with the coring site (LOB14 core site) in relation to Ashley et al. coring sites (1 and 7)

are consumed and evaporated as carbon dioxide. The samples were then cooled and their weight measured. The now remaining components of the samples were the non-carbonate inorganic matter, and include the mineral component of the samples plus an unknown amount of biogenic silica.

Analysis of aquatic invertebrate remains

Sampling for aquatic invertebrate remains was carried out at an interval of every 4 cm along the entire composite core length. 29 sediment samples were retrieved and each individually weighed to determine the initial weight. Each of the samples was then placed in a beaker and about 150 ml of 10% NaOH was added to the beaker to aid in the disintegration of the sediments. The solution was then stirred for 30 minutes at a temperature of 50^{0}C. 2 sieves (100 µm and 150 µm) were used in sieving the sediment solution to obtain the preserved animal remains from the sediments. The residue was then transferred into clean sample vials for later identification of major aquatic invertebrate remains. Identification and abundance estimation was done under a light microscope at low and high magnification. Identification keys were highly utilised. For this exploratory study only the major groups of aquatic invertebrate remains were identified and recorded.

Results

Loboi sediment statigraphy

The composite LOB14 core has a total length of 114 cm, and dark red to light brown colour with varying particle textures of clay, silt and sand. The upper 59 cm (Unit I) is a clay-silt mixture with clay fluctuating between 75% and 39% of the sediment bulk (Figure 2). Unit I also shows peaks in magnetic susceptibility (MS) up to 350-400 SI units, above a background value increasing from ca.70 SI units at the bottom of Unit I to ca.150 SI units at the top of the core. From 59 cm to the bottom of the core, silt is the dominant grain size class with volume of clay gradually

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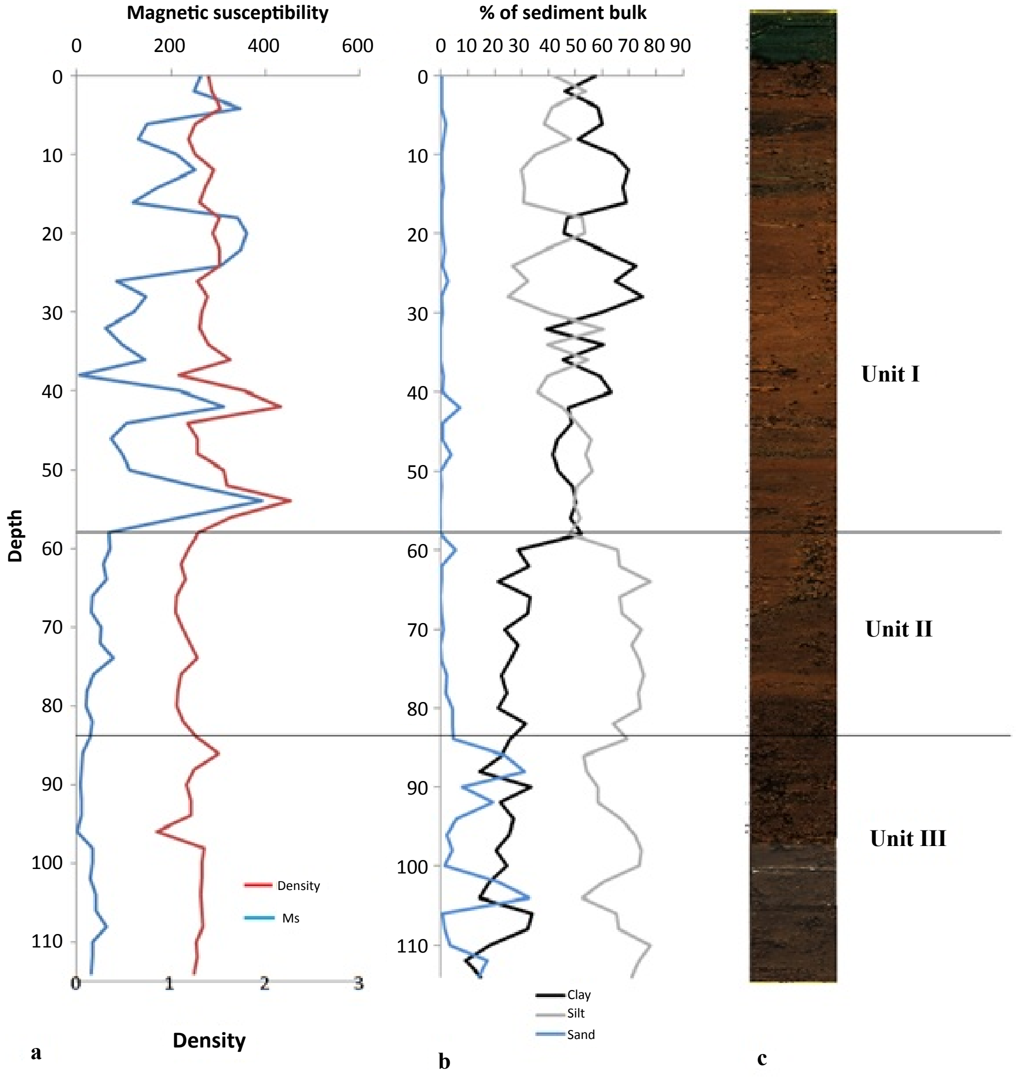

Figure 2: Magnetic susceptibility (MS) variation and main grain-size classes within LOB14 composite core, showing the MS values (blue line).

reducing towards the deeper sections. This whole section also has low MS values; varying between a minimum of 1.5 at 97 cm to 77 SI units at 74 cm. Between 59 and 83 cm (Unit II), sand grains are generally scarce. However, there are two striking increases at 85 cm – 88 cm and 102 cm - 104 cm with a peak of about 30% sand. This section with sand layers (83 cm - 114 cm) is defined as Unit III.

The sediment porosity (water content by volume) is generally high (>75%, excluding a few local minima) in the upper and mid sections of the profile (Units I and II) but falls to and below 50% after 90 cm depth and all through to the bottom of the core except for at a depth of 102 cm - 104 cm where there is a peak of 74%. The water content (by weight) follows a similar pattern, whereby for the most part of the depth profile (Units I, II and the top of Unit III) the values are between 50 and 80% but after the 90 cm depth (Unit III) the water content volume reduces to between 45% to 27% with the exception of the depth at 102 cm -104 cm where there is a peak of 55% (Figure 2). Also in Unit I there are three clear minima at 36 cm, 50 cm and 62 cm where the water content is only 41-43%.

The inorganic fraction constituted an average of about 86% of the dry weight, except however for the section between 78 cm - 88 cm which yielded values between 78% and 65% which are the lowest of the entire composite profile. On the other hand, the organic content was highest in this section with values between 17% and 29% as compared to the composite average of 11%. The $CaCO_3$ fraction is generally low with a values fluctuating irregularly between about 2% to 4% of the total LOI (Figure 3). Such low values may indicate that the sediment does not contain real carbonates, and that the recorded values are caused by release of H_2O molecules from inside clay lattices in the mineral fraction.

Aquatic invertebrate remains

Six major groups of aquatic invertebrate remains were identified: Bryozoa, Amoebae (*Centropyxis* and *Arcella*), acari, dipterans, other macroinvertebrate remains and the Bryozoa found are statoblasts (resting stages) of *Plumatella* (Figure 4). The Amoebae were the testate amoeba *Centropyxis* (Figure 5a) and *Arcella* Figure 5b. The acari are not Hydracarina Figure 5d (water mites) but Oribatida Figure 5e (semi-

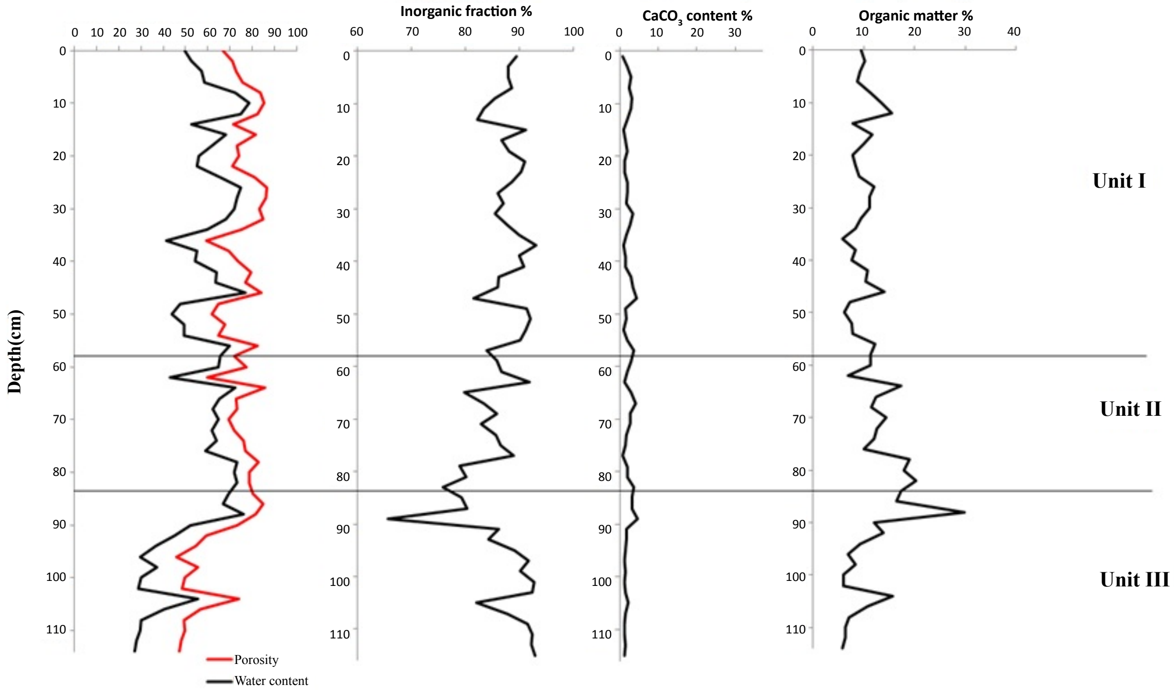

Figure 3: Bulk composition of composite core LOB14, showing sediment porosity as a % of the sediment volume, water content as a % of wet sediment weight, inorganic fraction.

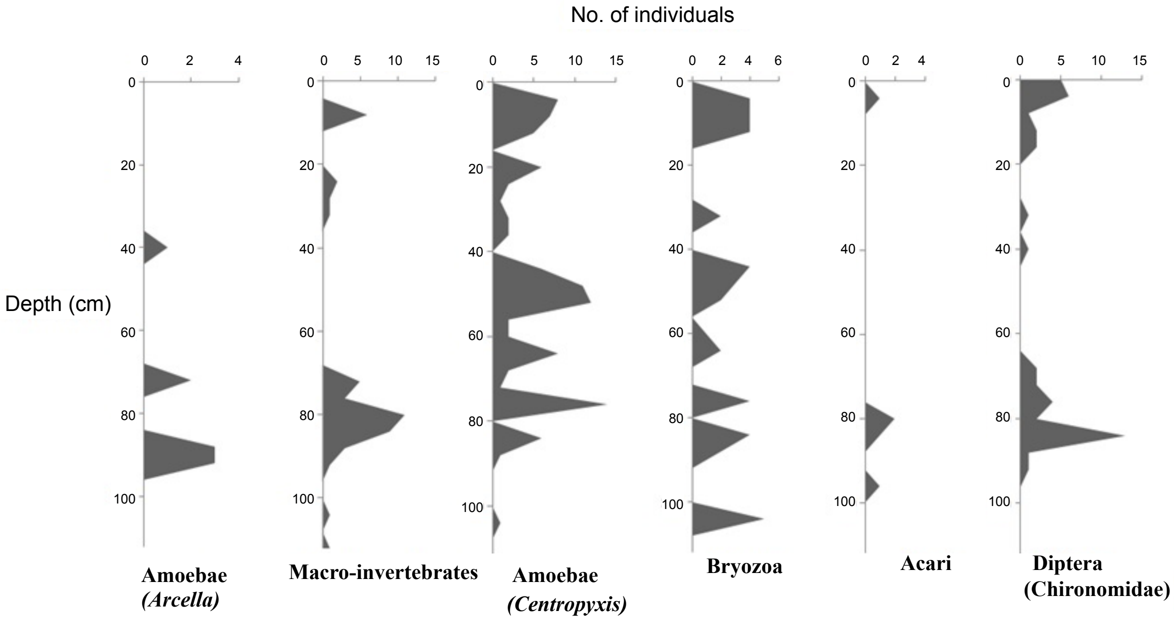

Figure 4: The stratigraphic distribution and counts of various aquatic invertebrates recovered from composite core LOB14.

terrestrial mites) which possesses a more sclerotized carapax (Figures 5h and 5k). The dipterans are the head capsules with dental structures of the Chironomidae larvae (non-biting midges). Finally a large variety of separate skeletal elements were found of large macro-invertebrates, such as the head of an ant (Figure 5c), beetle mandibles (Figures 5g and 5l) and legs (Figure 5j), and tergites of water bugs (Figure 5f). The amoebae and bryozoa were most abundant and occurred in almost along the entire depth of LOB14 composite. Acari and *Arcella* were the least abundant. At a depth of between 82 cm - 86 cm (i.e., the top of Unit III, and coinciding with the peak in organic matter content) the highest number of aquatic invertebrate and Diptera remains were found; it was the only section where all six groups occurred. This was

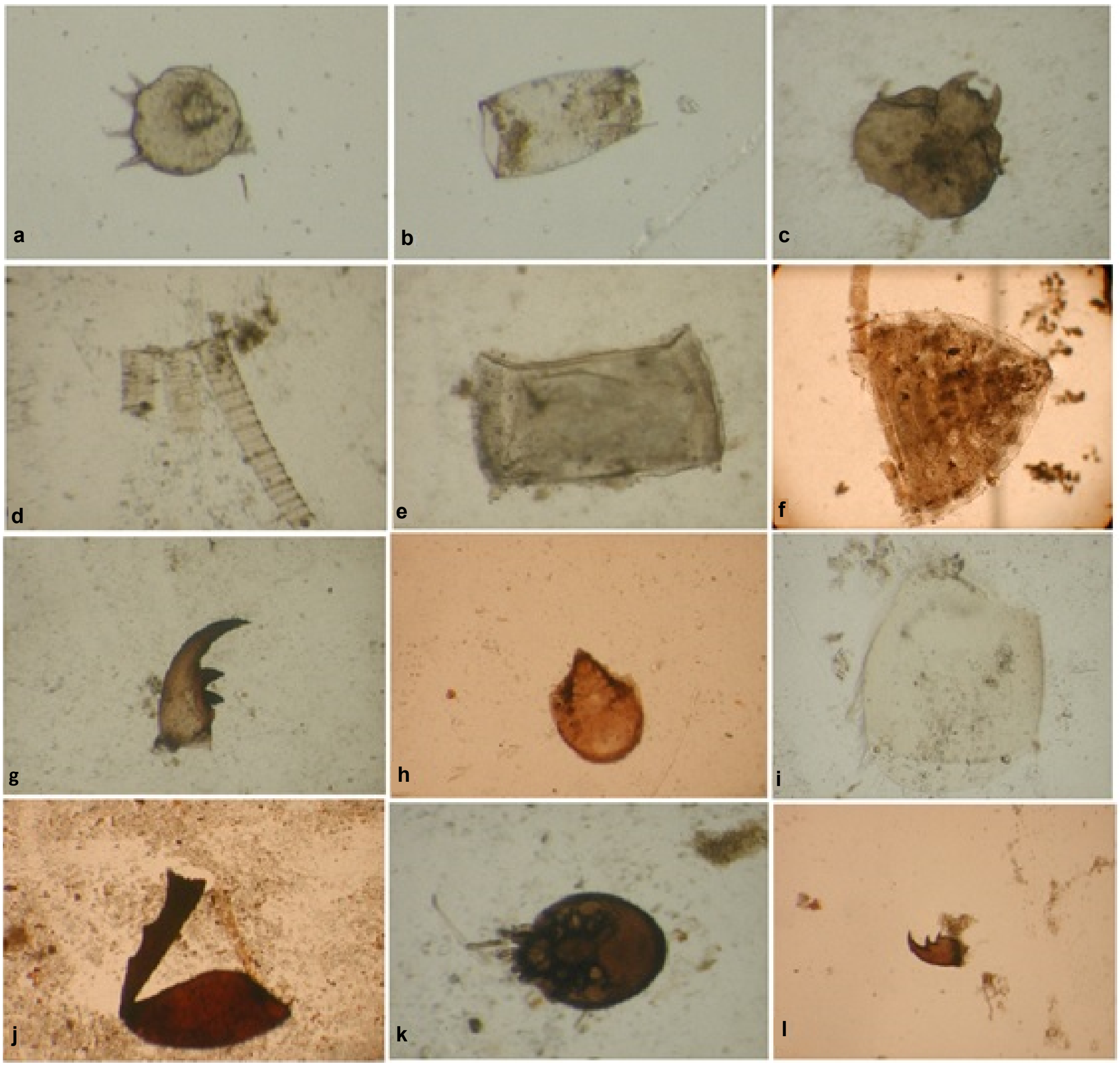

Figure 5: Aquatic invertebrate remains recovered from the sediment core. a: Thecate amoeba (Centropyxis), b: Diptera (chironomid head capsule), c, d, e and f: Macro-invertebrate.

preceded by a complete absence of any animal remains between 96 cm -100 cm and the generally also low number of remains below 100 cm depth (middle and lower portions of Unit III).

Discussion

The location of core LOB14 was at the transition between the papyrus and the typha zone. The typha vegetation usually establishes on firm ground which is occasionally or frequently flooded, while papyrus grows on permanently flooded water as floating mats.

From the statigraphic and lithological results, it is possible to identify periods of alternating lower and higher water-level conditions throughout the development of the sediments within Loboi swamp over the decades. These changes however may have been driven by either local hydrological parameters, regional climate changes, or both. Ashley et al., [13] suggest that Loboi swamp may have formed its permanent state about 700 years ago, and since then it has maintained its existence with periodical dry and wet conditions. In addition, since the natural diversion of Loboi River away from the swamp, surface and underground springs have helped sustain the existence of the wetland even during dry La Nina periods, and longer-lasting droughts that led to complete drying of nearby Lake Baringo.

The generally high MS values in the upper section (Unit I) of the LOB14 profile coincides with the high level of clay-sized grains. This may be explained by the high input level of mineral iron and aluminium oxides present in the highly weathered clay minerals [12], which have been flushed into the swamp since the start of local crop agriculture in the 1920s. However, within this section the four clear peaks in MS are not all matched with local maxima in clay content, so the relationship is probably not one-on-one. Also there is no correlation between high MS and the abundance of sand. On the contrary, in Unit III where two peaks in sand occur, MS is always rather low. The upper part of Unit III, section 76 cm – 90 cm has the lowest MS values despite the presence of coarser sand grains. This might be as a result of the increase in organic-matter content within this zone, which reduces the inorganic component and thus generally has a lower level of magnetic minerals.

The increase of organic matter between 76 cm – 88 cm depicts an environment under which organic matter deposited in the swamp would not possibly decompose and hence the better preservation that creates high values of organic matter content [2]. A high flooding scenario can create an anoxic condition on the bottom that reduces decomposition of the plant material. Also if the flooded state of the marsh wetland started shallow, this would provide optimum condition for growth of aquatic macrophytes, which later died when flooded more deeply and preserved under such conditions. The aquatic macrophyte habitat was ideal for a large diversity of aquatic life, which explains the peaks of dipterans and macro-invertebrate remains in this organic section. This flooded state of the wetland seems to have been preceded by a dry period shown to us by the low organic content of Unit III between 90 cm – 114 cm. Also the lowest water content and low porosity have been recorded within this section of the composite core. This indicates that the sediment has experienced drying and compaction, like can be expected when the swamp has fallen dry. This drying in the atmosphere has also promoted oxidation of organic matter previously contained in those sediments [7]. In addition the scarcity of aquatic insect remains in this section supports the possibility that the wetland may have been under a dry period and hence would not support aquatic life. The few remains of aquatic animals that are still found may be strongly sclerotic and thus survived oxidation.

The high MS and density values at 50 cm – 58 cm depth nearly corresponds to the section with low organic matter at 46 cm – 58 cm. Also within this same region only 2 of the 6 major aquatic invertebrate groups were recovered, represented by Bryozoa and Amoebae. This indicates a possibility that there might have been a period of low water levels together with the first increase of soil input from outside the wetland, probably in the mid-20th century [17,18].

The modest fluctuations in statigraphic and lithological signals are indicative that Loboi swamp is a rather resilient ecosystem. Although the region has been affected by extremely severe droughts in the past decades the wetland seems to have survived, although with low water levels for some period in time. This indicates the importance of spring input for the persistence of Loboi swamp.

Conclusion

From the results obtained above it is certain that multi-proxy use in paleolimnological studies can and is a very important tool in trying to piece together events that may have occurred many decades ago. However, it is also very important to employ caution when drawing conclusive assessments using just a few and not so in-depth analysis. In this case, the training involved very few days for the analysis of the statigraphy, lithological and aquatic invertebrate remains. For instance a more detailed scrutiny of the various animal remains will be important to be able to identify them to the level of genus, which would then be more useful in providing specific information about the ecological status of the wetland. Also the dating of plant macrofossils within the core ought to be done so as to provide information about the time in which some of the retrogressions occurred. This would help in linking some of the wet and dry events with the local hydrology, regional climate patterns or human activities within the wider region that could have led to the impacts. This wetland is part of the larger Baringo region under which lie two lakes currently under study with paleolimnological techniques. Thus these results obtained can be used to boost and improve on clarity of events that happened in the past at these lakes.

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