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# Influence of the local environment on lacustrine sedimentary phytolith records

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ABSTRACT

Fossil phytolith assemblages from soils and lake sediments are widely used to reconstruct past vegetation patterns and dynamics, especially in tropical environments where a phytolith index has been quantitatively calibrated to estimate tree cover. Most calibration studies have focused on comparing phytolith assemblages in modern soil with the present aboveground vegetation. However, little is known about phytolith taphonomy and the representativeness of phytolith assemblages and indices in lake sediments. The aim of this study is to improve the understanding of the composition of phytolith assemblages and their influx into recent lake sediments by comparing them with local land cover assessments. This study focused on three lakes in the Central African Republic located in savanna, forest–savanna mosaic, and forest. It appears that the local environment surrounding the lake was critical for interpreting current and past assemblages, and the ratio of dicotyledon to Poaceae diagnostic phytoliths (the D/P index). The presence of a riparian forest in an open environment had no impact on phytolith assemblages or the D/P index, which instead reflected both the local and regional landscapes. Conversely, contributions from a marsh, if present in a forested environment, completely dominated the phytolith records, which consequently reflected only the local environment of the lake. A high correlation between the Poaceae phytoliths influxes and the charcoal accumulation rates for the two lakes surrounded by a riparian forest has also been found. This finding, which was associated with a high proportion of burned Poaceae phytoliths, provides evidence that Poaceae phytoliths are mainly transported by wind in ash clouds produced by fires.

## 1. Introduction

Long-term ecological records from lake sediments are important for understanding responses of vegetation to climate change and anthropogenic pressure (e.g., Willis et al., 2010), especially in tropical and inter-tropical environments. Indeed, in these areas other sedimentary archives are rare (e.g. terrestrial soil profiles, loess or temporary swamps, Piperno and Becker, 1996; Runge, 1999; Albert et al., 2006; McMichael et al., 2012; Dickau et al., 2013) and generally do not allow continuous recording, contrary to lacustrine archives where most of paleoenvironmental studies are conducted (e.g., Piperno, 1993; Bush et al., 2007; Nelson et al., 2012; Colombaroli et al., 2014). In particular, lake sediments have helped determine the respective roles of climate and fire in initiating and maintaining savannas (Vincens et al., 1999; Gillson, 2004; Rull, 2009), and the impact of past climate change on the resilience of savannas (Gillson and Ekblom, 2009; Ekblom and Gillson, 2010) and forests (Brncic et al., 2007; Brncic et al., 2009). Savanna ecosystems are characterized by the co-dominance of trees and grasses (Scholes and Archer, 1997). Thus, tree cover is a key factor to consider when studying both savanna and forest ecosystems (Hirota et al., 2011). The relative importance of drivers that determine the structure of savannas is still under debate (e.g., Sankaran et al., 2005; Staver et al., 2011) and would benefit from further understanding of past interactions between tree cover and its potential drivers (e.g., climate, fire, herbivory, soil, land use), especially in forest–savanna mosaics areas (Iriarte et al., 2012).

Several paleo-environmental proxies are available to study past tree cover (Aleman et al., 2012). For pollen analysis, the ratio of arboreal to non-arboreal pollen provides qualitative information about tree cover and distinguishes between wooded and more open ecosystems (Liu et al., 1999; Vincens et al., 2000). However, pollen is associated with long distance dispersal (Nathan, 2006) and represents a regional signal of the vegetation around the lake (Sugita, 1994; Sugita et al., 1999). A commonly used indicator of the relative abundance of trees and grasses in tropical environments is the $\delta^{13}$C value of soil organic matter, which reflects the relative contributions to carbon fixation of the $C_3$ and $C_4$ photosynthetic pathways used by tropical trees and grasses, respectively (Boutton et al., 1998; Kelly et al., 1998; Gillson et al., 2004; Coe et al., In press). However, this proxy is rarely used in lakes as a vegetation

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proxy due to the multiple origins of lacustrine organic matter (allochtonous and autochtonous, e.g., Cole et al., 2002; Nguetsop et al., 2004). Phytoliths are increasingly used, especially in tropical environments where diagnostic phytoliths are produced by many tropical families (Pearsall, 2000; Piperno, 2006) and have proven to be very accurate in quantitatively reconstructing the cover of woody plants (Bremond et al., 2005a; Aleman et al., 2012) and the histories of tropical ecosystems (Alexandre et al., 1997; Boyd et al., 1998; Barboni et al., 1999; Neumann et al., 2009; Dickau et al., 2013; Whitney et al., 2013). Phytolith deposition and accumulation are associated with the decomposition of local vegetation (Piperno, 2006), thus examination of phytoliths can provide valuable complementary information to pollen analysis.

A problem is that modern assemblages used to calibrate past records are from soils (Fredlund and Tieszen, 1994; Piperno and Becker, 1996; Alexandre et al., 1997; Runge, 1999; Aleman et al., 2012) or fresh plants (Albert et al., 2006; Novello et al., 2012) rather than directly from recent lake sediments. Furthermore, factors affecting signals from current vegetation in sedimentary phytoliths in lake sediments have not yet been elucidated. Thus, imperfectly understood differences in the taphonomic processes (production, transportation, deposition and potential degradation of the bioproxies) between soil and lake sediments could complicate attempts to extrapolate calibration assemblages and phytolith indices from one material to the other (e.g. Aleman et al., 2012). Assessing the taphonomic signature of phytoliths contained in lacustrine deposits would be of great interest for paleoenvironmental studies. For example, Aleman et al. (2013a) showed that the direct environment around a lake can influence the mode of deposition of particles in recent sedimentary charcoal records. To explore the processes in more detail, the impact of the lake shoreline environment on phytolith assemblages and indices (notably the ratio of dicotyledon to Poaceae diagnostic phytoliths, D/P index) was investigated, using recent sedimentary records from three lakes in savanna, forest–savanna mosaic, and forest environments in central Africa. The relationships between the local environment of the lakes and the representativeness, transport and mode of deposition, of their phytolith assemblages were studied and the D/P index was then compared to land cover changes around each lake from 1974 to 2005.

## 2. Material and methods

### 2.1. Study sites

The sediments of three lakes, situated in savanna (Lake Gbali, 4°49′07″N, 18°15′46″E), forest–savanna mosaic (Lake Doukoulou, 4°15′10″N, 18°25′25″E), and forest (Lake Nguengué, 3°45′40″N, 18°07′19″E) in the Central African Republic (Fig. 1), were studied. The climate around Lakes Gbali and Doukoulou is tropical with ~1500 mm annual precipitation. The 4-month dry season from November to February is followed by an 8-month long wet season, (Bangui weather station, Hijmans et al., 2009). Lake Nguengué experiences a shorter dry season (December–February) and is wetter with an average rainfall of 1738 mm (1982–2007, Boukoko Meteorological station, A. Ougou, personal communication, 2008).

The three lakes are of various sizes (2, 36 and 14 ha for Lakes Gbali, Doukoulou and Nguengué, respectively), but all are shallow (2.00–2.35 m depth at the time of sampling) with a gently sloping bottom. Lake Gbali is bordered by a 200-m wide riparian forest mainly composed of *Hallea stipulosa* (DC.) Leroy and some *Raphia vinifera* P. Beauv. The woody savanna vegetation that surrounds the riparian forest is composed of the dominant grass *Imperata cylindrica* (L.) Raeusch., associated with *Cenchrus polystachios* (L.) Morrone and *Hyparrhenia diplandra* (Hack.) Stapf., and a woody cover of typical fire-resistant trees: *Daniellia oliveri* (Rolfe) Hutch. and Dalz., *Terminalia schimeriana* Hochst., *Prosopis africana* (Guill. & Perr.) Taub., *Hymenocardia acida* Tul., *Piliostigma thonningii* (Schumach.) Milne-Redh., *Sarcocephalus latifolius* (Sm.) E.A. Bruce, *Annona senegalensis* Pers. and *Crossopteryx febrifuga* (Afzel. ex G.Don) Benth. The lake is situated at around 400 m from a road and 1 km from a village, so some parts of the landscape burn at least once a year during the dry season (Aleman et al., 2013a).

Lake Doukoulou is surrounded by an extensive zone dominated by Poaceae with a gradient of *Vetiveria zizanioides*, *Imperata cylindrica* and *Pennisetum purpureum* from the lake edge towards a mosaic of dense savanna (herb layer of *I. cylindrica*, *V. zizanioides* L. Nash and *P. purpureum* Shumach.; woody layer of *P. thonningii*, *Erythrina sigmoidea* Hua, *Vitex doniana* Sweet., *Terminalia glaucescens* and very sparse *D. oliveri*, *Albizia zygia* (DC.) J.F.Macbr.) and very degraded forest including *Terminalia superba* Engl. & Diels, *Cola lateritia* K. Schum., *Pycnanthus angolensis* (Welw.) Warb. and the alien invasive

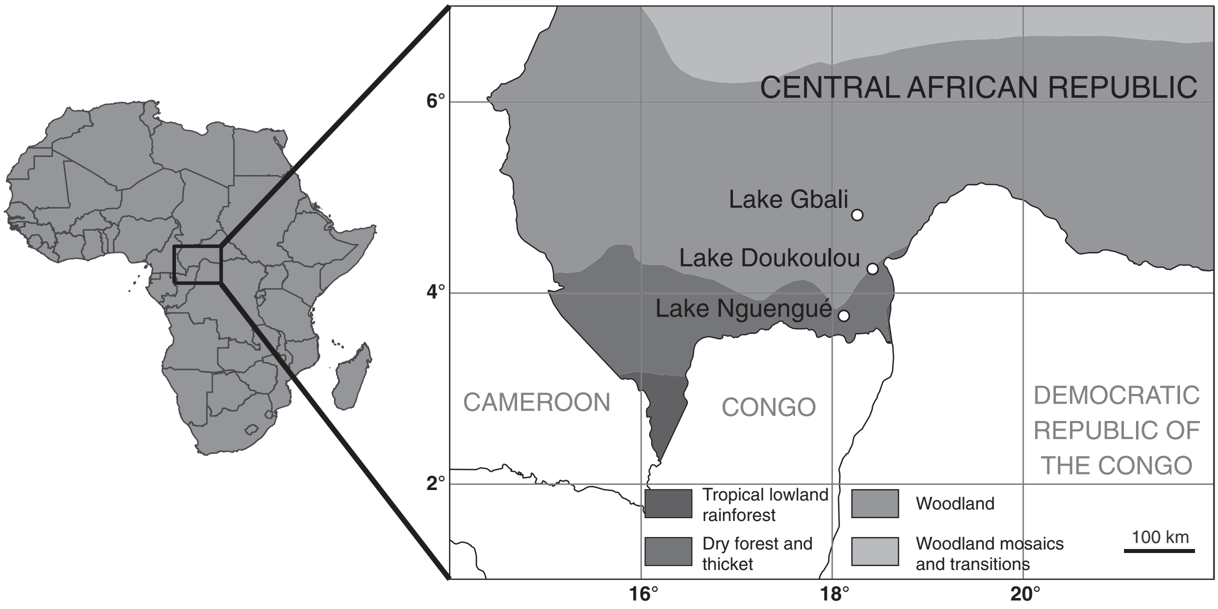

**Fig. 1.** Location of the three lakes and distribution of the major African vegetation types (from White (1983)) in the Central African Republic.