AFRIKA FOCUS — Volume 29, Nr. 2, 2016 — pp. 101-108

Studying Africa's hydroclimate history over the last 2000 years[1]

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Water-resource availability is one of the most important environmental factors on which Africa's agricultural societies are reliant. However, our knowledge of the natural background variability of rainfall and drought over Africa is currently still inadequate to allow a full grasp of the relevant climate-dynamical mechanisms and guidance of much-needed forecasts of future trends. This report presents two new efforts to improve insights into how hydroclimate has varied throughout the continent over the past two millennia. Firstly, a thorough synthesis of data from instrumental measurements, historical accounts and natural climate archives resulted in an extensive review of Africa's hydroclimate history. Secondly, the focus is narrowed to East Africa, where the sediments of hypersaline Lake Bogoria were used to reconstruct how a variable climate has driven large lake-level fluctuations over the last 1,300 years.

Key words: paleoclimatology, natural climate archive, lake-level change, sedimentology, Lake Bogoria National Reserve

Reviewing African hydroclimate change over the past two millennia

From the deserts of northern and southern Africa to the humid forests of the Congo Basin, Africa is characterized by a wide range of hydroclimate regimes (Nicholson, 2000). The livelihoods of a large part of its agricultural population are intimately linked to water-resource availability, and gravely affected by extreme events such as droughts and floods. Anticipation of future rainfall trends under anthropogenically-driven climate change is thus of utmost importance. However, whereas the mechanisms of global warming over the next century and beyond are well understood, and its expected magnitude in individual regions can be modeled with reasonable confidence, precipitation projections are inherently more uncertain (Rowell, 2012). At the moment, robust climate forecasting at spatial and temporal scales relevant to human societies is far from evident (e.g., for East Africa; see below). There is still a gap between climate science capabilities and end user needs, which needs to be closed if local governments and economies are to strategically prepare for the future (WCRP-ICPO 2011). The need for better characterizing

1 This is the report of PhD research carried out at Ghent University, under the supervision of Dirk Verschuren and Florias Mees.

the range of natural climate variability in the region is widely recognized in this respect (Rowell *et al.*, 2015).

The discipline of paleoclimatology encompasses all research fields occupied with the study of how and why Earth's climate has varied through time. Knowing how climate has behaved over the course of history has become invaluable for our understanding of climate dynamics all over the world. Furthermore, data describing past climatic conditions can serve as a baseline against which to compare modern-day anthropogenic climate change, which is essential to grasp present observations and to predict future trends (Masson-Delmotte *et al.*, 2013). Records of past climate change can even serve as a tool used by climate modelers to calibrate and test their models, validating their ability to project future scenarios (Schneider and Mastrandrea, 2007). The past decades have seen a spectacular increase in the appreciation and valorization of studies in paleoclimatology, as questions on abrupt climate change, the influence of external forcing factors on climate, and processes of variability internal to the climate system are more relevant to society than ever before (Smerdon and Pollack, 2016). In this regard, the Common Era (CE; i.e., the past two millennia) has been put forward as the period for which thorough knowledge of Earth's range of natural climate variability can be used as a context for studies of future change on time scales most relevant to human societies (Kaufman, 2014).

This work contributed to the effort of the Africa 2k Working Group of the International Geosphere-Biosphere Programme (IGBP) Past Global Changes 2k initiative (PAGES 2k; www.pages-igbp.org) to produce a thorough historical overview of hydroclimate change throughout the African continent over the last 2,000 years. Instrumental meteorological records and historical accounts extend only one to two centuries back in time, at best. To appreciate the complete range of climate variability, scientists have to rely upon natural archives that store signals of past environmental change as they form. In Africa, the most common and informative natural climate archives are the sediments accumulating on the bottom of lakes (Verschuren, 2003). Because younger sediments continuously get deposited on top of older material, going downward into the sediment column by collecting sediment cores can be seen as opening a window on an increasingly distant history of the lake and its environment. Other archive types that have traditionally been exploited in temperate and polar regions of the world, such as tree rings and ice cores, are much more rare in Africa. Reconstructions of climate change through time can be obtained by examining natural archives for measurable characteristics ('proxies') that, through their dependence on local climate conditions, act as surrogates for direct observation. For example, a wide array of potential proxies can be examined in lake sediments, ranging from plant pollen assemblages over fossil plankton remains to specific bio- and geochemical characteristics, each with their own merits and reflections of specific aspects of past environmental conditions (e.g., Haworth and Lund, 1984; Pienitz *et al.*, 2009). We produced an extensive assessment and discussion of proxy, historical and instrumental evidence for hydrological variability across the African continent over the past two millennia (fig. 1). The results focus on six major time windows, some of which have a widely described global climatic relevance such as the Medieval Climate Anomaly

(AD 900-1250), the Little Ice Age (AD 1250-1750) and the period of anthropogenic global warming during the most recent decades. A number of prominent spatial and temporal patterns of rainfall and drought are revealed, despite the limitations of a patchy geographical coverage and less-than-optimal data resolution. The resulting continent-wide synthesis of regional hydroclimate trends through time allows consideration of possible driving mechanisms and makes important suggestions for future research.

Lake Bogoria: a new hydroclimate record from the Central Kenya Rift Valley

In addition to reviewing the hydroclimate history of the entire African continent, new data on past moisture-balance changes in East Africa were produced. Much of tropical East Africa is characterized by a semi-arid or even arid climate regime, receiving relatively low amounts of total annual rainfall in combination with great inter-annual variability (fig. 1). More humid conditions are almost exclusively restricted to the interior highlands. Consequently, the ecosystems and societies of equatorial East Africa have traditionally been subject to low and irregular water-resource availability. Over the past decades, a series of droughts has highlighted the endemic vulnerability of the vast drylands of Kenya, Uganda, Ethiopia and Somalia to failing rains, with dramatic outcomes for the area's inhabitants. This was demonstrated again in 2011 by a severe famine in the Horn of Africa, affecting more than 13 million people (Hillier and Dempsey, 2012; Nicholson *et al.*, 2014). The drought in central and eastern Ethiopia earlier this year also demanded significant humanitarian assistance (FEWS Net, 2016). The history of East African countries has been punctuated by drought-related famine for as long as historical sources are available, often with huge tolls on livestock and human life. Recorded crises are obviously biased toward the last century, but a number of events has been traced back from written sources, most extensively for Ethiopia where limited evidence goes back to around the start of the CE (Webb and von Braun, 1994; Wolde-Georgis, 1997). Despite improvements in food-relief systems since the end of the 20th century (Graham *et al.* 2012), the challenge faced by these countries is to develop a sustainable agricultural economy in a future of climate change, growing demographic pressure and naturally scarce land and water resources. Severe, recurrent drought is one of the principal environmental hazards in the region. However, accu-

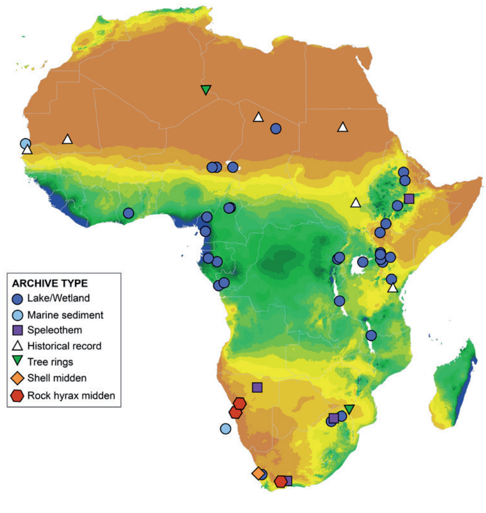

Figure 1: Map of Africa, with records informative of hydroclimate during the past 2,000 years. Background colouring follows the Global Aridity Index (Trabucco and Zomer, 2009), where higher values indicate more humid conditions

rately predicting 21st-century hydroclimate trends in East Africa under anthropogenic global change is still very problematic. The future of this vulnerable region is highly uncertain, as several studies have produced contradicting results in trying to delineate expected 21st-century rainfall patterns (e.g., Funk *et al.*, 2008; Shongwe *et al.*, 2011; Williams and Funk, 2011; Cook and Vizy, 2012; Niang *et al.*, 2014). The absence of a consensus on even the sign of probable future precipitation trends illustrates the need for a better understanding of the dynamics that drive East African rainfall (Rowell *et al.*, 2015). This requires additional studies on the natural variability in the region, to which newly developed paleoclimate records can make an important contribution.

Lake Bogoria is one of the few lakes in the Kenyan lowlands that have survived relatively recent intense droughts, making it one of the precious rare sites where an intact sediment archive going back further than just one or two centuries can be recovered (De Cort *et al.*, 2013). It is situated in the Central Kenya Rift Valley, 25 km north of the equator, and is classified among the 'soda lakes' of East Africa, characterized by high salt content (with Na+, CO32-, HCO3- and Cl- as major ions) and high pH. Its hydrochemistry is further influenced by numerous hot springs above and below the present-day water surface (Tiercelin *et al.*, 1987). In 2014, the maximum depth of Lake Bogoria was measured to be 16 m, with lake-level elevation at c. 996 m above sea level. Along its north-south oriented longitudinal axis, the lake is divided in three depositional basins of varying area and depth (Tiercelin *et al.*, 1987; Hickley *et al.*, 2003). The shallow northern basin is connected with the largest and deepest central basin (fig. 2) by a narrow passage across the relatively high north-central sill. A similarly narrow but lower central-south sill leads to the southern basin, which is much smaller in surface area than the central basin but nearly as deep. The largest inflowing river system, the Sandai-Waseges, drains two-thirds of the lake's catchment (Tiercelin *et al.*, 1987; Renaut and Tiercelin, 1994) and flows into Lake Bogoria from the north. The unique ecosystem of Lake Bogoria and the adjacent areas of its catchment are protected as the Lake Bogoria National Reserve, well known for the large numbers of flamingos feeding in the lake's productive waters. The upstream drainage basin, however, is situated beyond the reserve boundaries and hence susceptible to greater human impact.

Sediment cores from five key positions in Lake Bogoria were used to reconstruct its history of depositional and hydrological changes. Cores were collected from the deepest points of the three lake basins and from the crests of the sills separating them, ranging in length from 1.2 to 3 m. Sedimentological, geochemical and mineralogical composition of the cores was determined through a range of laboratory analyses including loss-on-ignition, granulometry, X-ray diffraction, charcoal counting and high-resolution scanning of magnetic susceptibility and X-ray fluorescence. To assign ages to the observed compositional variations, radiocarbon dating of carefully isolated charcoal remains was employed, supplemented by 210Pb dating of the most recent deposits. A detailed set of chronologically equivalent tie points between the high-resolution proxy time series of the five sequences allowed transfer of dates between the basins, enabling inter-basin comparison of sedimentation dynamics through time. The sediment-core data, which concern past deposits and thus represent past conditions, were supplemented with information on present-day sedimentation dynamics through deployment of sediment traps, which were installed in the water column of the lake and were sampled seasonally over the period of one full year.

The obtained multiproxy data, in combination with the spatially heterogeneous distribution of consecutive sediment units at different positions in the lake, allowed a reconstruction of at least partially hydroclimate-driven variability in sedimentation dynamics and lake level over the past 1,300 years. Importantly, the results demonstrate hydrological variability over this period far beyond the fluctuations documented throughout the 20th century. Between approximately AD 690 and 950, Lake Bogoria stood almost completely dry. In the sediment record of the central basin, this resulted in episodical deposition of trona, a sodium carbonate salt that precipitates following evaporative concentration of hypersaline brines under concentrations of CO_2 in equilibrium with the atmosphere (fig. 3a; Eugster and Jones, 1979). Between c. AD 950 and 1100, slightly increased water levels allowed the build-up of high pCO_2, leading to precipitation of nahcolite instead of trona (fig. 3b). Overall, Lake Bogoria was still very low during this period, with the central and south basins containing separate brine pools and maximum inferred water level still c. 14.5 m below the 2014 position. Afterwards, Lake Bogoria experienced a pronounced highstand between c. AD 1100 and 1350, with the first connection of the three basins since the start of the record, only to recede again afterwards. For most of the time between approximately AD 1350 and 1800, the northern basin was probably disconnected from the joint central and southern basins. During the last two centuries, finely laminated sediments suggest a deep, stable water column, indicating that lake level has uninterruptedly been relatively high over this time period (fig. 3c). This has important implications for local agriculture, which already relies heavily on irrigation schemes that draw water from nearby wetlands. The sediment record of Lake Bogoria suggests that severe, decadal-scale drought greatly exceeding the 20th-century range is inherent to the area and could therefore be expected to occur again in the future. Long-term water and agricultural management plans should incorporate the accumulating knowledge on this climate-driven water-resource variability.

Figure 2: Lake Bogoria's central basin, as seen from the western shore (Photo by Gijs De Cort)

Additionally, we found evidence for substantially increased sediment supply in recent decades due to anthropogenic soil erosion around the headwaters of the Sandai-Waseges River. Problematic land degradation and its adverse effects on lake ecology have extensively been described for nearby Lake Baringo (Anderson, 2002; Hickley *et al.*, 2004), but our research presents the first evidence that similar processes are taking place in the catchment of Lake Bogoria. This is a reason for concern, and more research is needed to better document these developments and their implications for Lake Bogoria's unique ecosystem.

This research was supported by the BELSPO BRAIN-be Project 'Patterns and Mechanisms of Climate Extremes in East Africa', BR/121/A2/PAMEXEA. Results are presented and discussed in detail in:

Nash, D.J., De Cort, G., Chase, B.M., Verschuren, D., Nicholson, S.E., Shanahan, T.M., Asrat, A., Lézine, A.-M., Grab, S.W. (2016). African hydroclimate variability during the last 2000 years. Quaternary Science Reviews, 154:1-22.

De Cort, G., Mees, F., Ryken, E., Wolff, C., Renaut, R.W., Creutz, M., Van der Meeren, T., Haug, G., Olago, D.O., Verschuren, D. Multi-basin depositional framework for moisture-balance reconstruction at Lake Bogoria (Central Kenya Rift Valley). Submitted.

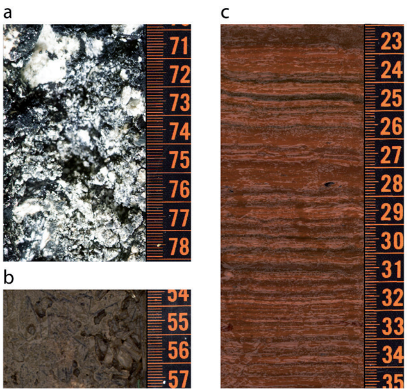

Figure 3: An illustration of the variation in the sediment composition of Lake Bogoria. a: Trona deposits attest to near-complete desiccation of the lake. b: Abundant nahcolite precipitation suggests a shallow and hypersaline brine pool rich in CO_2. c: Finely laminated clays indicate a deep, stable water column during the past two centuries.

References

Anderson, D. (2002). *Eroding the commons: the politics of ecology in Baringo, Kenya.* University of Ohio Press, Athens, USA, 336 pp.

Cook, K.H., Vizy, E.K. (2012). *Impact of climate change on mid-twenty-first century growing seasons in Africa.* Climate Dynamics, 39:2937-2955.

De Cort, G., Bessems, I., Keppens, E., Mees, F., Cumming, B., Verschuren, D. (2013). *Late-Holocene and recent hydroclimatic variability in the central Kenya Rift Valley: the sediment record of hypersaline lakes Bogoria, Nakuru and Elementeita.* Palaeogeography, Palaeoclimatology, Palaeoecology, 388:69-80.

Eugster, H.P., Jones, B.F. (1979). *Behavior of major solutes during closed-basin brine evolution.* American Journal of Science, 279:609-631.

Famine Early Warning Systems Network, FEWS Net. (2016). www.fews.net.

Funk, C., Dettinger, M.D., Michaelsen, J.C., Verdin, J.P., Brown, M.E., Barlow, M., Hoell, A. (2008). *Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development.* Proceedings of the National Academy of Sciences of the United States of America, 105:11081-11086.

Graham, J., Rashid, S., Malek, M. (2012). *Disaster response and emergency risk management in Ethiopia.* In: Dorosh, P., Rashid, S. (eds.), Food and agriculture in Ethiopia: progress and policy challenges, p. 256-279. University of Pennsylvania Press, Philadelphia, USA.

Haworth, E.Y., Lund, J.W.G. (1984). *Lake sediments and environmental history.* University of Minnesota Press, Minneapolis, USA.

Hickley, P., Boar, R., Mavuti, K. (2003). *Bathymetry of Lake Bogoria, Kenya.* Journal of East African Natural History, 92:107-117.

Hickley, P., Muchiri, M., Boar, R., Britton, R., Adams, C., Gichuri, N., Harper, D. (2004). *Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya.* Ecohydrology & Hydrology, 4:503-517.

Hillier, D., Dempsey, B. (2012). *A dangerous delay: the cost of late response to early warnings in the 2011 drought in the Horn of Africa.* Oxfam and Save the Children policy paper. Oxfam International and Save the Children, Oxford, UK.

Kaufman, D. (2014). *A community-driven framework for climate reconstructions.* EOS Transactions, American Geophysical Union, 95(40):361-368.

Masson-Delmotte, V., Schulz, M., Abe-Ouchi, A., Beer, J., Ganopolski, A., González Rouco, J., Jansen, E., Lambeck, K., Luterbacher, J., Naish, T., Osborn, T., Otto-Bliesner, B., Quinn, T., Ramesh, R., Rojas, M., Shao, X., Timmermann, A. (2013). *Information from paleoclimate archives.* In: Stocker, T., Qin, D., Plattner, G., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P. (eds.), Climate Change 2013: the physical science basis Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK and New York, USA.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P. (2014). *Africa.* In: Barros, VR., Field, CB., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, p. 1199-1265. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nicholson, S.E. (2000). *The nature of rainfall variability over Africa on time scales of decades to millennia.* Global and Planetary Change, 26:137-158.

Nicholson, S.E. (2014) *A detailed look at the recent drought situation in the Greater Horn of Africa.* Journal of Arid Environments, 103:71-79.

Pienitz, R., Lotter, A., Newman, L., Kiefer, T. (2009). *Advances in paleolimnology.* PAGES News, 17(3): 89-136.

Renaut, R.W., Tiercelin, J.-J. (1994). *Lake Bogoria, Kenya Rift Valley : a sedimentological overview.* In: Renaut, R.W., Last, W.M. (eds.), Sedimentology and geochemistry of modern and ancient saline lakes. SEPM Special Publication, 50:101-123.

Rowell, D.P. (2012). *Sources of uncertainty in future changes in local precipitation.* Climate Dynamics, 39:1929-1950.

Rowell, D.P., Booth, B.B.B., Nicholson, S.E., Good, P. (2015). *Reconciling Past and Future Rainfall Trends over East Africa.* Journal of Climate, 28:9768-9788.

Schneider, S., Mastrandrea, M. (2007). *Paleoclimate relevance to global warming.* In: Elias, S. (ed), Encyclopedia of Quaternary Science, p. 2010-2020. Elsevier.

Shongwe, M.E., van Oldenborgh, G.J., van den Hurk, B., van Aalst, M. (2011). *Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming.* Part II: East Africa. Journal of Climate, 24:3718-3733.

Smerdon, J.E., Pollack, H.N. (2016). *Reconstructing Earth's surface temperature over the past 2000 years: the science behind the headlines.* WIREs Climate Changes, doi: 10.1002/wcc.418.

Tiercelin, J.-J., Vincens, A. (1987). *Le demi-graben de Baringo-Bogoria, Rift Gregory, Kenya. 30000 ans d'histoire hydrologique et sédimentaire.* Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, 11:249-540.

Trabucco, A., Zomer, R. (2009). *Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) geospatial database.* CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at http://www.csi.cgiar.org.

Verschuren, D. (2003). *Lake-based climate reconstruction in Africa: progress and challenges.* Hydrobiologia, 500:315-330.

Webb, P., von Braun, J. (1994). Famine and food security in Ethiopia: lessons for Africa. John Wiley and Sons, Canada.

Williams, A.P., Funk, C. (2011). *A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa.* Climate Dynamics, 37:2417-2435.

Wolde-Georgis, T. (1997). *El Niño and Drought Early Warning in Ethiopia.* Internet Journal of African Studies 2.

World Climate Research Programme (WCRP), International CLIVAR Project Office ICP. (2011). *Drought predictability and prediction in a changing climate.* WCRP informal report no. 21/2011. ICPO publication series no 162.