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Late Quaternary vegetation development and disturbance dynamics from a peatland on Mount Gorongosa, central Mozambique

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A B S T R A C T

Few long-term climate and environmental records are available for southeast Africa where millennial scale shifts in the north-south position of the Intertropical Convergence Zone (ITCZ) and changes in Indian Ocean sea surface temperatures interact with local controls (e.g., fire, hydrology) to influence vegetation and ecosystem dynamics. Reconstruction of late-Pleistocene – Holocene environmental change from peat sediments obtained from Mount Gorongosa, central Mozambique, provides insight into vegetation, climate and disturbance interactions over the past c. 27 kyr. During the late Pleistocene, cool and wet climatic conditions supported *Podocarpus* forest and Ericaceae-heathland until drier conditions led to grassland expansion and a hiatus in peat deposition between c. 22.5 and 7.2 cal kBP. Increased temperatures and fire activity since c. 7.2 cal kBP led to further expansion of grasslands. Continued warming helped maintain grasslands and fostered a diverse mix of *Podocarpus* forest with a large number of subtropical trees and miombo woodland taxa (especially *Brachystegia* spp.) until regional land-use associated with the rise of Iron Age activity promoted an increase of disturbance related taxa over the last 1–2 millennia. Recent migration of people onto the Mount Gorongosa massif in the last fifty years are linked to an increase in fire activity that is unprecedented in the 27 kyr record, resulting in shifts in vegetation composition and structure. This long-term record of environmental change from central Mozambique highlights complex interaction between overlapping climatic influences and documents important vegetation transitions linked to millennial scale climatic controls, disturbance processes and more recent land-use change from a region where few records exist.

1. Introduction

Montane ecosystems in southern and southeastern Africa sustain unique mosaics of arboreal/grassland vegetation and are of particular interest because they host diverse and endemic plant and animal assemblages, are often the source of critical freshwater resources, and are culturally significant to the communities that surround them. Vegetation dynamics are poorly documented for mid latitudes of southern Africa (15–20°S), especially montane sites where *Podocarpus* forests persist within a diverse mix of miombo woodlands, subtropical forest taxa and grassland species. The records that exist for southern and eastern Africa offer few clues into the biogeography and expansion/contraction of podocarp, heathland, grassland and miombo woodland taxa for montane sites within this latitudinal zone. While previous research by Meadows and Linder (1993) and Tomlinson (1974) showed that montane grasslands were present for millennia at sites throughout southern and East Africa, attributing their development to cooler and drier conditions in the late-glacial and, more recently to land-use; the biogeography of high-elevation grasslands in Mozambique is still poorly understood. After decades of evaluating present-day ecosystem dynamics on Mount Gorongosa, Tinley (1977b) hypothesized that the genesis of Mount Gorongosa grasslands was a recent phenomena, likely a result of contemporary anthropogenic

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disturbances and hydrologic controls. The lack of information on long-term climate-vegetation and land-use interactions for this region highlight the need to augment well researched sites in South Africa and East Africa with records from Mozambique.

Previous research from southern and eastern Africa shows that climatic variability, human activity, disturbance and local edaphic conditions mediate the distribution of forest and savanna biomes and characteristics of the ecotonal boundaries that separate them (Bond, 2008; Chevalier and Chase, 2015; Meadows and Linder, 1993). Quaternary records from the Burundi Highlands and Lake Malawi show orbital induced shifts in the ITCZ and strengthening (weakening) of SE trade winds acted as strong controls on the spatial distribution of precipitation and associated vegetation (Beuning et al., 2011; Bonnefille and Chalié, 2000; Ivory et al., 2012; Powers et al., 2005), whereas palynologial records from afro-montane sites in the Drakensberg Mountains, South Africa (Neumann et al., 2014; Norström et al., 2014), emphasize the role of Indian Ocean sea surface temperature (SST) variability as the primary control on environmental change. Quaternary palynological records from the northeast coast of South Africa: Lake Sibaya (Neumann et al., 2008), Mfabeni peatland (Finch and Hill, 2008) and Lake Eteza (Neumann et al., 2010; Scott and Steenkamp, 1996) highlight climate, land-use and disturbance interactions as important drivers of long-term vegetation change as do records from savanna ecosystems including Wonderkrater, Tswaing and Tate Vondo in South Africa (Metwally et al., 2014; Scott, 1982a, b; Scott, 1999a, b; Scott et al., 2012). Quaternary paleoecological studies from Mozambique are restricted to the coastal plains of southern Mozambique (Ekblom, 2008; Ekblom et al., 2014; Ekblom and Stabell, 2008; Holmgren et al., 2012). Among these records, the longest record is available from Lake Nhaucati within the southern coastal plain and shows detailed changes for the last 1.6 kyr within miombo woodlands where the primary drivers of vegetation change are attributed to climatic variability and Iron Age land-use activities concentrated during the last 1 kBP (Ekblom et al., 2014).

1.1. Late-Pleistocene-Holocene climate variability

Previous research suggests important controls influencing millennial-scale late-Pleistocene-Holocene climate variability include Northern Hemisphere (NH) ice sheet extent and teleconnections between NH SSTs and Indian Ocean SSTs, direct insolation forcing and related shifts in the north-south position of the ITCZ and more local convective activity and temperate-tropical trough development (Castañeda et al., 2007; Chevalier and Chase, 2015; Tierney et al., 2008). It is clear that these controls interacted to influence both temperatures and precipitation yet the relative importance of each driver at subregional to local scales in southern and eastern Africa is still not well resolved.

Changes in late-Pleistocene-Holocene temperatures followed similar trends throughout southern and eastern Africa with the Indian Ocean moderating the magnitude of change from coast to interior. In southern Africa, cool LGM temperatures cooled further during the Pleistocene-Holocene transition, steadily increased several degrees during the early Holocene, then cooled during the last several millennia (Chevalier and Chase, 2015). In eastern Africa, temperatures were also cool during and after the LGM but increased earlier than at sites in southern Africa (Powers et al., 2005; Tierney et al., 2008; Woltering et al., 2011). Spatiotemporal variability in regional temperatures increased during the Holocene and most locations experienced thermal maximums during the early to mid Holocene.

Inter-hemispheric teleconnections between NH ice sheet extent, SSTs, and Indian Ocean SSTs (Tierney et al., 2008) and also insolation and the amplitude and seasonal north-south position of the ITCZ (Castañeda et al., 2007; Schefuss et al., 2011) all mediate the delivery of precipitation associated with moisture availability, storm track position and convective activity across southern and eastern Africa. Tierney et al. (2008) maintain that Indian Ocean sea surface temperatures and changes in the strength of SE trade winds were the primary driver of late Pleistocene – Holocene precipitation in eastern Africa. Millennial scale variability in precipitation for regions further south, including Mount Gorongosa, was likely influenced by an interplay between Northern Hemisphere boundary conditions, Indian Ocean SST and shifts in the ITCZ and Inter-Oceanic Confluence (IOC) and subregional storm genesis (Castañeda et al., 2007; Chevalier and Chase, 2015; Schefuss et al., 2011; Tierney et al., 2008; Wang et al., 2013). According to Scott et al. (2012) and Truc et al. (2013) southeastern Africa received more rainfall during the late Pleistocene-Holocene due to the warming of the Indian Ocean. In contrast, records from Lake Malawi indicate dry seasons were longer as a result of a northward shift in the ITCZ, and increase in SE tradewinds (Ivory et al., 2012). Reconstructions of precipitation derived from hydrogen isotope values (δD) of sedimentary terrestrial leaf wax from marine cores close to the Zambezi River delta (Schefuss et al., 2011; Wang et al., 2013) also highlight displacement (southward) of the ITCZ via high northern latitude forcing as primary controls on precipitation, especially increased precipitation during Heinrich Stadial 1 and the Younger Dryas.

We present the first paleoecological record from central Mozambique (18.4°S) which documents c. 27 kyrs (interrupted by a long hiatus bridging the Pleistocene-Holocene transition) of vegetation, climate and disturbance dynamics from a wetland on Mount Gorongosa and compare millennial-scale environmental change on the Mount Gorongosa massif with records from southern and eastern Africa. Here we set out to better understand long-term vegetation change in montane ecosystems during the late Pleistocene-Holocene. Key questions are: 1) How did plant communities respond to long-term changes in climate, fire and land-use? 2) When did grasslands and miombo woodland taxa develop on Mount Gorongosa and, 3) How does millennial-scale environmental change from Mount Gorongosa inform spatiotemporal dynamics of climatic variability of this region? We address these questions through analysis of pollen, charcoal, and geochemistry from a peat core obtained from a montane wetland and through comparisons with existing climate proxies specific to southeastern Africa (Ekblom and Stabell, 2008; Holmgren et al., 2012; Neumann et al., 2014; Norström et al., 2014; Powers et al., 2005; Schefuss et al., 2011; Tyson et al., 2000; Wang et al., 2013). This record from Mount Gorongosa provides important information on millennial-scale vegetation and climate interactions from a region where these are poorly understood and compliments recent work aimed at better resolving late-Quaternary climate variability in southeastern Africa (Chevalier and Chase, 2015). Investigating these interactions in the diverse plant communities of Mount Gorongosa will also provide historical context for land managers tasked with supporting an important ecological and cultural resource undergoing rapid land-use change.

2. Study site

Mount Gorongosa is a massive gabbroic-granitic inselberg of 30 km in length and 20 km in width (c. 700 km^2) of the Gorongosa Fracture Complex in the East African Rift System, located in the Gorongosa district of the Sofala Province 100 km from the Indian Ocean (Fig. 1) (Müller et al., 2012). Mount Gogogo is the highest peak of the massif (1863 masl). Mount Gorongosa rises 1400 m above the surrounding landscape and is one of the few southern African mountains above 1700 masl apart from the Drakensberg