RECONSTRUCTION OF LATE HOLOCENE VEGETATION AND CLIMATE OF HLUHLUWE-IMFOLOZI AREA USING PHYTOLITHS

Kirsten S.L. Gallaher

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Supervisor: Dr. Lindsey Gillson

ABSTRACT

This study presents a phytolith record from a late Holocene sedimentary core from the Hluhluwe-iMfolozi area in northeastern KwaZulu-Natal. Radiocarbon dating showed the oldest sediments to be from 2380 ± 40 BP. Phytoliths are present throughout the record. There was a high degree of unclassifiable phytoliths (>79% per sub-sample), but preliminary trends identified include a dominance of C_4 grasses throughout (Chloridoideae and Panicoideae; adapted to higher temperatures and greater insolation), and slightly more C_3 grasses (Pooideae; adapted to cooler temperatures and/or winter rainfall) towards the base. The tree cover density index (D/P) does not reflect increased bush encroachment at this site, but appears to show a closed forest at 36cm depth and relatively densely-wooded savannas throughout, while the humidity-aridity index (Iph) and water stress index (Fs) suggest a move towards a xerophytic short grass savanna, and increased water stress at the top of the sequence, which could reflect the climate becoming hotter and drier due to global warming. Future studies should be done to identify phytoliths specific to the vegetation of the study site and to calibrate the indices used to confirm their utility for this area.

1. INTRODUCTION

Savanna ecosystems are dynamic, with top-down and bottom-up controls (herbivory and fire, and substrate, topography and climate respectively) interacting to form the template from which biological heterogeneity stems (Scholes *et al.* 2003). In order to manage these ecosystems it is necessary to understand and interpret changes that are occurring today by putting them into the context of changes over time. The palaeorecord enables us to evaluate the importance of disturbance regimes over time (Schoonmaker and Foster 1991), but long palaeorecords are still uncommon in Southern Africa and often consist of proxies that are difficult to compare (Scott *et al.* 2008). The summer rainfall region of South Africa is of great importance for Quaternary palaeoecological and climatological research because it lies between the tropical and temperate zones and is therefore sensitive to changes in the positions of latitudinal belts of circulation in the atmosphere (Norström *et al.* 2009).

The Hluhluwe-iMfolozi Game Reserve in Northern KwaZulu-Natal is found in this region, and there are presently no palaeoecological studies in the area. Bush encroachment is a feature of this area, along with many other grass dominated ecosystems, and a shift from grassland to acacia savanna and finally closed broadleaf thicket may occur in as little as 40 years (Skowno *et al.* 1999; Wigley *et al.* 2010). A decrease in riverine forests has also been observed (L. Gillson *pers comm.* 2010). While it is known that many factors play a role, including Carbon dioxide and the associated human-induced climate changes, nutrients, fire and herbivory, it is necessary to uncover past patterns of vegetation change to determine the importance of each of these factors. It is therefore essential to use different palaeoecological proxies to provide a robust picture of the reserve through time.

Because grasses are such an important feature of savannas, it is necessary to ensure that past grass assemblages can be effectively identified (Bremond *et al.* 2008). The study of phytolith assemblages is a relatively new tool that has been used for reconstructing past vegetation, especially grasslands. Phytoliths are biogenic silica particles formed when plants absorb monosilicic acid ($Si(OH)_4$) from groundwater into the roots, where it is then transported throughout the plant and deposited intra- and extracellularly as an amorphous silica gel which takes the form of the space in which it is deposited (Piperno 1988; Mulholland and Rapp 1992). This leads to the formation of silt-sized silicon dioxide (SiO_2) shapes which, depending on the site of deposition, are often characteristic of certain parts of the plant, and plant taxa (Thorn 2007; Fahmy 2008). Phytoliths are highly polymorphic, and vary in colour depending on the amount of carbon coating them, from clear to opaque, and even brown (Elbaum *et al.* 2003; Prychid *et al.* 2004).

Phytoliths have advantages over the use of pollen and diatoms, other common palaeoecological proxies: they are more resilient, consisting of a relatively inert substance and persisting for long periods of time under oxidising conditions (Rovner 1988; Alexandre *et al.* 1997; Thorn 2007; Mercador *et al.* 2010). Phytoliths are particularly useful in areas where hot and arid climates prevent the preservation of plant fossils (Thorn 2007). They can be recovered from various types of soil and may be found in large quantities (Bremond *et al.* 2008). They may also give a more localised picture of vegetation as they are usually released directly into the soil as the parent plant dies and decays. They are more useful for determining the composition of grass-dominated ecosystems, as Poaceae produce pollen which is similar morphologically (Alexandre *et al.*1997; Bremond *et al.* 2007). Grass subfamilies generally show adaptations to temperature and moisture conditions (Taub 2000), and identification of phytoliths to this level can therefore be used to infer distribution, composition, and possibly temperature and rainfall patterns in grassland environments (Scott and Rossouw 2005; Mercador *et al.* 2010). Chloridoideae, Panicoideae and Pooideae have been particularly useful as these subfamilies produce morphologically distinct phytoliths and the species within each one have generally similar environmental requirements (Twiss 1992). Identification to genera level is also sometimes possible (Piperno and Sues 2005).

Only recently have phytolith assemblages been studied in a way which allows palaeoecological interpretation (Fahmy 2008), and there is still disagreement over the utility of phytolith data in some circumstances (Pearsall *et al.* 2004). Phytolith research in Africa is less developed than other parts of the world and studies in southern Africa are especially rare (Fahmy 2008; Finné *et al.* 2010).

I aim to contribute to phytolith and palaeoecological research in southern Africa by analysing the phytolith assemblages present in a sediment core. I hope to use this data to gain insight into past vegetation and climate present in the Hluhluwe-iMfolozi area. This will be done by comparing phytoliths from sediments to those in keys and plates, with the initial output a record of the phytolith assemblage, which will be matched with carbon dating at two levels to give an idea of the sediments' ages. Various indices will then be calculated based on the proportion of certain elements in the phytolith assemblage, to be used as a proxy for vegetation and climate. It is expected that the phytolith record will reflect the recent warming and drying that has characterised the late Holocene in many parts of Southern Africa (Scott *et al.* 2008), especially recently due to global warming. Bush encroachment is also expected to be evident in the phytolith record. Future research is anticipated to combine this data with pollen, charcoal, isotope, diatom and spore analyses to provide a complete picture of vegetation and climate change in this area.

2. METHODS

2.1 Study site

The Hluhluwe-iMfolozi Park is situated between 28°00’ – 28°10’ S, and 32°00’ – 32°10’ E in the northeast of KwaZulu-Natal, South Africa. The climate is warm and dry in winter and hot and wet during summer, with rains occurring between October and March, and fires in the dry season (Skowno and Bond 2003). The rainfall gradient in the park ranges from 990 mm (mean annual rainfall) in the higher altitude northwest to 635 mm in the river valleys of the southwest (Skowno and Bond 2003). There is a high interannual variability of rainfall in southern African savannas (Scholes *et al.* 2003). The topography is mostly composed of hills, and flat valley bottom areas, with altitude ranging from 90m above sea level in the valleys to 580m on the hilltops (Skowno and Bond 2003). Higher altitude areas support Northern Zululand Sourveld: a wooded grassland which may vary from sour grassland to dense bushveld thickets (Rutherford *et al.* 2006). Lower areas support Zululand Lowveld vegetation: tall grassveld with scattered trees and shrubs, interspersed with patches of bushveld, savanna thornveld, thicket, and woodland (Rutherford *et al.* 2006).

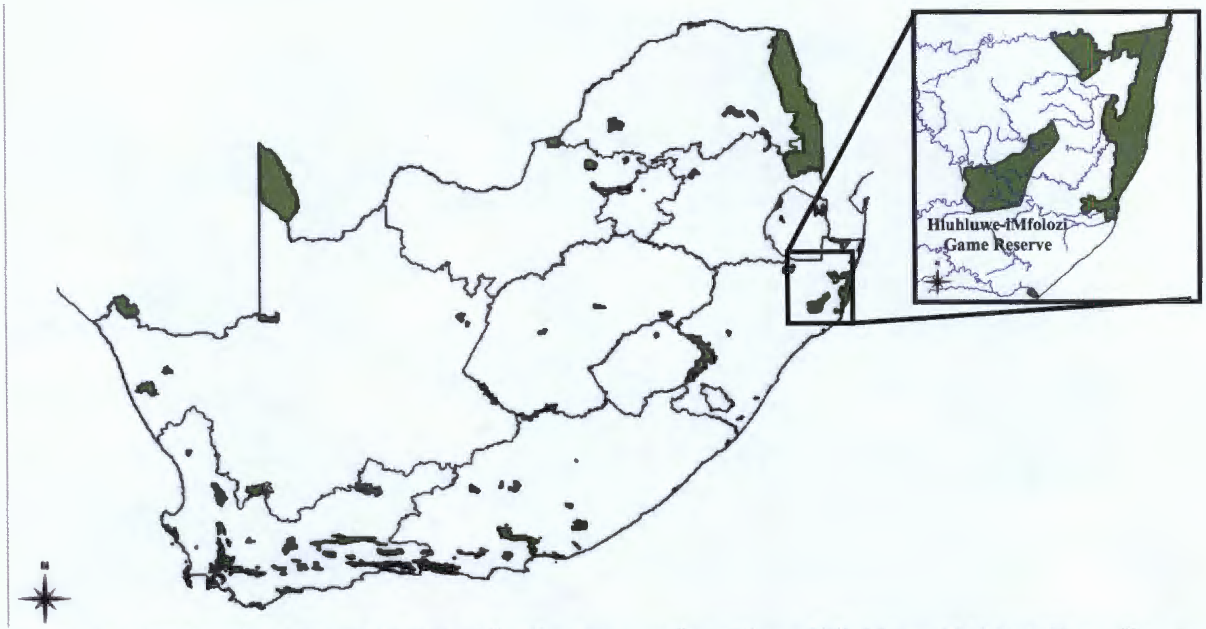

Figure 1. Map showing protected areas of South Africa, and position of Hluhluwe-iMfolozi Game Reserve

2.2 Data collection

2.2.1 Sample retrieval

Sediment cores were taken from a wetland just outside the reserve using a Russian corer. They were then stored at 0 C until analysis. 35 sub-samples were taken between 0 and 140cm in depth. AMS Radiocarbon dates were obtained from 100cm and 142cm.

2.2.2 Laboratory procedure

The samples were analysed following the procedure of Piperno (2006):

20 of the sub-samples were analysed (every 8cm or less). Between 0.81 and 3.87g of sediment was weighed using a massmeter, then deflocculated using a 5% sodium hexametaphosphate solution. Samples were stirred every 30min for a day. Wet sieving then occurred through 250µm and 75µm sieves. The sediment fraction greater than 250µm (generally made up of rootlets and other organic matter) was discarded; the fraction between 250µm and 75µm was set aside for later analysis. Clays were then removed using gravitational sedimentation (Jackson 1956), whereby large (600 – 1000ml) beakers were filled with the samples and distilled water to 10cm. They were left to settle for an hour before the supernatant was poured out. This step was repeated approximately 8 times, with a few samples requiring more treatment until the supernatant was clear. Carbonates were removed using a 10% hydrochloric acid (HCl) solution in a hot water bath, but the samples appeared to contain no carbonates. They were, however, rich in organic matter which was removed using concentrated nitric acid (HNO_3) (for the first half of samples) and 30% hydrogen peroxide (H_2O_2) for the rest. This process was performed in a water bath and took approximately two days. Excess organics and humic colloids were removed by heating the samples in a 10% solution of Potassium hydroxide (KOH) for 10minutes.

Heavy liquid separation was performed to separate the heavier inorganic silica from the biogenic silica (Thorn 2007). This was done following Piperno (2006) using Sodium polytungstate (SPT). Phytoliths have a specific gravity of 1.5 – 2.3 (Elbaum *et al.* 2003), so the SPT was diluted to a specific gravity of 2.4. 5ml of it was added to the samples, which were then centrifuged for 10 minutes at 3500rpm. The very top layer containing the phytoliths was removed, and this step was repeated to ensure recovery of all phytoliths.

Water was then added to this fraction in a ratio of at least 2.5:1 by volume, causing the phytoliths to begin to sink to the bottom. They were again centrifuged and the supernatant was removed using Pasteur pipettes and discarded. This step was repeated twice. Samples were rinsed twice with acetone to facilitate drying.

2.2.3 Classification and counting procedure

Samples were mounted in Dow Corning mounting solution, as a non-solid medium allowed 3-D identification, and its refractive index of 1.5 is between the optimum viewing limit of 1.51 to 1.54 for phytoliths, which have a refractive index of 1.4 (Elbaum *et al.* 2003).

Phytolith morphological classification was first proposed by Twiss et al. (1969), and amended by many others including Piperno (1988), and Mulholland and Rapp (1992). A light microscope was used to count 300 phytoliths per sample (at 400x and 1000x magnification) and they were classified into categories. The categories used are indicated below using common names from Bremond *et al.* (2005(a and b)) and the official names according to the International Code for Phytolith Nomenclature (ICPN) are indicated in brackets:

(1) cross, (2) dumbell (bilobate short cell), and (5) poly-lobate represent Panicoideae (Twiss *et al.* 1969; Twiss 1992; Fredlund and Tieszen 1994), and are mostly phytoliths from C_4 grasses adapted to warm, wet climatic conditions (Tieszen *et al.* 1979).

(3) saddle, produced by the Chloridoideae (Twiss *et al.* 1969; Twiss 1992; Fredlund and Tieszen 1994), and which represent C_4 grasses adapted to warm, dry climates or dry soils (Tieszen *et al.* 1979).

(4) conical (papillae cell), produced by the Pooideae grass subfamily (Twiss *et al.* 1969; Twiss 1992), which mostly consists of C_3 grasses adapted to temperate conditions and often found at high altitudes (Tieszen *et al.* 1979), as well as Cyperaceae (Wallis 2003). Square phytoliths were also identified as Pooideae, according to Scott and Rossouw (2005).

(6) point-shaped (acicular hair cell), (7) fan-shaped (parallelepipedal and cuneiform bulliform cells), and (8) sinuous and smooth elongate phytoliths are produced in the epidermis of all grasses (Kaplan *et al.* 1992; Twiss 1992; Bremond *et al.* 2005(a))

(9) crenate spherical (globular echinate), arising from Arecaceae (also known as Palmae (Runge 1999)

(10) rough spherical (globular granulate), produced by the wood of tropical trees and shrubs (Kondo *et al.* 1994). Woody species are, however, low phytolith producers: many species do not produce phytoliths and those that do often produce them in low concentrations (Tsartsidou *et al.* 2007), although Alexandre *et al.* (1997) found that phytoliths provided a good representation of forest species in the Sahelian region of Senegal.

(11) smooth spherical (globular psilate), which is not diagnostic due to its production in many different plant organs.

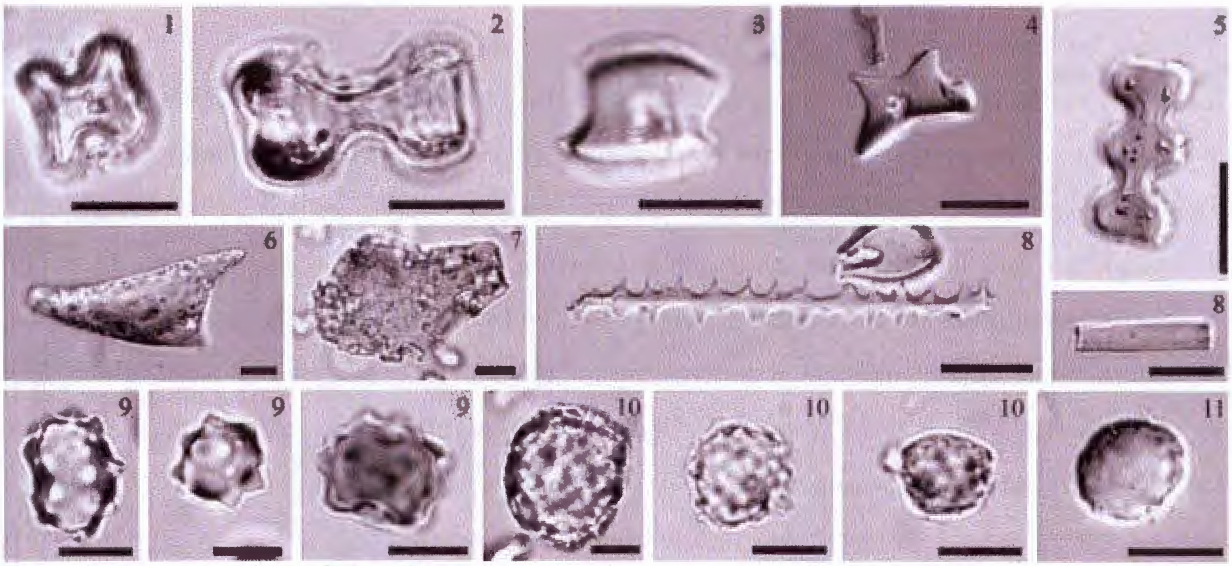

Figure 2. Representatives of phytolith morphotypes that were counted in this study (Bremond *et al.* 2005(a)). It shows: (1) cross, (2) dumbell, (3) saddle, (4) conical, (5) polylobate, (6) point-shaped, (7) fan-shaped, (8) sinuous and smooth elongate, (9) crenate spherical, (10) rough spherical, and (11) smooth spherical phytolith morphological types.

2.3 Data Analysis

A graph was plotted showing the proportion of phytoliths of each type as well as a total count using TILIA (Grimm 1997).

Various indices were used to interpret the phytolith assemblage as a proxy for vegetation and climatic parameters: The tree cover density index (D/P) was first used by Alexandre *et al.* (1997), and has since been used in both tropical and non-tropical environments to examine the approximate cover of woody plant species in relation to grasses (Bremond *et al.* 2005a). It is calculated by determining the ratio of rough spherical phytoliths (dicotyledons) to the sum of cross, dumbbell, saddle, point-shaped and fan-shaped phytoliths (grasses). The higher the ratio, the higher the tree cover density (Bremond *et al.* 2005 (b)).

The humidity-aridity index (Iph) attempts to reveal the degree of dominance of short C_4 grasses (mostly Chloridoideae) over tall C_4 grasses (mostly Panicoideae) (Bremond *et al.* 2005(b)). It was determined following the procedure of Diester-Haass *et al.* (1973), whereby the ratio of saddle type phytoliths (Chloridoideae) to the sum of cross, dumbbell and saddle type phytoliths (Panicoideae and Chloridoideae) was calculated. High values (>20–40%) indicate a xerophytic short grass savanna, and suggest a warm, dry climate, while low values suggest a mesophytic C_4 grass savanna, where climate is warm and humid (Bremond *et al.* 2005 (b)).

Finally, the water stress index (Fs) was used, as defined by Bremond *et al.* 2005(b). Bulliform cells in the epidermis of grasses and other monocotyledons are able to contract width-ways in response to moisture loss, causing leaves to roll (O'Toole and Cruz 1980; Andrejko and Cohen 1984). These cells give rise to fan-shaped phytoliths, and it is hypothesised that silicification of these cells would be due to high transpiration and/or submerging the roots (Andrejko and Cohen 1984), and this was confirmed by Bremond *et al.* 2005(b)). This index is calculated by dividing the percentage of fan-shaped phytoliths by the sum of grass phytolith types (cross, dumbbell, saddle, point-shaped and fan-shaped) but not including the elongate phytoliths.

3. RESULTS

The sediment sub-samples were all highly organic from the top to approximately 80cm depth, where they became low in organic material and high in clay and sand. The radiocarbon dating showed that sediment at 100cm was from 325 ± 30 BP, with a calibrated date between 1490 Cal AD and 1660 Cal AD (95.4% confidence). The sediment at 142cm was much younger (1 600 years) than a sample from 148cm from a core taken next to it, suggesting possible contamination with modern carbon. The age from the other core was therefore used, suggesting that the sediments at the base of the core were from approximately 2380 ± 40 BP, with a calibrated date of between 540 Cal BC and 340 Cal BC (76.7% confidence).

There were very high numbers of unclassifiable phytoliths (>79% per sub-sample). I can therefore only make inferences about preliminary trends evident in the data, which include higher amounts of grass phytoliths and low amounts of woody dicotyledon phytoliths, which remain relatively constant in abundance throughout. There is what appears to be a peak in grass phytoliths (point-shaped, fan-shaped and elongate) at 20cm depth (Figure 3). C_4 grasses (Chloridoideae and Panicoideae) appear to be dominant throughout, but especially towards the upper part of the sedimentary sequence, and C_3 grasses appear to be more dominant towards the lower part.

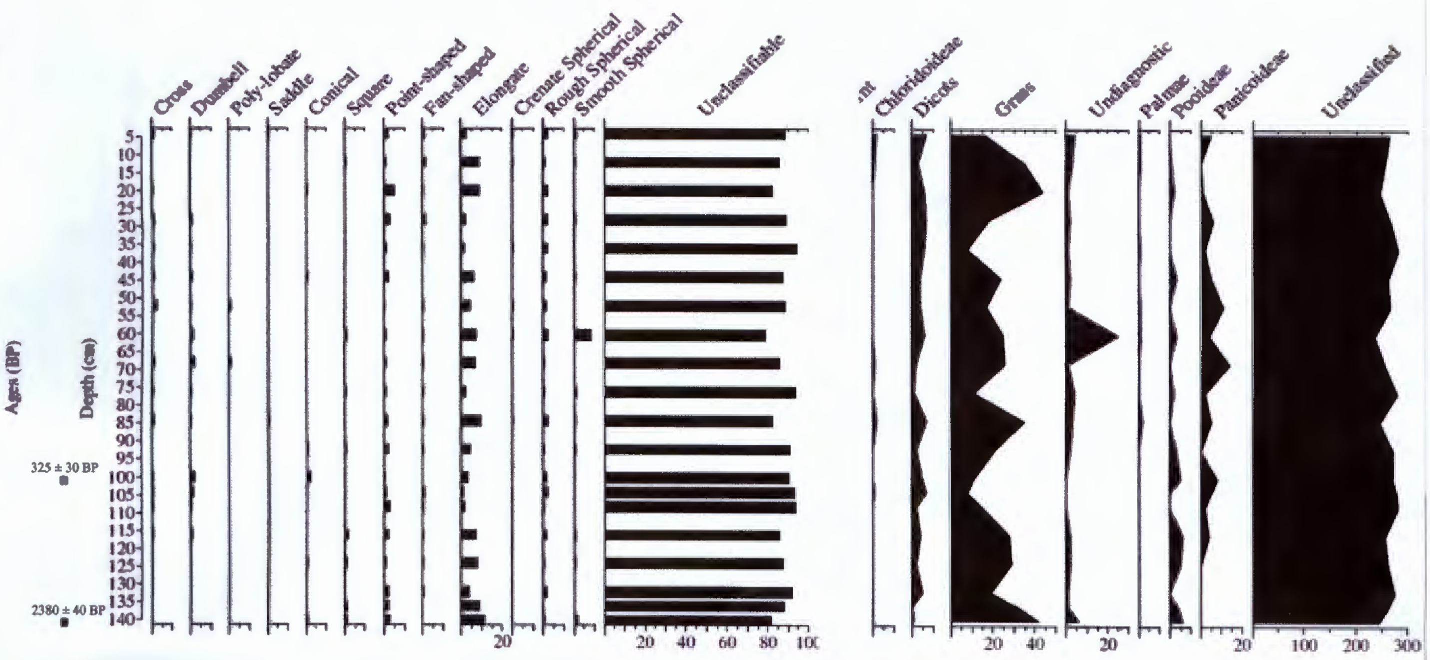

Figure 3. Proportions of each phytolith morphological type counted, along with total counts of phytoliths by grass subfamilies and taxonomic groups.

There appear to be peaks in woody vegetation cover at 36cm, 68cm and 132cm, and a relatively high woody vegetation cover at all depths except 136cm, when rough spherical phytoliths were absent (Figure 4a)). The humidity-aridity index suggests that xerophytic short grass savannas were dominant at 4cm, 12cm and 84cm depth, while mesophytic tall grass savannas are present at 68cm and 104cm. The water stress index shows peaks at 12cm, 28cm, 76cm and 104cm. These indices together suggest that the climate has become drier and warmer over the last few hundred years. There are no other patterns which are so clearly evident.

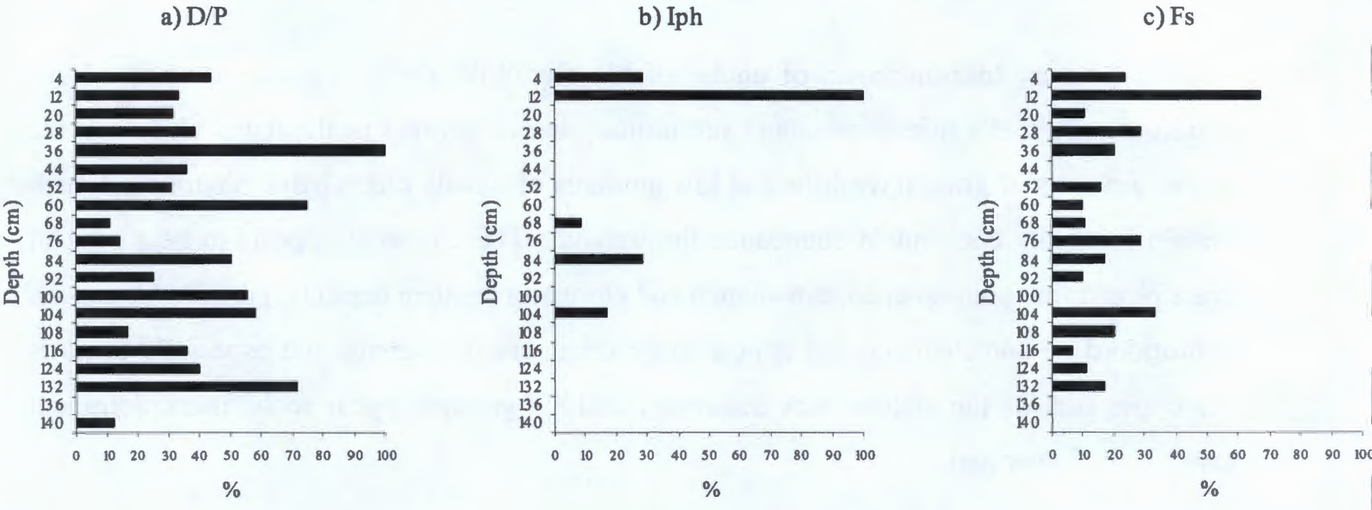

Figure 4. Phytolith vegetation indices plotted against depth a) Tree cover density index (D/P), with higher ratios suggesting higher tree cover density. b) Humidity-aridity index (Iph), where ratios over 20% suggest a xerophytic short grass savanna, while ratios under 20% suggest a mesophytic tall grass savanna. c) Water stress index (Fs). Higher ratios suggest higher rates of transpiration, or waterlogging of soil in which arid-adapted species grow.

4. DISCUSSION

Phytoliths were found at all sub-sample depths that were analysed. The large numbers of unclassifiable phytoliths in each sample meant that results are not likely to be significant, although other studies have also found also found reasonably high levels of unclassifiable phytoliths, for example Alexandre *et al.* (1997), with at least 38% unclassifiable. Future studies should use larger sediment samples, for example Bremond *et al.* (2005(a)), who used 20g sediment samples.

In order to use phytolith indices to accurately characterise past climate and vegetation, they should be calibrated using modern phytolith and vegetation assemblages, something which has yet to be done for this area. The interpretation of these assemblages was therefore guided by other areas of Africa, but it is unlikely to be completely accurate.

The phytolith assemblage is dominated by C_4 grasses throughout the record (Figure 3), which was expected because C_4 grasses dominate up to an altitude of 2000m in tropical and sub-tropical regions (Sage and Monson 1999). C_4 grasses are adapted to high solar radiation and temperatures during the season of growth, and are a dominant feature of many African ecosystems, while C_3 grasses are dominant in temperate regions, and those which experience winter rainfall (Ehleringer *et al.* 1997; Sage and Monson 1999). The dominance of C_4 grass phytoliths towards the upper part of the record, and greater numbers of C_3 phytoliths towards the bottom could suggest a warming trend. Mean annual temperature increases of over 0.1°C per decade were found over the period 1960 - 2003 in the KwaZulu-Natal eastern coastal region (Kruger and Shongwe 2004), and this correlates with this trend, at least for the recent past. The water stress index (Fs) (Figure 4c)) suggests that there has been an increase in transpiration, possibly indicating drier climates. The humidity-aridity index (Iph) (Figure 4b)) only had data for a few depths, but suggests that the top of the record is characterised by xerophytic short grass savanna, supporting the hypothesis that climate has become drier. This pattern appears to be the only clear climate trend in the record.

It was expected that woody dicotyledon phytoliths would be relatively rare in the sedimentary record as they are lower phytolith producers (Piperno 2006; Tsartsidou *et al.* 2007), and this appears to be true for this area. Alexandre *et al.* (1997) found that savannas could be differentiated from dense tropical forests if the D/P index was less than 100%. In this study, the D/P index was 100% at 36cm, suggesting a dense, forested ecosystem, while high values at 60cm and132cm suggest a densely wooded savanna (Figure 4a).). At 4cm, the D/P index is 43.75%, which also suggests a relatively densely forested savanna. The phytolith record does not appear to show any clear indication of bush encroachment. This is in contrast to the findings of Wigley *et al.* (2010), where large increases in woody cover were found in various land-use types in this area. This may be because of bush encroachment not occurring in the immediate vicinity of the study site or problems while counting the rough spherical (woody dicotyledon) phytoliths. There were many small round phytoliths which were assumed to be fragments, the D/P index is likely to be inaccurate for this area due to over- and under-estimation. It is worth noting that in non-tropical zones, it may be difficult to use the D/P index because some dicotyledons produce few phytoliths that can be distinguished (Stromberg 2002; Delhon *et al.* 2003).

There are other factors that should be taken into account when interpreting results: conical phytoliths are said to be easily fragmented and dissolved, so their abundance in the soil may not represent their actual abundance (Alexandre *et al.* 1997), and the fact that they may represent Pooideae or Cyperaceae also poses a problem (Twiss *et al.* 1969; Twiss 1992; Wallis 2003). Crenate spherical (Arecaceae) and point-shaped (all grass) phytoliths are thought not to be taxonomically uselful as they do not correlate to any known climatic or vegetation parameters (Bremond *et al.* 2008). The species of Arecaceae found in the area, however, are found either near water or in areas with a high water table: *Phoenix reclinata* (Wild Date Palm) is found along river banks in low-lying grassland and *Hyphaene natalensis* (Lala palm) is found in low lying sandy flood plains (Funston 1993; Coates Palgrave 2002). Their presence in the phytolith record could suggest periods of higher water availability. Smooth spherical phytoliths appear to be produced by several different groups, and at this point are not useful (Piperno 2006). The soil phytolith assemblage may also not provide an accurate representation of past vegetation types due to other factors, including soil geochemistry and silica content, degree of silica recycling by plants, and the likelihood of soil phytoliths to resist destruction by dynamic physical and chemical soil processes (Behrensmeyer *et al.* 2000). Mercador *et al.* (2009) suggested relatively high rates of phytolith destruction (around 50%), especially types that are only partially silicified or thin-walled. Fires may transport and re-deposit phytoliths (Twiss *et al.* 1969), and this must be taken into account in fire-prone ecosystems like the savanna. Wetlands are especially likely to accumulate phytoliths transported by rain, and may therefore show a more-regional picture of vegetation dynamics than expected (Finné *et al.* 2010).

Because phytoliths are a relatively new proxy, there is still much potential for future research. Phytoliths should be extracted from modern plants growing in the area for identification and classification purposes, as some of the types found in other parts of Africa may not be applicable here. They should also be extracted from the top of the sediment profile, and compared with modern vegetation assemblages to calibrate all of the indices that were used for this area.

Conclusion

The dynamism of the savanna environment appears to be evident in the vegetation data assessed in this study, with most of the samples showing no clear trend. This was especially evident with regards to tree cover density, suggesting that the phytolith record does not accurately represent the recent bush encroachment that has been taking place in this area or that shrub encroachment is not occurring in the immediate vicinity of the sample site. The only trend which I could identify, supported by the humidity-aridity index (Iph) and water stress index (Fs), was a possible increase in temperatures and decrease in precipitation near the top of the core (at 4cm and 12cm). This is in line with climate change projections for South Africa: over the 2080 – 2099 period, temperatures are predicted to rise by 4°C and precipitation is predicted to decrease by 4% relative to the 1980 – 1999 period (IPCC 2007). The use of phytoliths as part of a multi-proxy analysis in the Hluhluwe-iMfolozi area is likely to result in significant benefits for determining patterns of past vegetation and climate over the late Holocene, but work still needs to be done on calibrating the indices used for this area and attaining more significant results by counting larger phytolith samples.

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