18 Using the Past to Inform a Sustainable Future: Palaeoecological Insights from East Africa

Esther Githumbi, Rob Marchant and Daniel Olago

Abstract

An important aspect of the UN Framework Convention on Climate Change (UNFCCC), which aims to limit the increase in global temperature to 1.5 °C by 2050, has been the development of monitoring and evaluation plans that integrate climate change perspectives into new policies and programs for the protection and functioning of ecological systems. These include measures that enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change. Ecosystem change and the interaction of the different drivers of change in ecosystems have been studied at different temporal and spatial scales across different disciplines. However, the use of long temporal records documenting environmental and climatic change in understanding the impacts of the interacting drivers of change and planning sustainable use of resources is relatively new. We present examples of the use of palaeoecological data from East Africa in planning for the long-term sustainable use of natural resources by providing long-term historical perspectives on human–environment–societal–wildlife interactions and engagement with the biocultural heritage and societal evaluations of these spaces to achieve an increasingly diverse set of conservation, social and economic objectives. We link the Earth system processes whose associated boundaries can be directly related to sustainable development goals in our attempt to prevent unacceptable environmental change. The realisation that humans are having a significant impact on climate and landscapes means we now need to showcase the societal relevance of palaeoecological research and utilise its output especially in our efforts to remain within a safe operating space for humanity and ecosystems.

Keywords

Environmental history · Pollen · Remote sensing · Savannah · Swamps

18.1 Introduction

Climate change and human activities have impacted on ecosystems, with two-thirds of the earth's ecosystem considered degraded causing loss of ecosystem extent, loss biodiversity and associated essential ecosystem goods and

E. Githumbi (✉) · R. Marchant
University of York, York, UK
e-mail: esther.githumbi@york.ac.uk

R. Marchant
e-mail: robert.marchant@york.ac.uk

E. Githumbi
Linnaeus University, Växjö, Sweden

D. Olago
University of Nairobi, Nairobi, Kenya
e-mail: dolago@uonbi.ac.ke

© Springer Nature Switzerland AG 2020
M. Ramutsindela and D. Mickler (eds.), *Africa and the Sustainable Development Goals*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-030-14857-7_18

services reduced stability in community networks (Kan and Djoghlaf 2010; Thompson et al. 2017). The attribution of impacts on specific drivers is very contentious due to the complexity of natural systems and the interacting drivers. However, the study of different proxies over longer timescales provides scope for interpretation of cause and effect (Oldfield and Alverson 2003). Paleoecology is the study of past ecosystems using a variety of proxies to examine the relationship between organisms and their environment. Palaeoecological studies are the only approach that can contribute a long-term perspective on climate–human–ecosystem interactions. This is because they provide an understanding of processes that take long periods of time such as ecological succession, migration, community assembly, etc. (Rull 2014).

Environmental change has occurred naturally with the earth's regulatory capacity maintaining conditions suitable for human development. These suitable conditions are maintained within narrow operating safe spaces (Rockström et al. 2009) known as planetary boundaries. Rockström et al. (2009) identified nine earth system processes with critical threshold values and defined their planetary values while Dearing et al. (2014) defined social well-being spaces within which policy impacts can be increased due to the understanding of environmental and social systems. Deep time perspectives as well as social perspectives are key for addressing priority biogeographical and conservation questions and underpin the concepts of sustainability and what is a safe operating space (Fig. 18.1). These insights include, but are not limited to, identifying

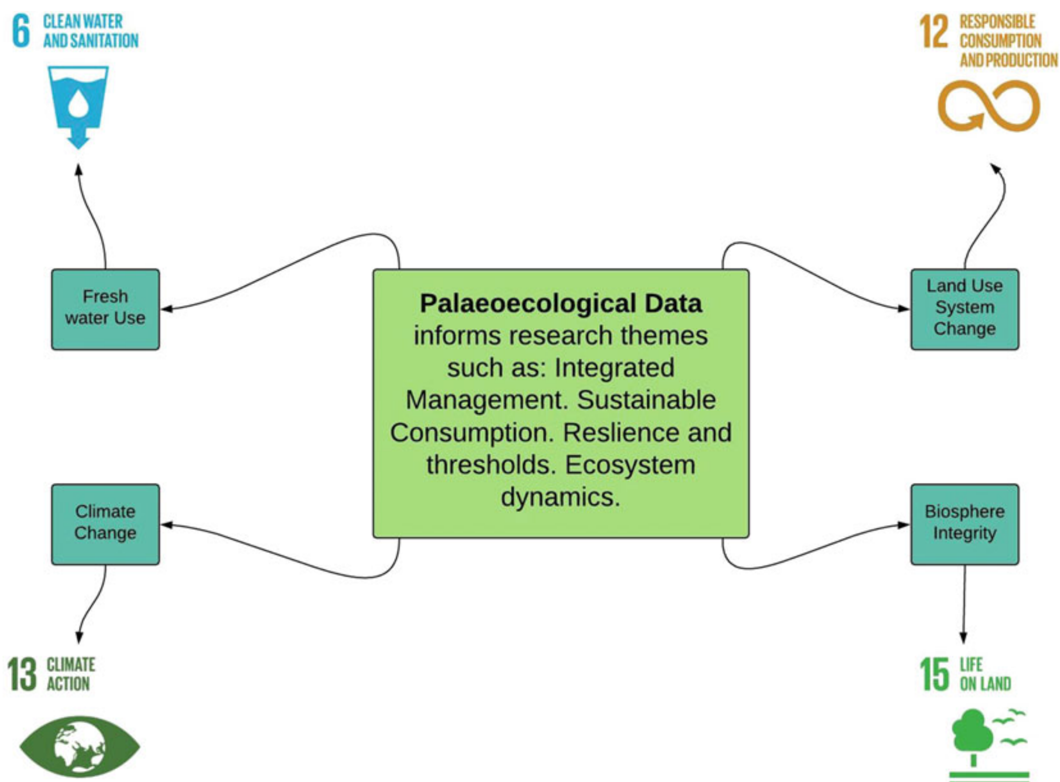

Fig. 18.1 Relationship between critical earth system processes (green squares), SDGs and examples of research themes where palaeoecological is useful (SDG images from https://www.un.org/sustainabledevelopment/sustainable-development-goals/)

locations that remain buffered under the present climate change trends, and how linking past and future ecosystem response to such changes can help mitigate biodiversity loss (Pfeifer et al. 2012). Indeed, largely as a result of analysing long-term palaeorecords, the impacts of global environmental change are now being understood and the realisation that we are now living in the Anthropocene where change is driven primarily by human activity (Ellis et al. 2013).

We have identified four earth system processes whose planetary boundaries have been identified (Rockström et al. 2009), four Sustainable Development Goals (SDGs), i.e. 6, 12, 13 and 15 and four examples of research themes that can be informed by palaeoecological data (Fig. 18.1). Data that can provide accurate reconstructions of long-term change is crucial for the validation of scenarios of future change. SDGs 6, 12, 13 and 15 are underpinned by ecosystems and the goods and services they provide. Goal 6 focuses on clean water and sanitation. Goal 12 focuses on sustainable consumption and production patterns through promoting resource and energy efficiency, and sustainable infrastructure. Goal 13 highlights the action that is needed to combat climate change and its impacts. Goal 15 focuses on securing life on land and aims to sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss (United Nations 2015).

Indeed, more widely the SDGs emphasise the enormous value that people place on the goods and services that they obtain from ecosystems, and the crucial role these goods and services can play in poverty alleviation and development (Cuni-Sanchez et al. 2016). In East African nations, ecosystems are *the* primary resource for human well-being and provide key functions essential to sustainable economic development. Most economies from the Global South are heavily dependent on agriculture, rangeland pastoralism, forestry management and wildlife tourism: for example, Tanzania had set aside ~31% of its land mass by 2003 in National Parks, Game Reserves and Forest Reserves (Brockington et al. 2008). Protected areas by landmass increased to ~38% as reported in 2014 (Lin et al. 2014).

Understanding past ecosystem processes enhances our capability of predicting future change and long-term studies of the past are essential as ecosystem variability exceeds what is captured by short periods of instrumentation and recent historical studies (Oldfield and Alverson 2003). We demonstrate that the significant understanding gained from the available long-term records as well as the continual study of long-term change can, and should, inform strategies implemented to ensure the attainment of the SDGs (Fig. 18.1). This chapter discusses how palaeoecological data can be used to inform SDGs. We identify four SDGs that can benefit directly from the knowledge gained and provide specific examples of the studies in which the information gained can already be used.

18.2 Goal 6: Clean Water and Sanitation

SDG 6 aims to ensure availability and sustainable management of water and sanitation for all. Palaeoecological proxies in accumulated lake sediments, such as diatoms (Cohen et al. 2007), chironomids, geochemistry (Burnett et al. 2011) and geomorphological evidence such as fossil strandlines and stromatolites (McKee et al. 2005), are indicators of changes in water level/volume. These, amongst other proxies, have provided information about long-term changes in water levels in most of the major African lakes as well as small wetlands. Large and sometimes abrupt fluctuations in the water balance have been experienced throughout the Holocene period (Odada and Olago 2005; Olaka et al. 2010). These are closely linked to long-term natural climate changes occurring over geological timescales (Gasse and Van Campo 1994; Trauth et al. 2003), and in the longer term to geological processes such as rifting, volcanism and tectonics (Olago et al. 2009; Olang et al. 2010; WoldeGabriel et al. 2016) that modify the regional climatic and hydrological expressions on and beneath the earth surface.

During the Holocene period (the last 10,000 years), abrupt hydrological changes have been observed, under boundary conditions that are similar to today (Oldfield and Alverson 2003). Furthermore, over the last 1,000 years, significant hydrological extremes (desiccation and high lake levels, respectively, lasting for a few decades or one to two centuries) have been recorded in lakes such as Baringo (De Cort et al. 2018), and Naivasha (Verschuren et al. 2000). Recent significant lake level increases in the rift lakes of Kenya (2011–2013) have destroyed infrastructure, property and livelihoods when previously dry shoreline areas were inundated (Onywere et al. 2013). Groundwater is similarly affected by the hydrological variability. Large swathes of East Africa are arid and semi-arid landscapes, and many communities are solely dependent on the groundwater resource for the potable water supplies, and for general water uses. There have been reported changes in groundwater resources, linked in part to modification of groundwater recharge areas, and higher variability in rainfall, its duration and intensity, among other factors. However, little is still known about the groundwater–surface water linkages in the region (Olago et al. 2009) and more evidence-based research is required to determine the interrelationships and what they mean for the sustainable management of groundwater resources in the context of a changing climate.

Water quality issues are also driven by both natural (long-term) and anthropogenic (short to long-term) factors. For example, fluoride levels in many of the East African rift lakes and groundwater systems exceed WHO guidelines for potable water (Nair et al. 1984). Pollution modelling studies have also shown that lakes such as Victoria, which are also used for potable water supplies, are extremely vulnerable to pollution, being able to reduce pollutant loads by only 10% one hundred years after exposure because of the long flushing time and residency of the pollutants (Lindenschmidt et al. 1998; Odada et al. 2004; Muwanga and Barifaijo 2006). Studies of the past can, therefore, be utilised to support present-day decision-making in the management of the various water resources. Palaeoecological studies of, for example, small wetlands in Amboseli, Kenya (Gillson 2004; Rucina et al. 2010; Githumbi 2017) have been used to inform their utilisation by the local and central government when planning and implementing water and sanitation management strategies. Such local sources of water are sometimes neglected in the local and national water planning and budgets.

18.3 Goal 12: Sustainable Consumption and Production Patterns

A major global challenge is to ensure sustainable production and consumption while maintaining ecosystem functions and services as well as biophysical services. This is exacerbated by the fact that traditional strategies of meeting social needs and protecting ecosystem services and functions can be sometimes antagonistic. Attempts to propose ecological boundaries (Rockström et al. 2009; Dearing et al. 2014) that global society should remain within, if it is to avoid 'disastrous consequences for humanity' are encouraging the integration of different perspectives in the decision-making process for sustainable natural resource management. Availability of long-term records is crucial in ensuring that ecological boundaries can be identified. Thresholds can be analysed in long temporal records covering wide spatial regions, as the effects of the different drivers of change are transboundary and can have lag effects (Gillson and Marchant 2014). This long-term specific data can be used to decide the acceptable level of change as well as determine threshold levels that ought to be considered during policy development and to guide political decisions, which often tend to be short term.

Applying a number of proxies to the East African, sediment records have provided data on the development of ecosystems as well as the impacts due to specific consumption patterns (Marchant et al. 2018). Records from small wetlands within East Africa such as within the Amboseli landscape have revealed the loss of wetlands due to the over-abstraction of water mainly for irrigation (Githumbi et al. 2018) as well as changes in the vegetation composition that signal a change in the ecosystem (Gillson and Duffin 2007). Consumption and production patterns influence changes in ecosystems such as the switch between savannah grasslands and woodlands; changes in ecosystems are further determined by the level of herbivory, fire, human management as well as climatic factors (Gillson and Duffin 2007; Gillson and Ekblom 2009; Rucina et al. 2010; Heckmann 2011; Biginagwa 2012; Githumbi et al. 2018). Commercial logging changes forest composition while clearing of forests for farming and settlement leads to more open landscapes (Mumbi et al. 2008; Rucina et al. 2009; McGlynn et al. 2013; Pellikka et al. 2013). The findings from analyses of long-term records on ecosystem history can be utilised in the monitoring and management of ecosystems at a large scale, such as forests managed by governments and protected areas managed as private property and/or public property, through their incorporation into management plans.

18.4 Goal 13: Take Urgent Action to Combat Climate Change and Its Impacts

It is widely recognised that there may be large local and regional departures from the global means of climate change (Griggs and Noguer 2002; Boko et al. 2007). Within East Africa, there are a number of changes in climate and environmental factors that are pointers as to the reason why actions should be taken to mitigate the impacts of climate change and to build the resilience of human and ecological systems that are impacted by it. A meta-analysis of palaeoecological records covering the last 20,000 years indicates that tropical Africa forests generally recovered faster from natural disturbances than those in South America and Asia, as do forests exposed to natural large infrequent disturbances. (Cole et al. 2014). The Eastern Arc montane forests are an example of environmental stability through different climatic periods over the last 38,000 years (Mumbi et al. 2008).

There are many reported changes associated with rainfall in the region, including changing dates for the onset and cessation of seasons, increased magnitude/frequency of short-duration storms, and higher magnitude, frequency and duration of flood and drought episodes. Changes in temperatures (T_{max} and T_{min}) have also been observed (King'uyu et al. 2000). Although for T_{max}, the signal is ubiquitous across the region, T_{min} changes are ambiguous, with increases observed in some areas and decreases in others (King'uyu et al. 2000; Olago et al. 2007). These climate changes have impacts on people, their well-being and livelihoods, as well as the ecological systems upon which many of them depend on for their livelihoods. Further, the ecological structure and functions of the lakes changed, leading to changes in the fishery resources, and impacts on local and international tourism, such as through the submergence of the well known and visited geysers of Lake Baringo. River flows have become more variable as a consequence of the enhanced variability of rainfall, with major impacts on the economy through, for example, reduced supply of energy from hydroelectric power stations (Siderius et al. 2018) and electricity rationing. Models predict increased warming in high altitude areas (Loomis et al. 2017) which will threaten high altitude ecosystems goods and services such as functioning as a water tower which is critical for lowland inhabitants.

18.5 Goal 15: Protect, Restore and Promote Sustainable Use of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification, and Halt and Reverse Land Degradation and Halt Biodiversity Loss

Research that assimilates the linkages between societal and ecological processes through time and across space is utilised to increase our understanding of the impacts such as habitat fragmentation, biodiversity loss and loss of ecosystems amongst others (Marchant et al. 2010; Marchant and Lane 2014). Sustainable use and development of different ecosystems (aquatic, dryland, forests, etc.) involve assessing the trade-offs between several development strategies in order to identify the impacts of each strategy (Davies et al. 2015).

Precolonial agronomies in East Africa can be used as examples of sustainable resource use due to their ability to maintain large rural populations at low water, soil and labour costs although due to the fragmentary nature of the available data, such conclusions require more data sources (Stump 2010). Food and water demand are expected to increase by 70–80% and 30–85%, respectively, over the next 50 years (Corvalan et al. 2005); this means that sustainable use of ecosystems is essential to reduce habitat and biodiversity loss accompanying the production strategies needed to meet these requirements. Vegetation composition change from a predominantly Afromontane forest to a more open forest such as the Eastern Arc mountain pre-LGM (Mumbi et al. 2008) or a pre- dominantly Afromontane forest to dryer forest composition as observed at Mau Forest Complex (Githumbi 2017) is partly attributed to long-term natural climate changes that have remained constrained within well-defined boundaries, at least for the past 800,000 years. Other factors contributing to the changes are forest clearance for agriculture or settlement as observed from Ugandan and Mt. Kenya records (Taylor 1990; Finch et al. 2009; Rucina et al. 2009; Marchant et al. 2018). Adaptive management with emphasis on feedback learning and its treatment of uncertainty and unpredictability intrinsic to all ecosystems is essential for sustainable management of forests.

Land degradation has been observed from several East African palaeoecological records, for example, high rates of soil erosion and land degradation are observed from completely different ecosystems, e.g. Lake Baringo (Kenya) and North Pare (Tanzania), at least for the past 350 years (Kiage and Liu 2009; Heckmann 2011, 2014). Highland degradation can lead to: decreased biodiversity, reduced capability of vegetation to capture atmospheric moisture and retain water in the vegetation cover, exposure of land to water and wind erosion, and changes in the radiation balance of the land surface as land is exposed and barren part of the year (Pellikka et al. 2013). Insights gained from these studies have identified the possible causes of land degradation, for example, the transformation of natural landscapes whether forested or not increases the risk of soil degradation. Over-abstraction of water from small wetlands leads to a reduction in water level or complete drying up of wetlands for example as observed in Tanzania using satellite data (Seki et al. 2018). This knowledge can be applied in the planning of current and future resource management strategies.

18.6 Conclusion

Focusing on the varied landscapes of East Africa, the environmental history derived from a suite of radiocarbon-dated sediment cores from numerous swamps and lakes across the region have been presented, and their utility in guiding us to achieve the SDGs has been discussed. Palaeoecological studies have provided long-term climate reconstructions spanning hundreds of thousands of years, with the use of multiple indicators to provide evidence of the interactions between climate and human interactions. These studies have significantly improved our understanding of change through time and interacting factors within landscapes. Changes in vegetation taxa and charcoal counts are associated with climatic changes, fire activity, anthropogenic interaction and developing land use change. The arrival of new technologies and cereal crops occurs consistently to provide a time-bound marker of increased anthropogenic activity. Sedentary agriculture has intensified dramatically through the colonial period; a transition accelerated during postcolonial administration under the most recent expansion. Intensive land use which is increasingly focused around protected area boundaries, severely challenges the adaptive capacity of plants, wildlife and the provision of ecosystem services that underpin the livelihoods of rural communities. Interpretation and presentation of palaeoecological data in a form suitable for ecosystem managers and policy developers will ensure strategic development of sustainable resource management.

We need to use past societal and ecological trends to examine the use of ecosystem services through time and under different landscape management regime, to better predict how human–environment–societal–wildlife relationships may respond to future climate change, management interventions and societal use in the future. Such long-term perspectives are crucial for current and future climate change and associated livelihood impacts, so that suitable responses to ensure sustainable management practices can be developed. We have identified ways in which palaeoecological data can be utilised in answering present and future problems. Further studies incorporating long-term environmental histories and management decisions in order to continue operating within safe planetary and social spaces while achieving the SDGs are crucial. This can lead to the development of datasets and knowledge that are useful to land managers with future planning and policy as a basis.

Collaboration between governments, non-governmental groups, civil societies and private businesses is necessary at a global level to achieve the SGDs. Frameworks to foster this joint effort such as associations providing a platform for collating thematic insights that are utilised in the implementation of the SDGs are crucial. An example would be the Sustainable Development Goals Center for Africa whose purpose is to 'provide technical support, neutral advice and expertise as input to national governments, private sector, civil society, academic institutions to accelerate the implementation of the SDG agenda across Africa' (Sustainable Development Goals Center for Africa 2015).

References

Biginagwa TJ (2012) Historical archaeology of the 19th century caravan trade in North-Eastern Tanzania: a zooarcaheological perspective. University of York

Boko M et al (2007) Africa. climate change 2007: impacts, adaptation and vulnerability. In: Contribution of working Group II to the fourth assessment report of the intergovernmental panel on climate change. pp 433–467

Brockington D, Sachedina H, Scholfield K (2008) Preserving the new Tanzania: conservation and land use. Int J Afr Hist Stud 41(3):557–579

Burnett AP, Soreghan MJ, Scholz CA, Brown ET (2011) Tropical East African climate change and its relation to global climate: a record from Lake Tanganyika, Tropical East Africa, over the past 90 + kyr. Palaeogeogr Palaeoclimatol Palaeoecol 303(1–4):155–167

Cohen AS, Stone JR, Beuning KR, Park LE, Reinthal PN, Dettman D, Scholz CA, Johnson TC, King JW, Talbot MR, Brown ET (2007) Ecological consequences of early Late Pleistocene megadroughts in tropical Africa. Proc Natl Acad Sci 104(42):16422–16427

Cole LES, Bhagwat S, Willis KJ (2014) Recovery and resilience of tropical forests after disturbance. Nat Commun Nat Pub Group 5(May):3906. https://doi.org/10.1038/ncomms4906

Corvalan C, Hales S, McMichael A (2005) Ecosystems and human well-being, millenium ecosystem assessment. Ecosystems and human well-being: health synthesi, Geneva. https://doi.org/10.1088/1751-8113/44/8/085201

Cuni-Sanchez A, Pfeifer M, Marchant R, Burgess ND (2016) Ethnic and locational differences in ecosystem service values: insights from the communities in forest islands in the desert. Ecosyst Serv 19:42–50

Davies J, Robinson LW, Ericksen PJ (2015) Development process resilience and sustainable development: insights from the drylands of Eastern Africa. Soc Nat Resour 28(3):328–343

De Cort G, Verschuren D, Ryken E, Wolff C, Renaut RW, Creutz M, Van der Meeren T, Haug G, Olago DO, Mees F (2018) Multi-basin depositional framework for moisture-balance reconstruction during the last 1300 years at Lake Bogoria, central Kenya Rift Valley. Sedimentology

Dearing JA, Wang R, Zhang K, Dyke JG, Haberl H, Hossain MS, Langdon PG, Lenton TM, Raworth K, Brown S, Carstensen J (2014) Safe and just operating spaces for regional social-ecological systems. Glob Environ Change 28:227–238

Ellis EC, Fuller DQ, Kaplan JO, Lutters WG (2013) Dating the anthropocene: towards an empirical global history of human transformation of the terrestrial biosphere. Elem Sci Anthr 1, 1–6

Finch J, Leng MJ, Marchant R (2009) Late quaternary vegetation dynamics in a biodiversity hotspot, the Uluguru Mountains of Tanzania. Quat Res 72(1):111–122

Gasse F, Van Campo E (1994) Abrupt post-glacial climate events in West Asia and North Africa monsoon domains. Earth Planet Sci Lett 126(4):435–456

Gillson L (2004) Testing non-equilibrium theories in savannas: 1400 Years of vegetation change in Tsavo National Park, Kenya. Ecol Complex 1(4):281–298

Gillson L, Duffin KI (2007) Thresholds of potential concern as benchmarks in the management of African savannahs. Philos Trans R Soc B Biol Sci 362 (1478):309–319

Gillson L, Ekblom A (2009) Resilience and thresholds in Savannas: nitrogen and fire as drivers and responders of vegetation transition. Ecosystems 12(7):1189–1203
Gillson L, Marchant R (2014) From myopia to clarity: Sharpening the focus of ecosystem management through the lens of palaeoecology. Trends Ecol Evol 29(6):317–325
Githumbi EN (2017) Holocene environmental and human interactions in East Africa. PhD Dissertation, University of York
Githumbi EN, Mustaphi CJC, Yun KJ, Muiruri V, Rucina SM, Marchant R (2018) Late Holocene wetland transgression and 500 years of vegetation and fire variability in the semi-arid Amboseli landscape, southern Kenya. Ambio 47(6):682–696
Griggs DJ, Noguer M (2002) Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Weather. https://doi.org/10.1256/004316502320517344
Heckmann M (2011) Soil erosion history and past human land use in the North Pare Mountains: a geoarchaeological study of slope deposits in northeastern Tanzania. University of York. http://www.tandfonline.com/doi/abs/10.1080/0067270X.2012.707484%5Cnpapers3://publication/doi/10.1080/0067270X.2012.707484
Heckmann M (2014) Farmers, smelters and caravans: two thousand years of land use and soil erosion in North Pare, NE Tanzania. Catena 113:187–201
Kan N, Djoghlaf A (2010) Planet our opportunity. Our Planet, (September), 1–36. www.unep.org/ourplanet, Accessed 28 Nov 2018
Kiage LM, Liu K (2009) Paleoenvironmental changes in the Lake Baringo Basin, Kenya, East Africa Since AD 1650: evidence from the paleorecord. Prof Geogr 61 (4):438–458
King'uyu SM, Ogallo LA, Anyamba EK (2000) Recent trends of minimum and maximum surface temperatures over Eastern Africa. J Clim 13(16), 2876–2886
Lin L, Sills E, Cheshire H (2014) Targeting areas for reducing emissions from deforestation and forest degradation (REDD+) projects in Tanzania. Glob Environ Change 24:277–286
Lindenschmidt KE, Suhr M, Magumba MK, Hecky RE, Bugenyi FWB (1998) Loading of solute and suspended solids from rural catchment areas flowing into Lake Victoria in Uganda. Water Res 32(9): 2776–2786
Loomis SE, Russell JM, Verschuren D, Morrill C, De Cort G, Damsté JSS, Olago D, Eggermont H, Street-Perrott FA, Kelly MA (2017) The tropical lapse rate steepened during the Last Glacial Maximum. Sci Adv 3(1):e1600815
Marchant R, Lane PJ (2014) Past perspectives for the future: foundations for sustainable development in East Africa. J Archaeol Sci 51:12–21
Marchant R, Finch J, Kinyanjui R, Muiruri V, Mumbi C, Platts PJ, Rucina S (2010) Palaeoenvironmental perspectives for sustainable development in East Africa. Clim Past Discuss 3:963–1007
Marchant R, Richer S, Capitani C, Courtney-Mustaphi C, Prendergast M, Stump D, Boles O, Lane P, Wynne-Jones S, Vázquez CF, Wright D (2018) Drivers and trajectories of land cover change in East Africa: human and environmental interactions from 6000 years ago to present. Earth-Sci Rev 178. https://doi.org/10.1016/j.earscirev.2017.12.010
McGlynn G, Mooney S, Taylor DM (2013) Palaeoecological evidence for Holocene environmental change from the Virunga volcanoes in the Albertine Rift, central Africa. Quat Sci Rev 61:32–46
McKee BA, Cohen AS, Dettman DL, Palacios-Fest MR, Alin SR, Ntungumburanye G (2005) Paleolimnological investigations of anthropogenic environmental change in Lake Tanganyika: II. geochronologies and mass sedimentation rates based on 14 C and 210 Pb data. J Paleolimnol 34(1):19–29
Mumbi CT, Marchant R, Hooghiemstra H, Wooller MJ (2008) Late Quaternary vegetation reconstruction from the eastern Arc mountains, Tanzania. Quat Res 69(2):326–341
Muwanga A, Barifaijo E (2006) Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of Lake Victoria basin (Uganda). Afr J Sci Technol 7(1):51–63
Nair KR, Manji F, Gitonga JN (1984) The occurrence and distribution of fluoride in groundwaters of Kenya. East Afr Med J 61(7):503–512
Odada E, Olago D (2005) Holocene climatic, hydrological and environmental oscillations in the tropics with special reference to Africa. Clim Change Afr pp 3–22
Odada EO, Olago DO, Kulindwa K, Ntiba M, Wandiga S (2004) Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. Ambio 33(1):13–24
Olago DO, Umer M, Ringrose S, Huntsman-Mapila P, Sow EH, Damnati B (2007) Palaeoclimate of Africa: an overview since the last glacial maximum. Global change processes and impacts in Africa: a synthesis. East African Educational Publishers, Nairobi, pp 1–32
Olago D, Opere A, Barongo J (2009) Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift. Hydrol Sci J 54 (4):765–780
Olaka LA, Odada EO, Trauth MH, Olago DO (2010) The sensitivity of East African rift lakes to climate fluctuations. J Paleolimnol 44(2):629–644 https://doi.org/10.1007/s10933-010-9442-4
Oldfield F, Alverson K (2003) The societal relevance of paleoenvironmental research. In: Alverson KD, Bradley RS, Pedersen TF (eds) Paleoclimate, global change and the future. Springer, Berlin, pp 1–11
Onywere S, Shisanya C, Obando J, Ndubi A, Masiga D, Irura Z, Mariita N, Maragia H (2013) Geospatial extent of 2011–2013 flooding from the Eastern African Rift Valley Lakes in Kenya and its implication on the ecosystems. In: Papers, Kenya Soda Lakes workshop. Kenya Wildlife Service Training Institute, Naivasha

Pellikka PK, Clark BJ, Gosa AG, Himberg N, Hurskainen P, Maeda E, Mwang'ombe J, Omoro LM, Siljander M (2013) Agricultural expansion and its consequences in the Taita Hills, Kenya. In: Developments in Earth surface processes, vol 16, pp 165–179
Pfeifer M, Burgess ND, Swetnam RD et al (2012) Protected areas: mixed success in conserving East Africa's evergreen forests. PLoS ONE 7: e39337
Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B (2009) A safe operating space for humanity. Nature 461:472–475
Rucina SM, Muiruri VM, Kinyanjui RN, McGuiness K, Marchant R (2009) Late Quaternary vegetation and fire dynamics on mount Kenya. Palaeogeogr Palaeoclimatol Palaeoecol 283(1–2):1–14
Rucina SM, Muiruri VM, Downton L, Marchant R (2010) Late-Holocene savanna dynamics in the Amboseli Basin, Kenya. Holocene 20(5):667–677
Rull V (2014) Time continuum and true long-term ecology: from theory to practice. Front Ecol Evol 2:1–7
Seki HA, Shirima DD, Courtney Mustaphi CJ, Marchant R, Munishi PK (2018) The impact of land use and land cover change on biodiversity within and adjacent to Kibasira Swamp in Kilombero Valley, Tanzania. Afr J Ecol 56(3):518–527
Siderius C, Gannon KE, Ndiyoi M, Opere A, Batisani N, Olago D, Pardoe J, Conway D (2018) Hydrological response and complex impact pathways of the 2015/2016 El Niño in Eastern and Southern Africa. Earth's Future 6(1):2–22
Stump D (2010) 'Ancient and backward or long-lived and sustainable?' The role of the past in debates concerning rural livelihoods and resource conservation in Eastern Africa. World Dev 38(9):1251–1262
Taylor DM (1990) Late Quaternary pollen records from two Ugandan mires: evidence for environmental change in the Rukiga Highlands of Southewst Uganda. Palaeogeogr Palaeoclimatol Palaeoecol 80:283–300
Thompson PL, Rayfield B, Gonzalez A (2017) Loss of habitat and connectivity erodes species diversity, ecosystem functioning, and stability in metacommunity networks. Ecography 40(1):98–108
Trauth MH, Deino AL, Bergner AG, Strecker MR (2003) East African climate change and orbital forcing during the last 175 kyr BP. Earth Planet Sci Lett 206(3–4): 297–313
United Nations (2015) Sustainable Development Goals. https://sustainabledevelopment.un.org/sdgs, Accessed 28 Nov 2018
Verschuren D, Laird KR, Cumming BF (2000) Rainfall and drought in equatorial east Africa during the past 1,100 years. Nature 403(6768):410–414
WoldeGabriel G, Olago D, Dindi E, Owor M (2016) Genesis of the East African Rift system. In: Schagerl M (ed) Soda lakes of East Africa. Springer, Berlin, pp 25–59

Esther Githumbi is Postdoctoral Researcher at Linnaeus University in Kalmar, Sweden. She is currently working on the LandClim II project, which seeks to quantify the biogeophysical and biogeochemical forcings from anthropogenic deforestation on regional Holocene climate in Europe. She is the lead coauthor of 'Pollen, people, and place: palaeoenvironmental, archaeological and ecological perspectives on vegetation change in the Amboseli landscape, Kenya', *Frontiers in Earth Sciences,* 2018, 5:113.

Rob Marchant is Professor of tropical ecology in the Department of Environment and Geography at the University of York, UK. He coordinates the York Institute for Tropical Ecosystems and worked on many multidisciplinary social, environmental and development research projects across East Africa. He is the lead author of 'Drivers and trajectories of land cover change in East Africa: human and environmental interactions from 6000 years ago to present', *Earth-Science Reviews,* 2018, 178: 322–378.

Daniel Olago is Professor in the Department of Geology, University of Nairobi. He has been involved in multidisciplinary research, training and capacity building activities on global environmental change in sub-Saharan Africa. He has recently coauthored 'Hydrological response and complex impact pathways of the 2015/2016 El Niño in Eastern and Southern Africa', *Earths Future,* 6(1): 2–22.