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Holocene vegetation changes in the Sahelian zone of NE Nigeria: The detection of anthropogenic activity

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ABSTRACT

The relative importance of climate change and anthropogenic activity in the vegetation history of the Sahel has been the subject of much recent discussion. Pollen diagrams from the Manga Grasslands (NE Nigeria) indicate a Holocene vegetation history primarily controlled by climate. During the relatively humid early and mid-Holocene the interdune depressions of the Mangas were occupied by swamp forest with Guinean affinities. Savanna, with Sudanian and Sahelian arboreal elements, occurred on the surrounding dunefields. The modern Sahelian vegetation of the region became established c.3300 yr BP as a result of drier conditions. Although the archaeological record indicates that the Manga Grasslands themselves have been occupied since at least c.3700 yr BP, there is little evidence of human activity in the pollen diagrams. The number of herb taxa recorded declines after c.3300 yr BP and unambiguous indicators of human activity are absent even from a diagram which covers the recent past. The drier post c.3300 yr BP conditions are probably masking human activity. In addition, nomadic pastoralism (which is still the major economic system) appears to be palynologically undetectable, the major effect of this activity today being the replacement of perennial grasses and herbs with more xeromorphic and less palatable species.

INTRODUCTION

The Holocene vegetational history of the Sahel zone has been subject of recent debate. Vegetation changes evident in pollen diagrams from Lake Chad (Maley, 1981) and Senegal (Lézine, 1988, 1989) have been interpreted in terms of climate change. In particular, it has been argued that humid conditions result in the development of Sudanian woodland as a result of the northward migration of vegetation belts. During arid periods the region is occupied

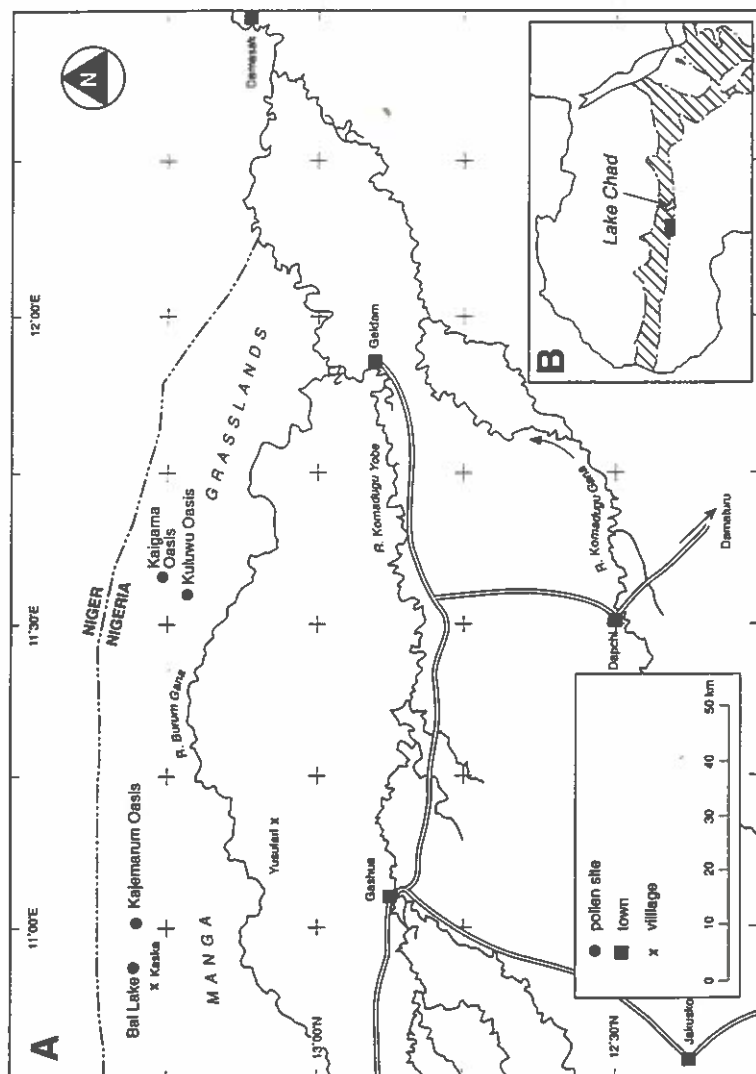


Figure 1. The Manga Grasslands

by semi-desert to wooded savanna as the belts move south (e.g. Ritchie & Haynes, 1987; Hooghiemstra, 1988; Lézine, 1988, 1989; Dupont & Agwu, 1992). In contrast, palynological work in the southern Sahara and Lake Oursi (Burkina Faso) led Schulz & Pomel (1992) and Ballouche & Neumann (1995), respectively, to suggest that the role of anthropogenic activity (pastoralism, agriculture, metal production and the use of fire), as an agent of vegetation change in mid- and late Holocene, has been considerably under-estimated.

Unfortunately, the latter hypothesis is difficult to test due to problems in unambiguously identifying anthropogenic activity in Sahelian pollen diagrams. Neumann & Ballouche (1995) advocate the use and development of indicator taxa (cf Behre, 1981, 1986) and argue that the effects of agricultural activity are likely to be easier to determine than pastoralism. In respect of agriculture, increases in *Mitracarpus scaber* and Combretaceae pollen are considered significant as these taxa are today associated with fields, ruderal communities and fallows. Pastoralism is likely to be more difficult to detect because of the presence of wild herbivores. In addition, although a number of pollen taxa (e.g. Amaranthaceae/Chenopodiaceae, *Cassia* and *Indigofera*) include species which increase with overgrazing, these taxa are not confined to such communities (Neumann & Ballouche, 1995). Alternative approaches include use of palynological preparations both to count microscopic charcoal and assess fire frequency (Schulz, 1994; Salzmann, 1996) and to identify coprophilous fungi (Van Geel, 1996).

The palynological dataset available for the Sahel zone has recently been expanded with diagrams constructed from interdune depressions in the Manga Grasslands of northeast Nigeria near 13°N. Previous publications have concentrated upon mid-Holocene vegetation history (Salzmann, 1996; Salzmann & Waller, 1998), here evidence for anthropogenically induced vegetation changes are sought from this new information and the possible approaches to the identification of human activity in Sahelian pollen diagrams are critically examined.

SITE DESCRIPTION

Situated in the western part of the Lake Chad basin on the border between Nigeria and Niger, the Manga Grasslands cover an area of approximately 7500 km² (Fig. 1). The region consists of upland, largely stable barchanoid sand dunes, separated by numerous depressions (which are up to 20 m lower). The depressions are occupied mainly by seasonal waterbodies (playas) though a few remain permanently wet. They appear to be fed exclusively by local precipitation (Carter, 1994) with the permeable dune sands resulting in lag of between 5 and 10 years between rainfall and groundwater outflow (Carter et al., 1994). Rainfall is largely confined to the monsoon season (May to September) when the Intertropical Convergence Zone (ITCZ) migrates northward. Annual rainfall declined from around 450 mm prior to 1971 to 310 mm in the period 1971 to 1991 (Carter et al., 1994).

The Manga Grasslands are occupied by both sedentary and transhumant stockowner-farmers and are also visited by nomadic stockowners (Mortimore, 1989). The dunefields are extensively grazed and, when the rains are adequate, *Pennisetum* (millet) is cropped. Probably as a result of a combination of these activities and the extended drought, the vegetation of the dunefields has been modified over the last 30 years (Mortimore, 1989). Formerly, perennial grasses (*Aristida* spp. and *Andropogon gayanus* var. *tridentatus*) predominated with scattered trees and shrubs (e.g. *Acacia* spp. and *Sclerocarya birrea*). Today the annual grass *Cenchrus biflorus* is abundant along with xeromorphic and less palatable herbs such as *Cassia* spp. and *Zornia* spp. The dominant trees and shrubs are *Balanites aegyptiaca*, *Calotropis procera* and *Leptadenia pyrotechnica*. Where the grazing is most intense, close to settlements, remobilization of dunes is occurring. The vegetation of the depressions consists of palm woodland (*Hyphaene thebaica* and *Phoenix dactylifera*) with reedswamp (*Phragmites* spp.) fringing the lakes. The depressions are intensively exploited through both rain-fed and dry-season cropping. The trona crust of the playas is collected in the dry season and sold as potash.

Archaeological evidence for human activity in the Lake Chad basin has recently been reviewed by Breunig et al. (1996). An early presence has been demonstrated with the excavations of a dug-out canoe from the Komadugu Ghana (dated to 8265 ± 275 yr BP, Gro-486) and a site on the Bama ridge (with a radiocarbon date of 6340 ± 250 yr BP, KN-4300). Pastoralism and ceramics appear to have been introduced from the Sahara region c.4000 yr BP and there is evidence for the domestication of *Pennisetum* from 3000 yr BP onwards (Neumann et al., 1996). Archaeological sites occur around a number of the Manga Grasslands depressions. Although their stratigraphy has been destroyed by deflation, typological comparison of potsherds with pottery from other sites in the Lake Chad basin points to occupation from at least 3700 BP onwards (Wendt pers. comm.).

Pollen analysis has been completed from four depressions (Fig. 1), three of which are occupied by seasonal playas; Kaigama Oasis ($13^{\circ}15.10'N$, $11^{\circ}34.08'E$), Kajemarum Oasis ($13^{\circ}18.30'N$, $11^{\circ}01.73'E$) and Kuluwu Oasis ($13^{\circ}13.04'N$, $11^{\circ}33.05'E$), while one remains permanently wet (Bal Lake $13^{\circ}18.41'N$, $10^{\circ}56.96'E$).

METHODS

Material for pollen analysis was collected using piston corers with the exception of the upper 175 cm at Kajemarum Oasis which was obtained from a pit. Standard preparation and counting techniques were used (Faegri & Iversen, 1989). Pollen grains were identified using type material and the literature (Maley, 1970; Sowunmi, 1973, 1995; Caratini & Guinet, 1974; Ybert, 1979; Bonnefile & Riollet, 1980; El Ghazali, 1993). Summary pollen diagrams showing the main taxa and life form groupings (Figs 2, 3, 4 and 5) have been

produced using the computer program TILIA*GRAPH (Grimm, 1991). For land pollen, a total land pollen (% TLP) sum has been used in their construction. Aquatics are expressed as % TLP+Aquatics and Pteridophytes as % TLP+Spores. Complete diagrams and a list of taxa arranged into phyto-geographic groups as defined by White (1983) can be found in Salzmann & Waller (1998). Nomenclature follows Cronquist (1981) for families and Hutchinson & Dalziel (1954-1972) for generic and specific names.

Charcoal particles have been counted at two sites, Kaigama Oasis and Kuluwu Oasis. The methodology follows Clark (1982) with the charcoal content expressed as surface area ratios per unit volume of sediment.

The 21 accelerator mass spectrometer (AMS) radiocarbon dates available from the cores used for pollen analysis are detailed in Table 1. Calibrations are provided using the CALIB program of Stuiver & Reimer (1993) though, to facilitate comparison with previous work, in the text all dates are referred to in uncalibrated years before A.D. 1950 (BP). Twenty of the dates were obtained from organic matter and one from carbonate. The carbonate date, the basal date for Bal Lake (9535 ± 80 yr BP, AA-21830), appears anomalously young which, following Tehet et al. (1990), may be due to diagenetic effects, recrystallization during low water-levels.

RESULTS AND INTERPRETATION

A detailed description of the local pollen assemblage zones (LPAZ's) for the four sites and modern pollen data from the Manga Grasslands can be found in Salzmann & Waller (1998). Here the major features of the pollen stratigraphy for the late Pleistocene and the early, mid- and late Holocene are summarised.

The late Pleistocene (pre-10,000 yr BP)

The late Pleistocene is probably represented at Bal Lake (pollen zone BAL-1) though because of the inverted basal radiocarbon date this is not certain. High Poaceae pollen values indicate that the dunefields were covered by open grassland. A few trees are recorded at low frequencies (including *Alchornea*, *Syzygium* and *Uapaca*). These taxa are associated with swamp forest (Trochain, 1940; Aubréville, 1950; De Leeuw & Tuley, 1972) and are therefore likely to have been present in the depressions. Lake levels appear to have fluctuated with aquatics (*Nymphaea* and *Typha*) becoming scarce towards the top of BAL-1.

The early Holocene (c.10,000 – c.8000 yr BP)

Humid conditions are indicated from 10220 ± 130 yr BP (AA-21831) at Bal Lake and 9940 ± 60 yr BP (UtC-5169) at Kuluwu by high *Typha* values (in BAL-2 and KUL-1) and the deposition of peat. From c.9600 yr BP onwards

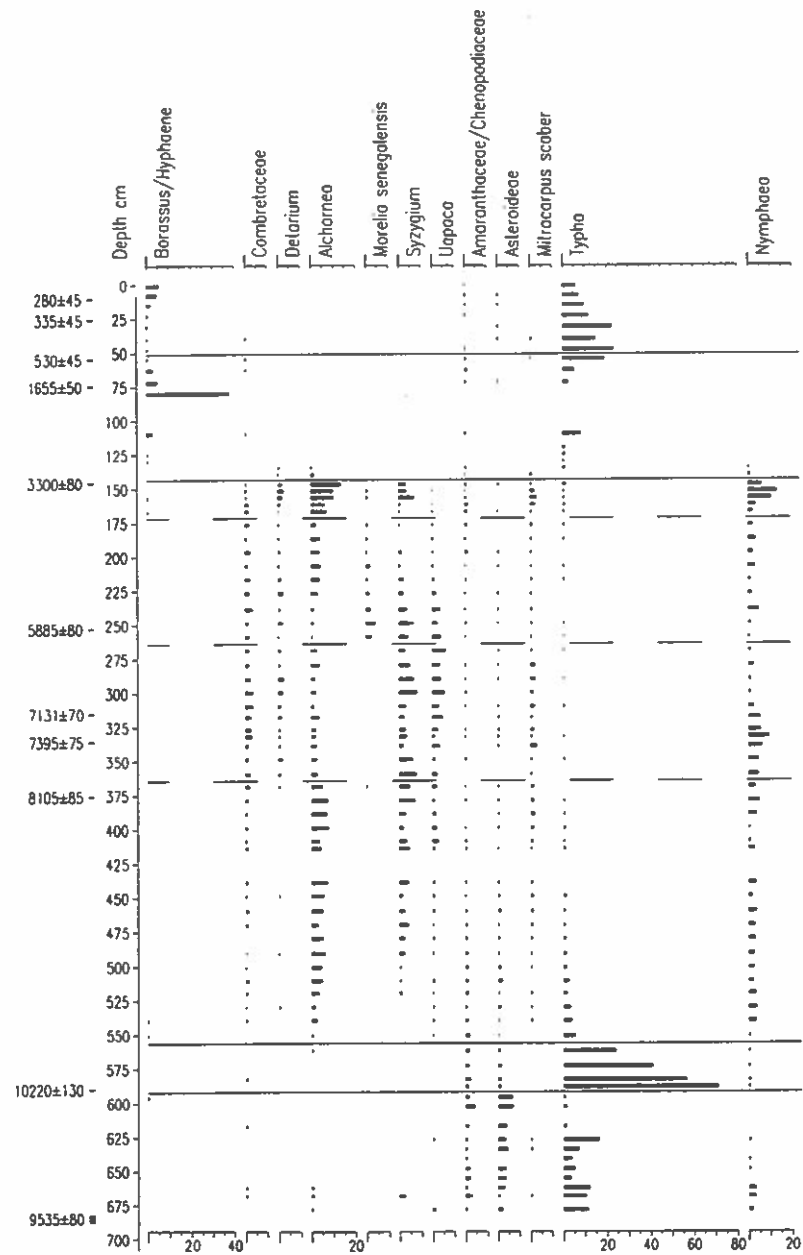


Figure 2. Summary pollen diagram for Bal Lake.

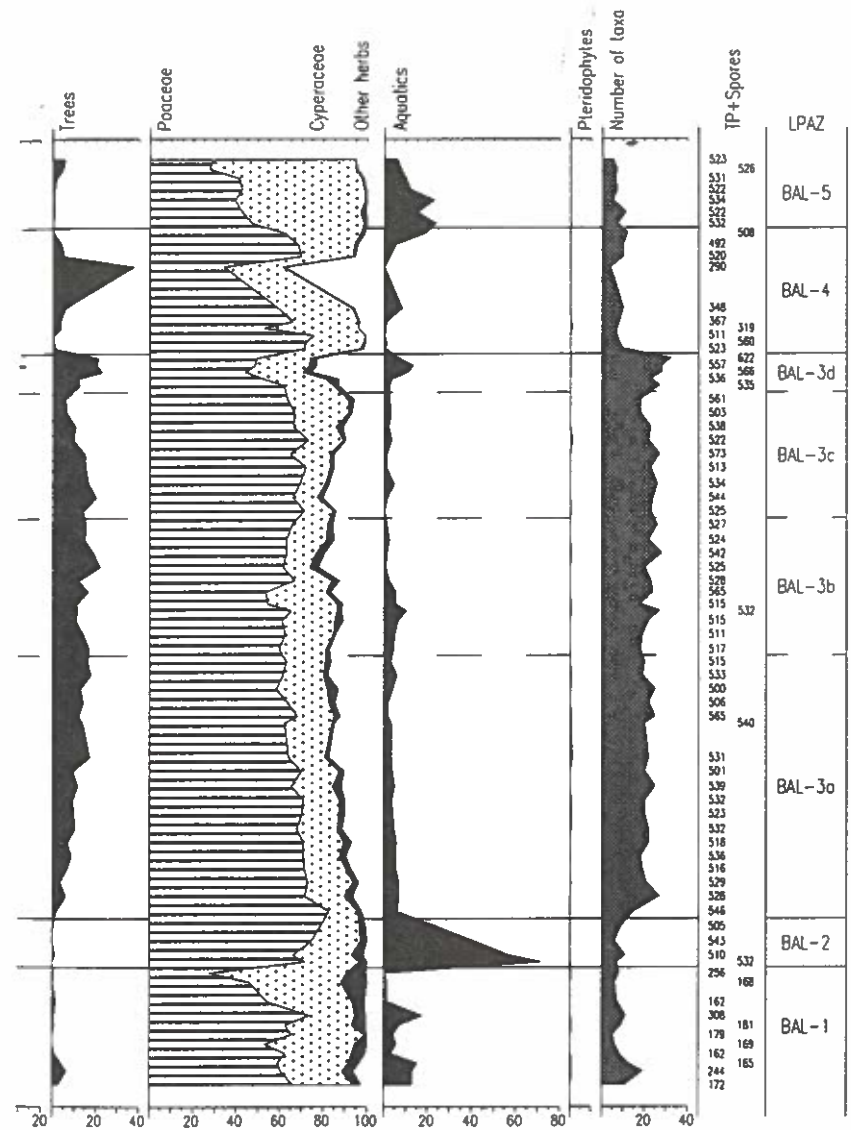


Figure 2. Continued.

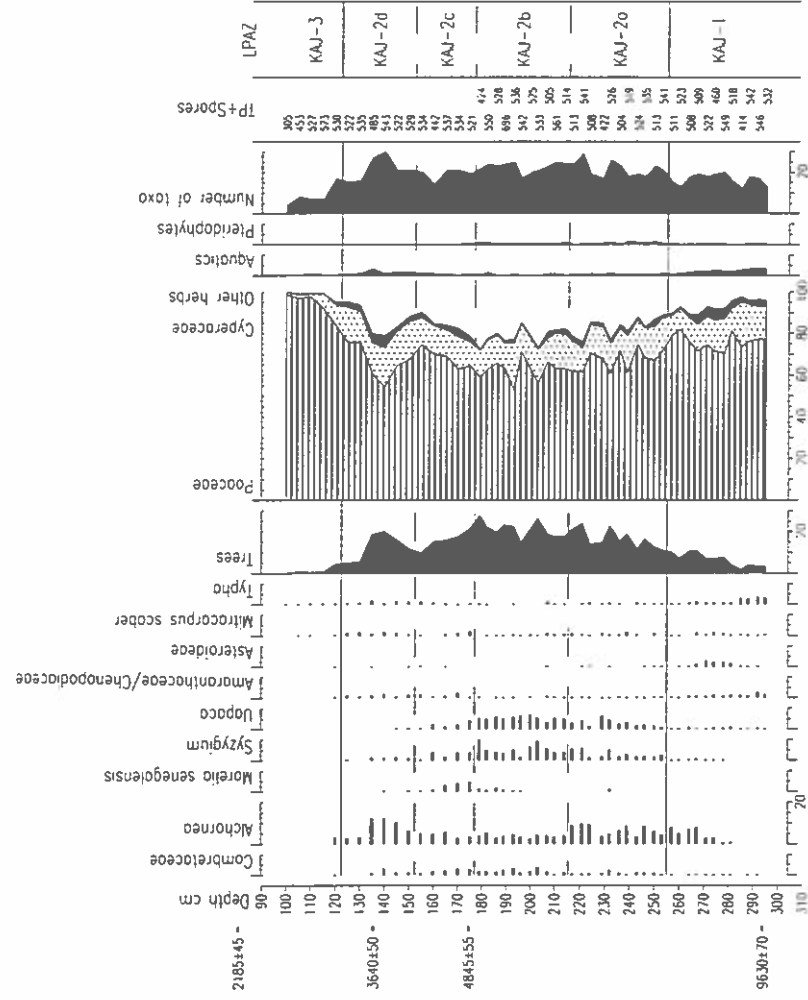


Figure 3. Summary pollen diagram for Kajamarum Oasis.

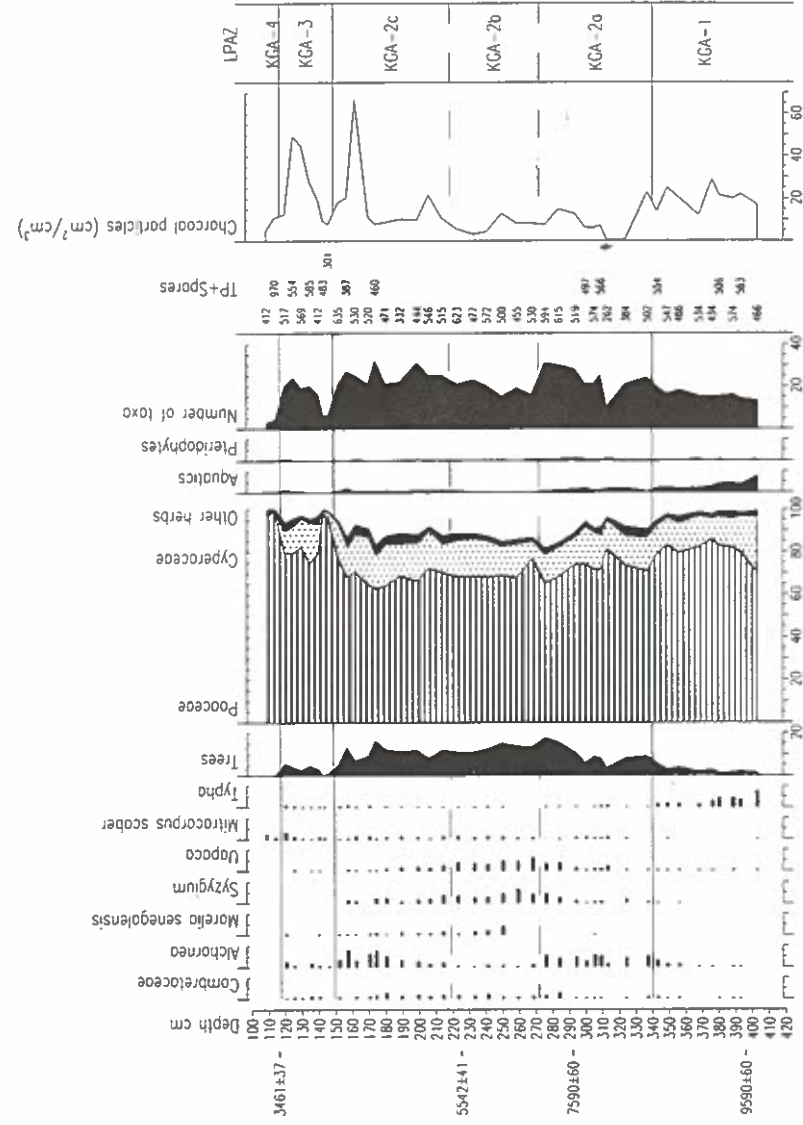


Figure 4. Summary pollen diagram for Kaigama Oasis.

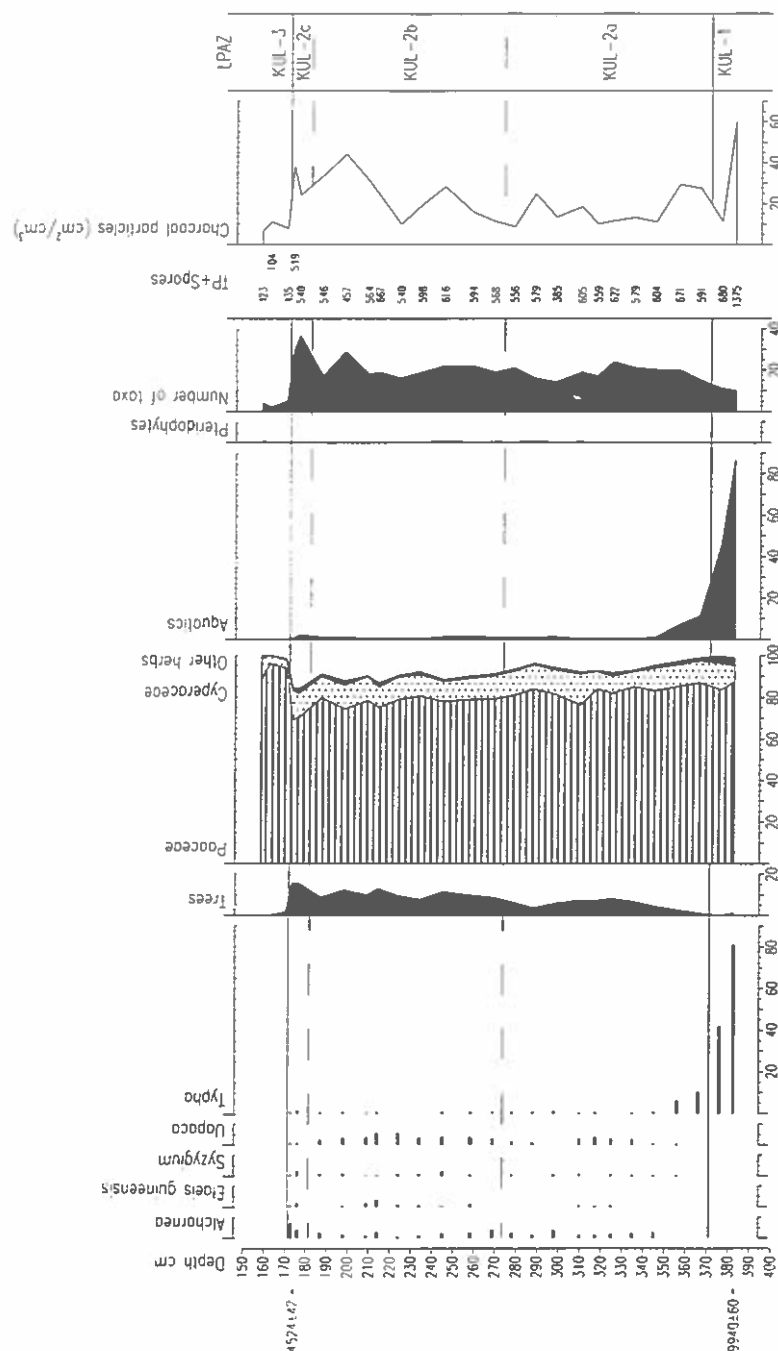


Figure 5. Summary pollen diagram for Kuluwu Oasis.

Table 1. Radiocarbon dates.

Site	Lab. code	Age ^{14}C yr BP ($\pm 1\sigma$)	Cal. yr BP ($\pm 1\sigma$)	Depth of sample (cm)
Bal Lake	AA-21840	280 \pm 45	289-423	9.5-10.5
Bal Lake	AA-21839	335 \pm 45	306-468	25-26
Bal Lake	AA-21838	530 \pm 45	515-549	54-55
Bal Lake	AA-21836	1655 \pm 50	1514-1601	74-75
Bal Lake	AA-21837	3300 \pm 80	3411-3627	145-146
Bal Lake	AA-21835	5885 \pm 80	6638-6843	252-253
Bal Lake	AA-21834	7131 \pm 70	7834-7954	314.5-315.5
Bal Lake	AA-21833	7395 \pm 75	8022-8302	335-336
Bal Lake	AA-21832	8105 \pm 85	8777-9194	375-376
Bal Lake	AA-21831	10220 \pm 130	12252-11347	589-590
Bal Lake	AA-21830	9535 \pm 80	10891-10420	682-687
Kaigama Oasis	UtC-4205	3461 \pm 37	3639-3817	115.5-116.5
Kaigama Oasis	UtC-5166	5542 \pm 41	6294-6401	224.5-225.5
Kaigama Oasis	UtC-5165	7590 \pm 60	8325-8407	291.5-292.5
Kaigama Oasis	UtC-4315	9590 \pm 60	10486-10913	395.5-396.5
Kajemarum Oasis	AA-17651	2185 \pm 45	2121-2306	80-81
Kajemarum Oasis	AA-17157	3640 \pm 50	3872-4062	135-136
Kajemarum Oasis	AA-17156	4845 \pm 55	5493-5642	174-175
Kajemarum Oasis	AA-17150	9630 \pm 70	10560-10953	293.5-294.5
Kuluwu Oasis	UtC-5296	4524 \pm 42	5050-5294	173.5-174.5
Kuluwu Oasis	UtC-5169	9940 \pm 60	11000-11320	382.5-383.5

the formation of lake muds demonstrate the presence of permanent waterbodies at all four sites. Accompanying changes in pollen stratigraphy (in BAL-3a, KGA-1, KAJ-1 and KUL2a) include increases in tree taxa with Guinean (e.g. *Alchornea*, *Syzygium* and *Uapaca*) and Sudanian affinities (e.g. *Celtis*, *Combretaceae*) and in the number of taxa recorded. As noted previously, the Guinean taxa are associated with swamp forest and were probably confined to the fringes of the lakes. In contrast, the dunefields themselves appear to have remained open with high Poaceae pollen percentages maintained. A peak in the charcoal particle curve occurs at Kuluwu Oasis.

The mid-Holocene (c.8000 – c.3300 yr BP)

During the mid-Holocene, the number of taxa recorded is at a maximum (> 20 taxa are consistently recorded), and pollen values for both the Guinean and Sudanian trees are at their highest. Amongst the additional taxa prominent at one or more sites is the Sudanian tree *Detarium* and the Guinean trees *Elaeis guineensis* and *Morelia senegalensis*. All the Guinean taxa present have a potential affinity with swamp forest and are likely to have occurred within the depressions rather than being constituents of Guinean savanna.

At three of the sites investigated (Bal Lake, Kaigama and Kajemarum Oasis) changes in pollen stratigraphy during the mid-Holocene follow a distinct pattern (Salzmann & Waller, 1998). High initial *Alchornea* values (pollen zones BAL-3a, KGA-2a, KAJ-2a) are succeeded by increases in *Syzygium* and *Uapaca* pollen. Pollen zones BAL-3c and the upper parts of KGA-2b and KAJ-2b are characterised by the presence of *Morelia senegalensis* pollen. A second peak in *Alchornea* follows (pollen zones BAL-3d, KGA-2c, KAJ-2d). In spite of this consistency the timing of these pollen stratigraphic events differs between sites, with, for example, the decline in *Alchornea* recorded at c.7900 yr BP at Bal Lake, c.7000 yr BP at Kaigama and c.6500 yr BP at Kajemarum. Local factors appear therefore to be important in determining the establishment (e.g. *Morelia senegalensis*) and demise (e.g. *Alchornea*) of taxa. As the competitive ability of the swamp forest taxa is likely to be linked to water-levels, variations in the depth of the watertable between sites due to differences in the altitude of the depressions could be significant (Salzmann & Waller, 1998).

Higher values for Sudanian taxa recorded in the mid-Holocene are difficult to interpret as they cannot simply be seen as a product of competitive interaction with the Guinean trees (Salzmann & Waller, 1998). Distinctive savanna taxa such as *Butyrospermum* and *Bombax* are present suggesting an increase in tree cover on the dunefields. Nevertheless the dunefields must still have remained substantially open as not only do Poaceae percentages remain high but sand layers occur in the lake basins suggesting incomplete vegetation cover.

An increase in charcoal particles occurs at both Kaigama Oasis and Kuluwu Oasis towards the end of the mid-Holocene. At Kaigama two peaks in the charcoal particle curve are followed by decreases in tree pollen and increases in Poaceae. At Kuluwu Oasis the charcoal count is consistently higher in the latter part of KUL-2b, though there are no obvious accompanying changes in pollen stratigraphy.

The late Holocene (post c.3300 yr BP)

In contrast to the preceding periods, there is evidence of a synchronous event in the late Holocene with major pollen stratigraphic changes occurring c.3300 yr BP at Bal Lake, Kaigama Oasis and Kajemarum Oasis (the BAL-3d/4, KGA-3/4 and KAJ-2d/3 boundaries). The Guinean and Sudanian trees virtually disappear, few taxa are recorded (generally < 10) and Poaceae values increase to > 90% TLP (with the exception of Bal Lake). In addition, the lake muds are replaced by calcareous silts. At Kuluwu Oasis similar changes are recorded at 4524 ± 42 yr BP (UtC-5296) though it is likely that the sequence here has been truncated either by subsequent deflation or desiccation. All the above changes are consistent with a shift to a drier climate (Salzmann & Waller, 1998), an interpretation which is supported by palaeohydrological investigations (stable isotope ratios in bulk carbonate and ostracod calcite and Sr/Ca ratios in ostracod shells) from Kajemarum Oasis (Holmes et al., 1997).

Only at Bal Lake does the pollen record extend into the late Holocene and at this site pollen preservation is poor, with the number of indeterminate grains rising in the latter part of BAL-4 and in BAL-5 and pollen absent from part of BAL-4 (Salzmann & Waller, 1998). High Poaceae values are maintained throughout BAL-4 indicating open grassland on the dunefields possibly with scattered trees (e.g. *Acacia*, *Balanites*). The palm woodland of the depressions appears to have become established c.3300 yr BP with *Borassus/Hyphaene* pollen recorded throughout BAL-4 and BAL-5. Increases in Cyperaceae and *Typha* pollen in BAL-5 (c.500 yr BP) are attributable to low water-levels and an expansion in the emergent communities fringing the lake, which led to the establishment of vegetation within the depression similar to that present today.

Amongst the few other taxa regularly recorded are the open ground indicators Amaranthaceae/Chenopodiaceae and Asteraceae (both Asteroideae and Lactuceae). However, the anthropogenic indicators of Neumann & Ballouche (1995), *Mitracarpus scaber* and Combretaceae, although regularly recorded throughout the early and mid-Holocene, are only sporadically present after 3300 yr BP.

DISCUSSION

The Holocene vegetational history of the Manga Grasslands appears to have been primarily controlled by climate. The early and mid-Holocene were comparatively humid, with a major shift towards aridity occurring c.3300 yr BP. However, there are a number of difficulties in using the Manga Grasslands pollen diagrams for climatic reconstructions (Salzmann & Waller, 1998). The Guinean tree taxa present in the early and mid-Holocene are associated with swamp forest and are therefore likely to be confined to the depressions. They appear to have been growing extrazonally, that is under favourable conditions beyond their main distribution (Walter, 1984), and cannot be taken to indicate the movement of Guinean savanna as far as 13°N. In addition, differences in timing of vegetation changes between the depressions, and the lack of information on the ecological preferences of the taxa involved, limit the inferences that can be made from the changes in the representation of Guinean and Sudanian taxa. For example, it is not clear whether, as suggested by previous investigations from West Africa (e.g. Lézine, 1989; Gasse et al., 1990; Street-Perrott & Perrott, 1993), the early Holocene was wetter than the mid-Holocene.

There are no unambiguous indications of anthropogenic activity in the Manga Grassland pollen diagrams. The major late Holocene (c.3300 yr BP) biostratigraphic change is followed by increasing Poaceae values and a decline in the representation of other herbs, the reverse of changes seen at Lake Oursi and said to be indicative of agriculture (Ballouche & Neumann, 1995; Neumann & Ballouche, 1995). This lack of evidence of anthropogenic activity in

the pollen diagrams has to be set against the archaeological evidence for a human presence in the Manga Grasslands since at least c.3700 yr BP (Wendt pers. comm.). The Manga Grasslands diagrams demonstrate the difficulties of detecting human activity in the Sahel zone rather than implying such activity was absent.

There are a number of reasons why anthropogenic activity may be particularly difficult to palynologically detect in the Manga Grasslands. Such activity is probably masked by the drier post c.3300 yr BP conditions, with aridity having similar effects on the species composition and physiognomy of the vegetation as human activity. Possible synchronicity between climate change and increased human activity, with the drier conditions of the late Holocene resulting in the introduction of pastoralism from the Sahara, is an additional complicating factor.

Pastoralism is likely to have been the major economic system of the Manga Grasslands in the past (as it remains today). As previously noted pastoralism is particularly difficult to detect in pollen diagrams. The major change produced by modern overgrazing is the replacement of perennial grasses and herbs with more xeromorphic and less palatable species (Le Houérou, 1989). Taxa associated with pastoralism are recorded in the post c.3300 yr BP assemblages at Bal Lake (BAL-4 and BAL-5), however, most occur only sporadically (e.g. *Borreria* spp., *Cassia* spp., *Indigofera* spp.) and others decline in the late Holocene, after being consistently present during the mid-Holocene (eg. *Amaranthaceae/Chenopodiaceae*).

Of the potential agricultural indicators of Neumann & Ballouche (1995), the representation of both the *Combretaceae* and *Mitracarpus scaber* declines post c.3300 yr BP. It seems that particular caution is needed before adopting *Mitracarpus scaber* as an anthropogenic indicator in the Sahel zone. Although Neumann & Ballouche (1995) suggest high *Mitracarpus scaber* percentages indicate the proximity of fields and settlements, the pollen of this taxon not only persists in the Manga Grasslands diagrams throughout early and mid-Holocene but attains frequencies of up to c.3% TLP (in BAL-3b) during these periods. In addition, increases in pollen values of this taxon in the late Holocene may not just be the product of human activity. The natural habitat of this species, probably sandy shorelines (Lebrun et al., 1972), is likely to have expanded with the drier conditions.

Anthropogenic activity in savannas would be expected to be accompanied by an increase in fire frequency, with burning used to improve pasture (Schulz & Pomel, 1992). Microscopic charcoal is regularly counted on palynological preparations to assess fire frequency. There are a number of methodological problems, not least of which is that, unless contiguous samples are counted, changes in charcoal influx may not be adequately represented by the sampling interval (Patterson et al., 1987). In addition, the origin of the fires remains obscure. The peaks in charcoal at Kaigama Oasis may be the result of anthropogenic burning possibly, given the accompanying decline in fringing woody vegetation, intended to improve access to the lake (Salzmann, 1996). How-

ever, the increase in charcoal particles towards the end of the mid-Holocene may equally be attributed to the onset of drier conditions. Lower water-levels might have resulted in the swamp forest vegetation becoming more open and sensitive to seasonal fires. Natural fires also appear to have occurred during relatively humid periods as suggested by the charcoal peak at Kuluwu Oasis at the beginning of the Holocene. The importance of natural fires in maintaining savanna ecosystems is emphasised by the consistency of the charcoal curve through the Holocene at Lake Tilla a site situated within the modern Sudanian zone (Salzmann in prep.).

Fungal analysis may offer an alternative approach to the detection of pastoralism as coprophilous fungi are often specific to a few types of dung (Van Geel, 1986). Although offering a promising area for future research, information on the ecological preferences of coprophilous fungi and the identification of their spores is not currently available for West Africa.

Other possible early human activities in the Sahel region include the selection and propagation of trees of economic value (Schulz & Pomel, 1992). While the loss of Guinean swamp forest trees and the decline in Sudanian trees on the surrounding dunefields c.3300 yr BP are consistent with a drier climate, the persistence of palm woodland within the Bal Lake depression, with *Borassus/Hyphaene* pollen present throughout BAL-4 and BAL-5, could have been promoted by human activity. Trees belonging to these genera have a long history of cultivation and a multiplicity of uses (Maydell, 1990). Whether certain savanna trees and shrubs were selected for, or propagated, on the dunefields is unknown. The identification of such activity is likely to be hampered by the over-representation of *Poaceae* pollen in respect of the Sahelian trees, with the latter only sporadically recorded.

CONCLUSIONS

Climate change, increased aridity, appears to be the primary factor responsible for the establishment of Sahelian vegetation in the Manga Grasslands. Anthropogenic activity is likely to be masked by the drier post c.3300 yr BP conditions. As a consequence the role played by this activity remains to be elucidated. Investigations are continuing at a second site where the pollen record persists through into the late Holocene (Waller, in prep.). However, the major form of anthropogenic activity in this region, nomadic pastoralism, may be palynologically silent, necessitating the development of alternative techniques. That human activity has similar effects as increasing aridity not only hampers attempts to understand the origins and development of the vegetation of the Sahel region, the same problem underlies the current controversy concerning the roles of aridification and desertification in the recent environmental changes (e.g. Mortimore, 1989; Reichelt et al., 1992; Kadomura, 1994).

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