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Impact of climate change on the ecology of the Kyambangunguru crater marsh in southwestern Tanzania during the Late Holocene

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ABSTRACT

Instrumental records of temperature and hydrological regimes in East Africa evidence frequent droughts with dramatic effects on population and ecosystems. Sources of these climatic variations remain largely unconstrained, partly because of a paucity of Late Holocene records. Here, we present a multi-proxy analysis of a 4-m continuous sediment core collected in the Kyambangunguru crater marsh, in southwest Tanzania, covering the last 4000 yrs (cal. BP). We used microscopic (macro-remains, microfossils, palynofacies, pollen), elemental (carbon, nitrogen contents), molecular (br GDGTs, *n*-alkanes) and compound-specific isotopic (δ^2H *n*-alkanes) investigations to reconstruct the environmental history of the marsh. The multi proxy record reveals that, 2500 years ago, the marsh underwent a major ecological transition from a lake to a peatland. Temperature and hydrological reconstructions evidence warmer and drier conditions between 2200 and 860 cal. BP, which probably triggered the establishment of a perennial peatland. This study is one of the first combined temperature and precipitation record of Late Holocene in the region and highlights changes in the spatial distribution of the East African climate regimes. Several cold periods are observed, between 3300 and 2000 cal. BP and since 630 cal. BP, the latter corresponding to the Little Ice Age. Moreover, wetter conditions are reported during the Medieval Climate Anomaly in contrast to other north-eastern African records suggesting that Tanzania is located at the transition between two hydro-climatic zones (north-eastern versus southern Africa) and has experienced variable contributions of these two zones over the last millennium.

1. Introduction

Tropical highlands are major sources of food and freshwater for more than 35 tropical countries (Williamson et al., 2014). The

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climate dynamics and variability of these topographically complex environments, however, remain poorly studied. While it has been shown that the Quaternary climatic trends in East Africa were primarily controlled by orbital forcing (e.g. Garcin et al., 2006; Tierney et al., 2008), the shorter scale climate dynamics of this region is largely unconstrained. Notably, mid-to late Holocene records of many East African lakes (e.g. Gasse, 2000; Wanner et al., 2011) suggest rapid and frequent, high amplitude, climatic fluctuations at the centennial scale. These fluctuations and their consequences are not well understood due to a general lack of highly resolved records (Nicholson et al., 2013). Furthermore, the timing and intensity of these events are not always synchronous from site to site (Tierney et al., 2011, 2013). Here, we present detailed records of climate and ecosystem changes from a sequence of sediments covering the late Holocene (the last 4000 years) in the Kyambangunguru marsh. This marsh is located in the Rungwe Volcanic Province (RVP; southwest Tanzania), a highland representing one of the four major food crop producing regions in the country (Majule, 2010).

Marshes and peatlands have a great potential for quantitative high-resolution palaeoclimatic records (Amesbury et al., 2012; Blackford, 2000) notably in the tropics (e.g. Bonnefille et al., 1990; Bourdon et al., 2000; Page et al., 2011; Rucina et al., 2010; Swindles et al., 2018). However, they are highly dynamic ecosystems where the vegetation cover and the hydrology functioning can be totally modified at a centennial scale (Loisel and Yu, 2013). This may complicate the interpretation of climatic proxies, notably those based on biological markers as their fluctuations may be related to ecological, local change rather than regional climatic change. A major challenge in using marsh/peat records as climatic archives is thus to disentangle biological signals linked to dynamic changes of the peatland ecosystem itself from those that are driven by local to regional environmental change (Chambers et al., 2012; Morris et al., 2015). The focus of this study is to investigate the internal, ecological changes within the marsh in the context of regional climatic variations. We aim to retrieve detailed (quantitative) air temperature and (qualitative) hydrological condition records of the late Holocene from the southernmost part of East Africa to test whether rapid and high amplitude climatic events (e.g. Russell and Johnson, 2005; Wanner et al., 2011) were recorded in this area in comparison to other East African records. Additionally, the multiproxy approach, combining microscopic observations and geochemical characterization, intends to determine potential feedbacks of these rapid climatic events in the tropical highland wetlands as well as potential human impact in the region.

Analysis of pollen, non-pollen palynomorphs (NPPs), macroremains, palynofacies and bulk elemental (C and N content) determination was conducted to characterize the ecological states of the wetland, complemented by biomarker-based proxies to determine past variations in air temperature and hydrology. Branched glycerol dialkyl glycerol tetraethers (br GDGTs) and compound specific long chain *n*-alkane hydrogen isotopic composition (δ^2H_{wax}) were used for mean annual air temperature and hydrological conditions reconstruction, respectively. Br GDGTs are membrane lipids produced by unknown bacteria (Sinninghe Damsté et al., 2000) whose relative abundances in environmental samples have been shown to correlate with temperature and pH (Weijers et al., 2006, 2009). This enabled the reconstruction of past pH and air temperatures from the br GDGT distribution in sediments, peats and soils (Nichols et al., 2014; Peterse et al., 2011; Weijers et al., 2007a). Long chain *n*-alkanes are constituents of the epicuticular wax layer of leaves (Eglinton and Hamilton, 1967). It has been shown that their hydrogen isotopic composition (δ^2H_{wax}) reflects the hydrogen isotopic composition of the water taken up by the plants (e.g. Estep and Hoering, 1980; Sauer et al., 2001; Sessions et al., 1999). Accordingly, they can be used to reconstruct variations in local palaeohydrology as shown in several lacustrine sedimentary archives from the Quaternary and the Holocene in East Africa (e.g. Loomis et al., 2015; Powers et al., 2005; Tierney et al., 2008; Verschuren et al., 2000). The combined use of these two proxies allows distinguishing the temperature from the hydrological signal which has been a major limitation in lake-based East African climatic reconstructions (Verschuren, 2003). Moreover, in settings with high sedimentation rates like marshes, they can offer highly detailed and independent reconstruction of the temperature and the hydrological conditions.

2. Regional setting: the Rungwe Volcanic Province and the Kyambangunguru marsh

The Rungwe Volcanic Province (RVP; SW Tanzania; Fig. 1A), is a large volcanic mountain region (1500 km^2) located at the triple junction of the Malawi Rift, Rukwa/Tanganyika Rift and the Usanga Basin in the southern part of the East African Rift System (Fontijn et al., 2010, 2012). The RVP is delimited by the Poroto Mountains in the north, Lake Malawi in the south and the Livingstone escarpment in the west (Fig. 1B). The area is known to be seismically active with volcanic eruptions occurring from the late Miocene (9.2 Ma) to the 19th century, with hot spring activity still found today (Branchu et al., 2005). The region contains three major stratovolcanoes: the Ngozi, Kyejo and Rungwe (Fontijn et al., 2010, 2012). South of these high-altitude sites and north of Lake Malawi lies the Karonga plain. Several monogenic maar-type craters were created during late Pleistocene phreatomagmatic explosions along the Mbaka fault system and are now filled by closed lake hydro-systems (Fontijn et al., 2012, Fig. 1B). The region belongs to the humid equatorial zone of Africa, mainly determined by the migration of the Intertropical Convergence Zone (ITCZ), a key atmospheric feature of tropical atmospheric circulation with low-pressure air masses accompanied by high precipitation. The ITCZ reaches its southernmost position (centred at ca. 15°S, Fig. 1A) in January, resulting in seasonal fluctuations between hot humid conditions from November to May and relatively colder and dry conditions from June to October (Fig. 1C). The RVP is among the most humid regions of Tanzania along with the coastal zone (Basalirwa et al., 1999). It is characterized by a different rainfall distribution with persisting rainfall in April–May. Nivet et al. (2018) showed that the Indian tropical Ocean and the Austral Ocean are the main sources of moisture in the area, with only a minor influence of the Congo Air Mass. Thus, the currently observed variability of the regional rainfall is likely highly impacted by the Indian Ocean Dipole, through Sea Surface Temperature anomalies. Over the last century, climatic trends from the RVP point towards drier conditions associated with a shorter rain season Williamson et al., 2014) and a continuous increase in temperature ($\approx 1\,°C$ for the last 100 yr; Branchu et al., 2005). Typical vegetation of the region includes Zambezian Miombo-type woodland at low altitude and Afromontane vegetation at higher altitude (Garcin et al., 2006; Williamson et al., 2014). In many locations, the woodland has been replaced by diverse crops (banana, rice, cocoa, tea, coffee, maize; Coffinet et al., 2017; Williamson et al., 2014). The RVP is today one of the main agricultural resources of Tanzania (Majule, 2010).

The Kyambangunguru marsh (9°22′ S - 33°47′ E, 660 m a.s.l.) is located in one of the numerous maar craters of the RVP, between the Mbaka River and the Mbaka fault. These maar craters are essential water and biodiversity resources for the region. At Kyambangunguru, no human activity has been recorded nor is known within the crater (no land or water use). Human settlement expands in the plains surrounding the volcano (mainly family-scale