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Drivers and trajectories of land cover change in East Africa: human and environmental interactions from 6000 years ago to present

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Abstract

East African landscapes today are the result of the cumulative effects of climate and land-use change over millennial timescales. In this review, we compile archaeological and palaeoenvironmental data from East Africa to document land cover change, environmental, subsistence and land use transitions over the past 6000 years. Throughout East Africa there have been a series of relatively rapid and high magnitude environmental shifts characterised by changing hydrological budgets during the Holocene. For example, pronounced environmental shifts that manifested as a marked change in the rainfall or seasonality and subsequent hydrological budget throughout East Africa occurred around 4000, 800 and 300 radiocarbon years before present (yr BP). The past 6000 years have also seen numerous shifts in human interactions with East African ecologies. From the mid Holocene, anthropogenic land use has both diversified and increased exponentially associated with the arrival of new subsistence systems, crops, migrants and technologies, giving rise to a sequence of significant phases of land cover change. The first large scale human influences began to occur around 4000 yr BP, associated with the introduction of domesticated livestock and the expansion of pastoral communities. The first widespread and intensive forest clearances were associated with the arrival of iron-using early farming communities around 2500 yr BP, particularly in productive and easy to clear mid-altitudinal areas. Extensive and pervasive land cover change has been associated with population growth, immigration and movement of people. The expansion of trading routes between the interior and the coast starting around 1300 yr BP and intensifying in the 18th and 19th centuries, was one such process. These caravan routes possibly acted as conduits for spreading New World crops such as maize (*Zea mays*), tobacco and tomatoes, although the processes and timing of their introduction remains poorly documented. The introduction of SE Asian domesticates, especially banana, rice, taro, and chicken, via transoceanic biological transfers around and across the Indian Ocean, from at least around 1300 yr BP, and potentially significantly earlier, also had profound social and ecological consequences across parts of the region.

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Through an interdisciplinary synthesis of information, we explore the different drivers and directions of land cover change, the associated environmental history and multiple interactions with the distribution of various cultures, technologies, and subsistence strategies through time and across space in East Africa. This review suggests topics for targeted future research that focus on areas and/or time periods where our understanding of the interaction between people, the environment and land cover change are most contentious and/or poorly resolved. The review also critiques how this perspective on regional land use change can be used to inform and provide perspective for contemporary issues such as climate and ecosystem change models, conservation and the achievement of nature based solutions to development.

Keywords: Archaeology, iron technology, pottery, pastoralism, agriculture, livelihoods, palaeoenvironments, savannah, PAGES, LandCover6K, Sustainable Development Goals, land use

1 Introduction

There is little doubt that physical, biological and climatological systems have influenced the timing and the trajectory of development of human societies (Marchant and Lane 2014). For example, the early to mid Holocene was a time of profound cultural transitions: settled agrarian societies emerged and were established across much of the world, a broad range of species were domesticated and their distribution ranges dramatically altered, new technologies were developed, and various complex societies emerged and collapsed. Given the evidence of complex spatial and temporal climatic variability in the Holocene, palaeoecologists and others question the extent to which human activities were the primary cause for many palaeoecological changes detected within the sedimentary record (Huntley, 1990; Ruddiman et al., 2015; Wright, 2017). As more palaeoecological and archaeological records become available it is apparent that the only constant in the earth's climate is change and that this change interacts with living populations as they develop and adapt.

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An important contributing factor to all stages of hominid evolution that took place in Africa during the Plio-Pleistocene, was that of climatic change; this affected both hominid evolution and how humans have shaped and interacted with the environment (e.g., deMenocal, 1995; Deocampo et al., 2002; Maslin, 2016). Presently humans across the globe constitute the dominant controls on modifying ecosystem composition and distribution, and will continue to do so into the future. However, how ecosystem composition and distribution has changed over time and space and how both humanly-induced and environmentally-induced land use changes have interacted remains largely unresolved. Since people started to have more of a visible impact on their environments there has been little understanding of the enmeshed nature of both the natural and cultural drivers of the temporal and spatial character of land cover change. When paleoecology is combined with archaeological data there is the potential to begin to empirically explore these past interactions, by providing linked and extended time-series that document various components of the living environment (Gillson and Marchant, 2014). Palaeoecological records provide perspectives on the long-term (decadal-to-millennial) scale of ecosystem changes; although these are often partial and discontinuous they do provide a ‘natural experiment’ framework for testing ecosystem response to changed scenarios of climate, fire, and human impact (Watts et al., 2016). The interpretative power of palaeoecological records increases dramatically when they are partnered with insights provided by archaeological evidence, particularly where there is tight chronological control.

Across East Africa, when investigating how climate change has impacted ecosystems and how those ecosystems have responded, sedimentary records have proven to be invaluable (Graham et al., 2003) over a range of time scales. The historical fluctuation of lake levels across the region (e.g. Cohen et al., 1997; Gasse, 2000; 2002; Kiage and Liu, 2006; Street-Perrott, 2000; Verschuren et al., 2002) and ecosystem change (Elenga et al., 2000; Finch et al., 2016; Hamilton, 1982; Mumbi et al., 2006; 2014; Rucina et al., 2009) has been well documented by various studies and demonstrates the sensitivity of East African ecosystems,

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in particular to moisture regime variability (Bollig, 2016; Vincens et al., 1999) and the ensuing interaction with secondary drivers such as fire (Colombaroli et al., 2014; Finch et al., 2016). Drought and flood episodes throughout the longer time span of the last 6000 years have been more dramatic and more persistent than those captured by the relatively temporally short instrumental records available; the latter fail to capture the spectrum of climatic variability across the region (Gasse, 2000). Despite this clear value of available palaeo-archives, growing awareness of the drivers of environmental changes, and an increasing ability to identify interactions between and natural and human-induced climate change, understanding abrupt climate change in the past remains problematic (Overpeck and Webb, 2000). Understanding climate change remains of paramount importance, and to date, focus has been principally on understanding the impacts of increasing global temperatures, ice sheet melting, and rising levels of atmospheric carbon dioxide (IPCC, 2014). However, there is great complexity in the processes and associated impacts of climate change, which are the results of interactions between changes in solar activity, atmospheric composition, land surface conditions, ocean currents, atmospheric circulation and human activities (Marchant and Lane, 2014).

Within the Global Change community there is an increasing recognition of the importance of the tropics for shedding light on complex climatic and environmental histories, as well as a growing understanding of how these histories interact with those of people through time. This review paper draws on this realisation to provide new insight into tropical ecosystem histories by collating available archaeological and palaeoecological evidence for cultural and environmental change across the East African region (Figure 1). East Africa has been a focus for work on revealing cultural and environmental prehistory (Butzer, 1968; Marchant and Lane, 2014), as such it is an ideal test-bed to investigate environmental-cultural dynamics and to discuss the interrelationships of these and suggest theories for the current correlations between the gathered palaeoenvironmental and archaeological data for the region from 6000 years before present (yr BP) (see SM1 and SM2 for palaeoecological and archaeological sites lists). Archaeologists and palaeoecologists are (again) currently addressing the correlations in

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both types of data through the PAGES LandCover6K initiative (Gaillard et al., 2015a; 2015b; Morrison et al., 2017), in particular addressing the seemingly interrelated connections between environmental change in the mid-Holocene and changes in land-use seen across the world.

This review is a contribution to the PAGES LandCover6k initiative, for both its “land-cover” and “land-use” activities. These activities have the goal to achieve pollen-based reconstructions of Holocene land cover/plant cover change and archaeological/historical reconstructions of land-use types and quantifiable attributes such as intensity of irrigation, wood harvest, use of fire, etc. (e.g. Gaillard et al., 2015a; Morrison et al., 2017). The major aim of these reconstructions is to provide empirical information on anthropogenic land-cover change to climate modellers for the study of climate-vegetation cover interactions over time (e.g. Strandberg et al., 2014). For this review, our approach will be based on synthesizing palaeoenvironmental and archaeological evidence to provide a timeline of land cover change from 6000 yr BP to present. The review will therefore explore the spatial and temporal linkages between East African societies and environmental change. The review is organised into six main sections; following an introduction the East African region is introduced. This is followed by the third section where a presentation of the types of evidence for environmental change since 6000 yr BP is made in four subsections. The archaeological evidence for cultural change for the same time periods is also reviewed here. The fourth section investigates possible interconnections between the evidence from archaeological and environmental data, while also discussing the challenges of linking these data and inferring cultural environmental interrelations. The fifth section investigates the utility of information of past land cover change in a number of areas such as ecosystem modelling, biogeochemical cycling, ecosystem services and conservation. The final section discusses developing methodologies and areas for targeting future research activity in the context of our current understanding of land cover change across the East African landscape. Ages are consistently expressed in calibrated years before present (BP; present=1950) throughout the text.

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2. The East African Interlacustrine region

For the purposes of this review, the East African Interlacustrine region comprises the countries of Kenya, Tanzania, Uganda, Rwanda, and Burundi that surround Lake Victoria (Figure 1). To provide context, the present-day key environments and ecosystem types found in East Africa will be detailed.

2.1 Climate systems in East Africa

The climatological patterns in East Africa are highly complex due to the superimposition of a major convergence zones upon regional feedbacks, which are in turn associated with the lakes and varied topography that dominate the region (Figures 2 and 3). The equatorial location of the study area also means that the climate is governed by air circulation and precipitation associated with the Inter-Tropical Convergence Zone (ITCZ). Other supra-regional climate systems include the Congo Air Boundary (Costa et al., 2014) (with airflows from the west and southwest), and the northeast (NE trade winds) and southeast (SE trade winds) monsoons.

The ITCZ is directly linked to the meeting of the trade winds from both hemispheres, however, the subtropical high pressure cells that are located 20–30° north and south of the equator, shift with the seasons (Nicholson, 1994; 1996a; 2000). The region experiences a twice-yearly passage of the low pressure ITCZ, and whilst it is linked with the seasons it also lags behind the zenith position of the sun by approximately 1-2 months (Ogallo et al., 1988). As the passage of the ITCZ changes with the seasons, it creates a strongly bimodal pattern of seasonal rainfall, although this exhibits considerable variation across the region (Figure 3C) (Bergonzini et al., 2004). The northern and southern parts of East Africa experience unimodal rainfall regimes during June to August and December to February respectively. The Lake Victoria Basin and Eastern Rift Valley experience a third rainfall regime during the northern Hemisphere summer (June-August) when the zonal and the meridional arms of the ITCZ are displaced to the north and east resulting in enhanced convergence of moist air mass from the Congo Basin (Ogallo et al., 1988). Combined effects of the Lake Victoria trough and the highlands west of the Rift

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Valley also contribute to the third rainfall peak (Omeny et al., 2008). For much of East Africa, monsoonal winds from the southeast in March to May bring long periods of rain. In comparison, the rainy periods in October to December, brought in by the northeasterly monsoon are generally shorter. The combination of these two rainy periods accounts for the majority of the region's annual rainfall, however there can large interannual variability to the point where one or more of the rainy season can fail (Nelson et al., 2012).

The major characteristic of a changing climate across the tropics is increased rainfall variability manifesting as changes to precipitation intensity, duration and timing. It has been challenging to reproduce rainfall variability within climate models, particularly for East Africa where rainfall is influenced by a range of large and local-scale drivers and feedbacks. Much of the variability that occurs during the short rainy season is linked to large-scale climate systems such as the El Niño Southern Oscillation (ENSO) (Ogallo et al., 1988; Mutai and Ward, 2000, Indeje et al., 2000) and the Indian Ocean Dipole (IOD) (Saji et al., 1999; Behera et al., 2003; Shreck and Semazzi, 2004; Behera et al., 2005; Owiti et al., 2008; Marchant et al., 2007; Tierney et al., 2013; Cai et al., 2014). At the intra-seasonal timescale, different phases of the Madden-Julian Oscillation (MJO) are linked to modal wet and dry periods over equatorial eastern Africa (Pohl and Camberlin, 2006; Omeny et al., 2008) that consist of three to four 10-day duration anomalous rainfall events totalling 100-150 mm followed by prolonged dry spells (Kabanda and Jury, 2000). Opposite phase relationships exist between the west and the east of equatorial eastern Africa (Omeny et al., 2008). Tropical cyclones over the Indian Ocean contribute to intra-seasonal events indirectly by creating a west-east pressure gradient resulting in enhanced rainfall over much of the western and central equatorial sub-region of East Africa and contrasting dry conditions over the eastern equatorial sub-region (Shanko and Camberlin, 1998). Topographical variation associated with the Great Rift Valley and large inland water bodies (e.g. Lake Victoria) greatly influence the spatial distribution of seasonal rainfall in the region especially the March-May long rainy season (Nyakwada et al., 2009) where the western highlands tend to be wetter due to advection of moisture from the south-

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westerly winds and Congo air mass, while the eastern highlands tend to be wetter during the short rainy season (October-December) due to moisture advection from the Indian Ocean associated with north-easterly winds (Oettli and Camberlin, 2005).

Atmosphere, insolation, vegetation and moisture all interact on diurnal and longer times scales crucially influencing the environmental conditions of the isolated massifs and mountain chains of East Africa (Figures 1, 2 and 3). As water towers, mountains provide critical connections to the more arid lowlands (Rucina et al., 2009; Cuni-Sanchez et al., 2016). Climatic variations with altitude are complex, resulting from various factors superimposed on the general climatic regime described above. This factor can be summarised as an adiabatic lapse rate. Although lapse rates have often been 'determined' from altitudinal changes in temperature (Marchant and Hooghiemstra 2004), results vary considerably and are known to change through time (Loomis et al., 2017). One standard that is constant is the dry adiabatic lapse rate; this can be defined as the cooling of an absolute dry parcel of air as it passes to higher altitudes due to changes in pressure (Barry and Chorley, 2009). The laws of thermodynamics fix this rate of cooling at -9.8 ^{o}C 1000 m^{-1}. However, cooling air invariably produces condensation, and the liberalisation of latent heat, which reduces the rate of temperature decrease (Barry and Chorley, 2009). The saturated adiabatic lapse rate varies considerably with ambient temperature; at high temperatures the rate can be as low as -4 ^{o}C 1000 m^{-1}, and increases with decreasing ambient temperature to approaching -9 ^{o}C 1000 m^{-1} at -40 ^{o}C (Barry and Chorley, 2009). Thus, the actual adiabatic lapse rate, or environmental lapse rate, varies according to levels of ambient moisture and temperature and the environmental lapse rate commonly used for eastern and central Africa (-6.5 ^{o}C 1000 m^{-1}; Kenworthy, 1966) is likely to vary according to aspect, topography, radiation balance, and to have been different under past climatic regimes (Nicholson et al., 2013; Loomis et al., 2017). Thus, caution is prudent when applying lapse rates to time points in the past, or indeed different areas from where the rate was computed.

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2.2 East African geology, topography and drainage

Since the Precambrian, the rocks currently making up the African continent have been less conspicuously affected by the major global epochs. This geologic stability, relative to other continents, has resulted in a gentle topography for much of the African continent. However, East Africa has undergone tectonic dislocation, beginning in the Mesozoic (Chorowicz, 2005; Summerfield, 2005; Braile et al., 2006; Macgregor, 2015) which resulted in the formation of the Western and Eastern Rift Valleys, with uplift ranging from 700m to over 4000m (Hamilton, 1982; Calais et al., 2006). The most active tectonic phase took place from mid-Tertiary times, particularly centered around 22, 6 and 2.5 million years ago (Grove, 1989; Maslin et al., 2014), and was accompanied by an extensive volcanism which produced many of the singularities of the East African topography. This is the case of the Virunga volcanoes in northern Rwanda and western Uganda, that originated during the Quaternary period and mark the hydrological divide between the headwaters of the Congo and Nile river systems. Similarly, Mount Kilimanjaro and Mount Kenya are relatively new features on the landscape originating from the early Quaternary period. In contrast to this volcanic activity, the Ruwenzori and Eastern Arc mountains were formed by up-thrust of Precambrian crystalline rocks (Schulter, 2008). Tectonic activity also produced the high Plateau that characterises much of East Africa (Figure 2). Most of the tectonic uplift had occurred before the start of the Quaternary glaciations (Karlen et al., 1999), with each phase of uplift the associated erosion and deposition of the uplifted geology resulted in the topographically complex landscape that we see as the Rift Valleys today (Figure 1, 2A and 2C). One of the characteristic features of East Africa is the numerous deep lakes located along the Great Rift Valley and subordinate valleys (Trauth et al., 2007; 2014). Towards the south of the region, Lake Tanganyika dominates, with a chain of lakes (Albert, Edward, George and Kivu) along the Rift Valley (Figure 1). The rifting process has had considerable effect on central African watersheds (Walling, 1999), resulting in a reversal of previously west-flowing rivers and the creation of Lake Victoria near the centre of equatorial eastern Africa (Street and Grove, 1975) (Figures 1 and 2B).

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2.3 Soils and edaphic factors influencing ecosystem composition in East Africa

The diversity and distribution of soil types in East Africa result from the range of geological and climatic conditions of the area acting upon a tectonically modified topography (Figure 2D). According to Bamuzate (2015), 25 soil types are represented in this area, demonstrating a large pedodiversity when compared to the 29 types that have been identified by Dewitte et al. (2013) for continental Africa as a whole. For the purpose of this soil description, the study area is divided into three broad units following topographic and lithologic criteria: The Rift Valley area, the Tanzanian Craton, and Eastern Kenya and Tanzania; and soil types are designated according to the World Reference Base classification system (IUSS 2015) (Figure 2C).

2.3i Rift Valley Area

The Rift Valley formation dominates the soils distribution to the west (Figures 2C and 2D). It consists of a vast tectonic depression where extensive territories have subsided between the fault lines caused by the separation of Africa and the Arabian Peninsula (Schlüter, 2008; WoldeGabriel et al., 2016). The valley floor is occupied by several large and shallow lakes. There, the most common pedogenetic process is the formation of Fluvisols (e.g., Sakané et al., 2011), young soils developed in alluvial deposits with a weak horizon differentiation, but usually fertile and productive (IUSS, 2015). In locations with high evapotranspiration rates, Saline soils (Solonchacks and Solonetzs) appear. In the semi-arid basin of Lake Turkana, for example, where 15–20% of the rangelands are affected by soil salinity, increasing temperatures and low precipitations also produce large extensions of Calcisols, sodic Solonetz and weakly developed Regosols (Mace, 2012; Mbaluka and Brown, 2016).

Either side of the Rift Valley, the elevation increases steeply by around 600 m to a high plateau (1000-1500 m asl) and a number of volcanic peaks, both features linked to the rifting process (Trauth et al., 2007; Schlüter 2008; Maslin et al., 2014). In this area, weathering of volcanic materials (basalts, ash and lava deposits) produce fertile and sandy-loam Andosols

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with a thick, dark and organic rich topsoil as a result of the accumulation of organic matter and the formation of noncrystalline materials (Funakawa et al., 2012; Matus et al., 2014; Mizota et al., 1988; Shoji et al., 1993). On the slopes of volcanoes, fertile Nitisols are also frequent. These are well known for coffee and tea production in, for example, the Kenyan Highlands (Kikuyu Red Clays; e.g. Kapkiyai et al., 1999; Lal, 2010), which are one of the most intensive agricultural production regions in East Africa. Nitisols develop mainly from basic iron-rich rocks such as basalt, and have a dark red colour and a well-developed structure (Wangoju et al., 2003; Kakuru et al., 2012). However, the large reactive aluminium and iron contents in both Andosols and Nitisols frequently result in a large phosphate-fixation capacity and therefore a low phosphorous availability to vegetation (Nandwa and Bekunda, 1998; Batjes, 2011; Kisinyo et al., 2013; Verde and Matusso, 2014; Nziguheba et al., 2016). Considerable extensions of Ferralsols in Uganda, Rwanda and Burundi are the result of large weathering intensity due to higher rainfall (Bekunda et al., 2002; Verdoot and van Ranst, 2006; Gray 2011; Wasige et al., 2014; Musinguzi et al., 2015; Shi et al., 2015; Syldie, 2017). Ferralsols are capable of supporting climactic rainforest ecosystems, as a result of a fast turnover of organic matter and nutrients. However, they are fragile, not resilient soils, and can be easily degraded under deforestation processes (Nyombi et al., 2010; Bamutaze, 2015; Oyana et al., 2015).

2.3ii The Tanzanian Craton

The central unit includes the uplifted Archaean Tanzanian Craton (WoldeGabriel et al., 2016), characterized by a more acidic and predominantly plutonic and sedimentary lithology, and a flatter topography (Figures 2A, 2C and 2D). The Lake Victoria basin, the Serengeti and Mara plains and the west of Tanzania are included in this area, which it is partially limited to the east by the eastern branch of the Rift Valley and the Ngorongoro Conservation Area (Dawson, 2008; Schlüter, 2008; Selway, 2015; Kasanzu, 2016). In the northern part of this area, Planosols are frequent, mainly in the Lake Victoria basin (Lufafa et al., 2003; Rwetabula et al., 2012). These are poorly drained soils with a high clay content in the subsoil that may impede

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or limit drainage resulting in poorly structured topsoils (Biamah, 2005; IUSS, 2015). Also in the Lake Victoria Basin and interspersed with Planosols, are vast areas of clay-rich Vertisols (Sakané et al., 2011) and Luvisols (Lufafa et al., 2003) that develop preferentially on the level ground of river valley floors. These are naturally productive clay-rich soils that form deep, wide cracks upon drying due to the presence of shrinking and swelling clays. In the extensive grasslands of the Serengeti and Mara Plains, the predominant soils are organic and lime-rich Phaeozems (Blake et al., 2008). In western Tanzania, in turn, the more acidic lithology is reflected in extensive areas of less developed Cambisols, with Vertisols forming only in the river valleys, related to sedimentary deposits formed by weathered volcanic materials (Sakané et al., 2011).

2.3iii Eastern Kenya and Tanzania

To the east, the topography drops in elevation. A large, predominantly sandy plain extends towards the Western Indian Ocean coastline, where the terrain is dissected by deep valleys and predominantly sandy surfaces running down towards the coast. The coarse grained material gives rise to Arenosols and red coloured Ferralsols (Figure 2D) (Gichangi et al., 2015; Hartemink and Hutting, 2005; Mganga et al., 2015), while the evaporation of saline groundwater originates the widespread occurrence of Solonetz (Omuto, 2013). In the central part of Kenya, Lixisols develop in areas with a pronounced dry season (Omuto, 2013). In eastern Tanzania, in turn, the Mozambique Belt conditions the lithology and is responsible for a steeper topography (Schlüter, 2008; Selway and Karato, 2014; WoldeGabriel et al., 2016). Luvisols develop on the metamorphic and sedimentary rocks where the relief is more pronounced (in, for example, Kilimanjaro, Pare and Usambara Mountains: Mizota et al, 1988; Rwehumbiza et al., 1999; Msanya et al., 2002; Gachimbi, 2002; ISRIC, 2006; Pachpute et al., 2009; Mathew et al., 2016). These soils have a distinct increase in clay content with depth as a result of clay illuviation, a well-developed soil structure and a high water and nutrient-holding capacity (IUSS, 2015). To the south, the undulating topography and the lithological variation of the parent materials has resulted in a mosaic of soil types. Extensive areas of Fluvisols and

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dark, clayey Vertisols developed in alluvial sediments of the river systems of central Tanzania (the highly productive floodplains of the Rufiji River and its tributaries and the wetlands of the Ruaha River are examples of this; Karlsson and Messing, 1980; Majule, 2012; Jones et al., 2013; Armanios and Fisher, 2014; Mbungu and Kashaigili, 2017). Fertile Nitisols and more acidic Acrisols occur on gentle slopes, their distribution depending on underlying lithology (Lyon et al., 2015). Moving southwards, increasing aridity and the predominance of grassland savannah (Dondeyne et al., 2003; 2004) gives rise to extensive Lixisols and Cambisols (Msanya et al., 2002).

2.4 East African ecosystem composition and distribution

The vegetation distribution in East Africa (Figure 3) closely reflects the climatic regime with topographic conditions, rainfall amount and seasonality being particularly important in determining ecosystem composition, structure and distribution. Additionally, edaphic and disturbance regimes impart important local controls, particularly in grassland, savanna and forest boundaries. Six major phytochoria can be delineated in East Africa (Lind and Morrison, 1974; White, 1983) (Figure 3), consisting of mangrove, coastal rainforest, open savanna grasslands, wooded savanna, (Figure 5), montane forest and Ericaceous scrub (Figure 6). A relatively thin strip of coastal mangrove forest is present within the tidal coastal strip (Figure 5A) (Punwong et al., 2013a; 2013b; 2013c) that quickly grades in coastal rainforests (Figure 5B); the latter, now fragmented, are a globally recognised hotspot of biological diversity (Burgess et al., 1998a). Many species are endemic to the coastal forests, for example 44% of plants are endemic and 40% of plant genera are confined to a single forest patch. Unfortunately, coastal forests have been the target of forest operations over the past centuries and along with the relatively restricted mangrove forests have been intensively impacted (Bollig, 2016): coastal forests currently extend to around 5% of their original extent with extant forests confined to forest reserves or under community-protected ‘Kayas’ in Kenya (Tabor et al., 2010).

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Remnant patches of coastal forest quickly grade into savanna (Figure 5F), with savannas being the most extensive biome found in the tropics. Their composition and structure have been largely shaped by a long and interwoven history of interaction with climatic, animal and anthropogenic factors, which include fire and herbivores as main drivers. As such, and given their extensive distribution across East Africa savannas deserve a special place in this review. The development of savannas occurs where the establishment of extensive tree cover, in the form of seasonal forest, would normally form, but has been prevented due to edaphic conditions or disturbance. Whilst 'savannas' vary regionally, they are characterised by the continuous cover of grasses and an open canopy of drought-, fire- or browser-resistant trees. An ecosystem dominated by *Acacia–Commiphora*, consisting of a heterogeneous tree and shrub layer and a herbaceous matrix dominated by C_4 grasses (Figure 5I) is an example of a savannah ecosystem. Savannas are often characterised by areas of dense thicket, that are typically interspersed with more open, park-like vegetation and maintained by edaphic, fire and/or herbivore influence (Figures 5E-I). For example, edaphic savannas (e.g. the grass savanna of the Serengeti), form on free-draining substrates where the growth of hydrophilous trees is restricted. Fires, both natural and anthropogenic, occur frequently and has led to the dominance of plants adapted to survive regular and periodic burning (Carcaillet et al., 2002). Whilst people have interacted with savannas for millennia, contributing substantially to their contemporary composition and distribution, the third main control on savannas is herbivory - the act of eating plants by a herbivore - in this instance, by large mammals. Whilst the African savannah is home to the world's greatest diversity of ungulates, where numerous species coexist (Arsenault and Owen-Smith, 2002; Hopcraft et al., 2010; Sinclair et al., 2010), it is largely elephants who maintain the open woodland structure. They do this by debarking and knocking over trees, which has the effect of 'opening' the woodland and allows grasses to invade. This, in turn, attracts more grazing animals of greater variety into the area in question. Species of shrubs and trees with defensive thorns and hooks establish themselves in clearings, leading to thorny thickets that exclude grazers. Common trees and shrubs to savanna ecosystems include *Grewia* spp., *Lannea* spp., *Newtonia hildebrandtii, Premna resinosa,*

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Salvadora persica and *Terminalia* spp. amongst these larger trees are often scattered, such as *Adansonia digitata, Balanites aegyptica, Delonix elata, Kigelia africana* and *Melia volkensii* (Gillson, 2015). Moving up the altitudinal gradient, around 1600 m savanna woodland grades into Lower Montane forests dominated by semi-drought-deciduous trees and shrubs (Fries and Fries, 1948; Herlocker and Dirschl, 1972). These forests are primarily composed of taxa such as: *Celtis* spp., Urticaceae, Myrtaceae, *Croton* spp, *Holoptelea* spp*., Prunus africana, Podocarpus milianjanus* and *Ilex mitis* (Bussmann, 1994).

Montane vegetation belongs to three broad phytochoria: Afroalpine, Afromontane and Guineo-Congolian (White, 1983). These phytochoria are regional divisions of vegetation, based upon floristic composition and distribution. There is a noticeable altitudinal overlap between the different phytochoria and significant within-phytochoria differences; this has led to the grouping together of some phytochoria, and sub-divisions of others. Hedberg (1951) classified vegetation into a series of belts (regionally recognisable vegetation associations), and zones (locally based altitudinal bands); in ascending order these are the Montane Forest Belt (Figure 6D-F), the Ericaceous Belt (Figures 6B and C) and the Afroalpine Belt (Figure 6A). These broad vegetation associations are characterised by complex plant distributions that are not simply restricted by elevation zonations and reflect long and complex dispersal and disturbance patterns (Hemp, 2006). Montane forest (3300 to 1600 m) comprises broad-leaved, hardwood trees, and less frequently conifers (Hamilton, 1982). Several different zones are recognised (Eggeling and Dale, 1951; Hedberg, 1951; 1954; Langdale-Brown et al., 1964; Livingstone, 1967; Chapman and White, 1970; Lind and Morrison, 1974; White, 1983), that, unfortunately, have used different terminology for similar zones, and have delimited different ‘transitional altitudes’ between the zones. Indeed, Boughey (1955) identified a total of thirty-nine different synonyms for montane forest. This plethora of terms has led to confusion, and possible misinterpretation, of data on vegetation distribution. Therefore, with standardisation in mind, we shall use the classification proposed by Hamilton (1982) where montane forest is divided into lower and upper altitudinal zones, the adjectives moist and dry being used where appropriate. At lower altitudes, the forest has structural and floristic similarities to lowland forest, although being more species rich than the dry lower montane forest (Chapman and White, 1970). The vegetation is dominated by *Celtis* spp., *Juniperus procera* and *Olea capensis* ssp. *hochstetterii*. For the moist lower montane forests, on the lower slopes of valleys, frequent species include *Entandrophragma excelsum*, *Neoboutonia macrocalyx*, *Parinari excelsa* and *Syzygium cordatum*. In the mid-altitudes *Cassipourea ruwensorensis*, *Chrysophyllum albidum*, *Drypetes albidi*, *Ilex mitis*, *Strombosia scheffleri* and *Zanthoxylum* spp. can be found. And finally, within the higher altitude Upper Montane forest, in areas that are edaphically drier, common taxa include *Faurea saligna*, *Hagenia abyssinica*, *Nuxia congesta*, *Olea capensis* ssp. and *Podocarpus milanjianus.* It is also worth noting that these are not fixed altitudinal lists, as taxa that are usually associated with dry environments in high altitude areas can also be present at lower altitudes, but in wetter locations (Marchant and Taylor 2000). For example, *Podocarpus milanjianus*, is present on the north-west side of Lake Victoria at 1200 m, but it is a species usually found in a dry upper montane environment (Lind and Morrison, 1974). Within a number of mountainous areas (e.g. Mount Elgon, the Aberdares and the Rukiga Highlands) bamboo-dominated (*Synarundinaria* spp.) forest can also be found. The Arundinoid grass *Arundinaria alpina* dominates the bamboo ‘zone’ where it can form mono-specific stands. Within East Africa bamboo is not thought to be a distinct vegetation type in its own right, but rather that it represent a successional stage within montane forest, (Hemp, 2005, 2006; Marchant and Taylor 2000). This interpretation is further supported by the co-occurrence of taxa indicative of the regeneration of lower montane forest within bamboo stands (Marchant and Taylor 2000). The upper altitudinal limit of the upper montane forest varies from place to place, and reaches up to 4000 m along stream courses on Mount Kenya (Coe, 1967) and can be as low as 2100 m on the Eastern Arc Mountains of Tanzania (Finch et al., 2014).

In the lower parts of the Ericaceous Belt (3300 to 2700 m), which can experience nightly conditions of frost, overheating and physiological drought during the day, montane forest taxa

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can be present (Figure 6C). More regular rainfall, or occult precipitation, can encourage tree growth at higher altitudes, as can be seen in topographically protected, humid valley slopes (Coetzee, 1967; Coe, 1967). Therefore, the floristic composition of the lower part of the belt is very sensitive to the local climatic regime. Ericaceous Belt vegetation is characterised by a microphyllous, thorny habit; other xeromorphic features are common (Figure 6B). Three main communities are recognised (Hedberg, 1953). Sub-Alpine arborescent Ericaceous and *Senecio* forest (Figure 7A foreground) is dominated by *Agauria salicifolia*, *Artemisia afra*, *Cliffortia nitidula*, *Erica arborea*, *E*. *ruwenzoriensis*, *Hypericum* spp., *Philippia johnstonii*, *P*. *keniensis* and *Stoebe kilimandscharica*. Sub-Alpine ericaceous and mixed shrub communities are dominated by species of *Alchemilla* and *Helichrysum*. There is relatively close floristic similarity between the composition of Ericaceous Belt vegetation on different mountains of East Africa; the following genera being common; *Alchemilla*, *Artemisia*, *Cliffortia*, *Deschampsia*, *Helichrysum*, *Hypericum*, *Philippia* and *Stoebe* (Hedberg, 1951; Hemp, 2006). Although having relatively poor species diversity, the Afro-Alpine flora (>3800m) is sufficiently distinct from the surrounding lower floras to warrant its own zonation (Hedberg, 1964). No less than 80% of the taxa are endemic to the high mountains of East Africa, indicating that as a vegetation type it has long been isolated from other African mountains and more temperate areas (Hedberg, 1964). *Alchemilla* spp., *Helichrysum* scrub and *Senecio* spp. are the dominant taxa in this zone (Hedberg, 1951; Hamilton, 1969), other genera present include *Carduus*, *Festuca* and *Lobelia*. As one moves into the lower altitudes, Afro-Alpine vegetation intergrades with microphyllous thicket (Hedberg, 1964). Within this *Philippia* and more rarely *Erica* dominate. These can form dense forest or open scrub depending on local edaphic and climatic factors (Harmsen et al., 1991). Above the Afro-Alpine vegetation one grades into the nival zone and rocky barren areas and sparse vegetation cover of the Afromontane deserts of the highest peaks (Figures 6A, 7A and 8A) of Mount Kilimanjaro, Mount Kenya, the Virunga range and the Ruwenzori Mountains.

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2.5 Disturbance factors influencing ecosystem composition

The preceding description is based on the species distributions that occur when climate is the determining factor; superimposed on this dominant control, vegetation composition and distribution express local disturbance influences such as fires and grazing regimes. Given the long-term record of human inhabitation in East Africa, it is not unexpected that there has been extensive clearance and modification, with disturbance regimes spanning from total conversion to intensive agriculture and pasture through to mixed agroforestry and seasonally exploited migratory rangelands. Much of the forest clearance has focused on the mid altitudes with very little primary montane forest existing between 1500 and 2500 m (Goudie, 1996). Montane forest vegetation is now largely restricted to protected areas such as Bwindi-Impenetrable Forest, Mount Elgon, Udzungwa and the Virunga Volcanoes National Parks; much of the remaining montane vegetation has been modified to varying degrees by people. The resultant vegetation often has components indicative of disturbance, such as ruderal species of *Chenopodium*, *Dodonaea*, *Plantago*, *Rumex* and *Vernonia*. Tree genera also indicative of disturbance can be locally more common; such as species of *Alchornea*, *Croton*, *Dombeya*, *Erythrina*, *Hagenia*, *Harungana*, *Macaranga* and *Polyscias*. However, care must be taken when translating the presence of these taxa as disturbance as they all occur naturally within montane vegetation, albeit at relatively low values.

Fire is an important ecological driver at the forest-savanna ecotone, promoting open grassland ecosystems at the expense of forest (e.g., Cochrane et al., 1999; Bond and Keeley, 2005). Fire can even maintain a grass-dominated ecosystem in regions where the environmental (precipitation) regime would commonly support forest ('unstable savanna': Sankaran et al., 2005). Satellite and long-term field data has shown that fires in areas of grass-dominated savanna are controlled principally by the availability of fuel (Bond and Keeley, 2005). Although somewhat counter-intuitively, wetter conditions allow the production and accumulation of herbaceous litter, which means there is more fuel available for the fires; in contrast, drier conditions have the reverse effect as the production of herbaceous litter is more limited

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(Archibald et al., 2010). Over large areas of East Africa, the observed spatial and inter-annual variability in biomass burning is primarily controlled by precipitation (relative drought) and land use (deliberate ignition, landscape fragmentation) (Carcaillet et al., 2002; Archibald and Roy, 2009; Colombaroli et al., 2014). East African ecosystems appear to have experienced less direct and less predictable responses, depending on the type of land use (pastoralism or farming) and the ecosystem involved (e.g., dry grassland versus wet savanna woodland). In climates allowing rain-fed agriculture (e.g., large areas of western Uganda), intensive human impact associated with high demographic pressure has often resulted in fire suppression, due to establishment of a modern cultural landscape consisting almost entirely of cropland under near-continuous rotation (Andela and van der Werf, 2014). In the drier climates characterizing much of Kenya and eastern Tanzania, a combination of pastoralism and dispersed subsistence agriculture instead results in more frequent and extensive burning, to either clear marginal farming land or promote the nutritional quality of grazing pastures (Laris, 2002; Laris and Wardell, 2006).

The impact of herbivory on primary production is explained by grazing optimization theory (Georgiadis et al., 1989), whereby herbivores promote or suppress tree cover depending on their size, density and mobility. For example, small browsers have been shown to suppress shrubs and large browsers can alter the structure and density of woodlands (Bond and Keeley, 2005; Bond 2008; Midgley and Bond, 2015; Hempson et al., 2015). Moreover, elephants and humans are keystone species in regulating savanna patch dynamics (Western and Maitumo, 2004). Large and mobile herbivore populations, particularly African savanna elephants (*Loxodonta africana*), can destroy tree cover causing perceived habitat degradation, cause the loss of habitat for browsing species (Guldemonde and Van Aarde 2008), and modify tree species compositions (Rugemalila et al., 2016). Whilst mature savanna trees are probably relatively unresponsive to these impacts, in that they are able to withstand prolonged droughts and grazing, juvenile specimens will be more acutely affected.

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3 Reviewing evidence for environmental and cultural change in East Africa

East Africa has long been a locus of cultural and socio-economic changes and a major conduit and contact zone between diverse food-producing traditions. The region is able to support a diverse range land use types in a relatively small area due to a wide range of environments that extend from mountains through to extensive lowland rangelands. Throughout the year the alternating dry and wet seasons also provide ideal growing and planting seasons on nutrient rich volcanic soils. The different forms of evidence for documenting change over the past 6000 years across the East African landscape will be presented in four time slices of 1500 years. These time slices correspond to different broad environmental regimes: the global mid Holocene Climate Optimum, the extensive drought centred around 4000 yr BP at the latest termination of the African Humid Period, the subsequent relatively mesic period, followed by the last 1500 years characterised by alternate dry and wet phases. The review will initially focus on the environmental evidence and then on human history.

3.1 Evidence for environmental change across East Africa

Multiple evidence streams for documenting past environmental change are available in East Africa; each with different constraints and limitations to inform our understanding of palaeoenvironments. Palaeoenvironmental research makes use of geoarchives and other sources of Earth history to examine signals of environmental variability, often through the use of environmental indicators and proxy measurements (Last and Smol, 2001; Smol et al., 2001a, 2001b). As sediments accumulate in a depositional system, the properties of the sediment stratigraphy maintain environmental signals that provide a history of ecosystem variables, such as precipitation, biological productivity, and vegetation type (Romans et al., 2016). Variability in these environmental signals can be caused by natural and anthropogenically-modified processes; thus, they provide us with insights into long-term environmental processes, abrupt perturbations and associated environmental consequences, and human-environment interactions.

In East Africa, the most numerous records of past environmental variability have been established from the analysis of lacustrine, palustrine and peat geoarchives (Figures 7 and 8); and there have been studies of coastal deposits, Indian Ocean marine sediments, corals, cave deposits, and other sources such as tree growth rings (Stahle et al., 2009). The environmental signals embedded within geoarchives provide us with information on how ecosystem processes varied at multiple spatial and temporal scales and these resolutions are dependent on the different sources of palaeoenvironmental information, the degree to which the signal is captured by the system, and sampling intensities.

3.1i Geoarchives and palaeoenvironmental change

There are multiple sources for examining the geological and environmental history of East Africa for the past 6000 years. East African topography is characterised by several large lakes, numerous small lakes (Figure 7), and many swamps, mires and peatlands (Figure 8). Deposits that have accumulated in these basins can be analysed to provide palaeoenvironmental data; each depositional environment has its unique challenges and utility, and provides insights at differing spatiotemporal scales. The large basins are influenced by broad-scale regional processes, such as climate and climate-mediated erosion rates, and the sediment bases are often much older extending beyond the Quaternary (Butzer et al., 1972; Johnson et al., 2002). The large, shallow, flamingo lakes of the Rift Valley respond more rapidly to hydroclimatic changes and can even dry out completely, often leading to discontinuous late Holocene sediment histories, but when multiple coring locations are studied, a composite history can be described (Figures 7E and 7H) (Verschuren et al., 2002). Small lake basins are often much younger, forming at the end of volcanic processes or within low depressions on the landscape, these can provide sediment records from the Pleistocene, or much earlier in some cases (Figure 7B and 7C) (Maslin, 2016). Each lake can have multiple high and low stands as the hydrological budget changes (Nash et al., 2016). These systems are often influenced by a combination of broad-scale climatic, as well as local-scale, factors. An important mechanism at the highest elevations since the mid-Holocene is the retreat of the montane ice caps

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creating deglaciated valleys containing small lakes and mires that provide recent environmental information (Figure 7A) (Perrott, 1982a; Rietti-Shati et al., 1998; Karlén et al., 1999; Courtney-Mustaphi et al., 2017).

Mires, peat deposits and swamp (palustrine) deposits provide another source of sedimentary palaeoenvironmental records that extend from the Pleistocene in mesic regions (Figure 8C) and from the late Holocene in semi-arid areas (Figures 8D and 8E). Swamp deposits can also be sensitive to drying and subsequent breaks in sediment accumulation, bioturbation from plant root growth, and large animals may disturb the temporal sequence of the stratigraphy. Other sources of palaeoenvironmental history for East Africa come from coastal mangroves (Figure 8F) and corals, glacial deposits (Figure 7A background and 8A), geomorphology, dendrochronology (Figure 8H), speleothems (Figure 8I), soils (Figure 8G), and marine sediments.

The number of published sediment-based records for past environmental change from East Africa (e.g., Karlén et al., 1999) is steadily increasing. A long tradition of palaeoecological research, extending to some of the pioneering work of Livingstone, Coetzee, Morrison and Van Zinderen Bakker since the late 1950s and early 1960s, has established an increasingly dense assemblage of palaeoecological archives that clearly demonstrate the highly responsive nature of East African ecosystems to past climatic variability (Finch et al., 2016). Recent advances in database development and repositories for palaeoenvironmental datasets have begun to build the foundation for large-scale analyses to examine spatiotemporal patterns in ecosystem change and human-environmental interactions (Vincens et al., 2007a; Goring et al., 2015; Courtney-Mustaphi and Marchant, 2016). These are facilitating a move away from the largely descriptive phase of environmental ontogenies and histories.

3.1ii Detection of cultural changes in East African geoarchives

From the early Holocene through until the present day, human-induced vegetation change,

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has gone from being relatively minor and restricted to a few locations, to becoming a widespread and dominating force across even remote and inhospitable environments (Hamilton, 1982); with an increasing human pressure on natural resources radiating out from urban centers. Detecting anthropogenic signals and diagnostic characteristics in palaeoenvironmental data can be achieved through examining sedimentologic measurements (e.g., sediment magnetism, particle sizes, isotopes) and proxy indicators (e.g., pollen types, plankton and mollusc remains) associated with known types of human land use or land cover change consequences and temporal associations with archaeological or documentary evidence. Running modelling experiments and testing hypotheses regarding land cover change within a modelling framework offer additional ways to query the palaeoenvironmental evidence. Bringing each of these approaches together enables a holistic examination of anthropogenic modification of the environment and can be used to partition the degree of change exerted by human activities.

Two of the main types of evidence for anthropogenic change, are a reduction in arboreal cover and an increase in fire activity. These interpretations of anthropogenic change are inferred from the pollen record (a reduction in arboreal pollen) and other proxies, such as peaks in microscopic charcoal (indicative of burning). This is exemplified from numerous locations such as at Ahakagyezi (Hamilton et al., 1986; Taylor, 1990) and Muchoya Swamps (Taylor, 1990; Marchant and Taylor, 1998) in Uganda, Sacred Lake (Street-Perrott et al., 1997) in Kenya, and Lake Tanganyika (Cohen et al., 1997; Msaky et al., 2005) and Lake Masoko (Vincens et al., 2007b) in Tanzania (for locations see Figure 1). Similar changes in the composition of vegetation and modified burning regimes are also evident in mid-elevation records from Mount Shengena, in the Arc Mountains (Finch et al., 2016). These indicators are generally interpreted to be associated with human land use and intensification of human activities (Finch et al., 2016), rather than the mere presence of people in the landscape.

Of course, such simplistic interpretations are often challenged when there are multiple drivers

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interacting (Salzmann et al., 2002; Marlon et al., 2013, 2016; Heckmann et al. 2014). It has been seen that forest clearance is also often accompanied by an increase in grass pollen (e.g., Vincens et al., 2007a). This could be indicative of a preference for agroforestry trees (e.g., *Arundinaria alpina*), the presence of cultivated crops (e.g., *Ricinus communis*) and/or disturbance, shown through the presence of pollen from ruderal plants indicating clearance for agriculture or pastoral activities. Poaceae pollen grains >80 µm are assumed (*a priori*) to represent the non-native crop *Zea mays* (Eubanks, 1997), while grains 60-80 µm fall in the cereal category, but cannot be attributed with certainty to maize (Tsukada and Rowley, 1964; Fearn and Liu 1995). They are hence attributed to the indigenous cereals such as millet and/or sorghum. Poaceae pollen grains <60 µm are counted as wild grasses as they cannot be attributed to cereals. It is not possible to positively identify pollen from most cultivated plants in the palaeoecological record, with light microscopy alone (cf. Msaky et al., 2005), which makes detailed studies of land-use from pollen alone unachievable at present. This is exemplified at the archaeological site of Munsa, where it proved to be impossible to distinguish between sorghum and millet from wild grasses - both in the preserved pollen assemblage and in phytoliths. However, maize can be identified from phytoliths (Lejju et al., 2006; Lejju, 2009), and these samples are thought to postdating 170 yr BP (c. AD 1780).

From the mid-Holocene onwards it is not always possible distinguish between a climatic or anthropogenic signal in the palaeoenvironmental record. This equifinality is best demonstrated with an example. High levels, or peaks, in microscopic charcoal often occur with high percentages of grass pollen, in the section above it has been suggested that this can be an indication of human land use, however, it can also be considered as a drought event (cf. Marchant and Hooghiemstra, 2001). In certain situations, particularly in swamps and peatlands where the pollen signal is likely to relatively local (compared to lakes), dung fungal spores can be used to aid in differentiating between a human or climatic cause for the environmental signature present. Certain fungal spores, and assemblages of them, can be indicative of human activity e.g. settlement sites, as well as the presence of grazing

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herbivores. Importantly, these fungal assemblages differ from those of undisturbed natural ecosystems (van Geel et al., 2011). Thus far, there has been limited use of fossil fungal spores in palaeoenvironmental studies in East Africa, the main exception to this has been work carried out in the vicinity of the archaeological site of Munsa in Uganda (Lejju et al., 2006; Lejju, 2009; Szymanski, 2017).

Fire regimes represent one area where human-environment interactions are deeply entangled. Even before the development of farming, humans have used fire as a tool on the landscape, a long history that has greatly expanded the range of variability of fire regimes. Patterns of landscape-scale fire use vary according to land use regime; this variability means that humans have influenced different components of fire regimes in varying degrees of importance through time (Archibald et al., 2012). Details matter: the timing, frequency, and scale of burning structure ecological impact and complicate our understanding of the effects of anthropogenic burning on biodiversity and vegetation structure (Brockett et al., 2001; Parr and Anderson, 2006; Gil-Romera et al., 2011; Donaldson et al., in press). These important ecological outcomes may be difficult to differentiate in palaeoenvironmental records and require testing in modelling and field experiment frameworks (Marlon et al., 2016; Hawthorne et al., 2017).

A point where it should be possible to link archaeological and palaeoenvironmental records is through chronology, as both types of sites have often been dated using radiocarbon dating. However, comparison and correlation between sites is complex (Blaauw et al., 2007; Parnell et al., 2008; Gearey et al., 2009), and proves challenging at the moment for a number of reasons, the first of which is the accuracy of sample selection. Chronologies are only as good as the often-inconclusive association between the material being dated and the event of interest (Bird et al., 2005). Within palaeoecology most work has been undertaken at lake sites where there is in an absence of short-lived, single-entity plant macrofossils, this means that sediment samples are often dated instead. This is potentially problematic, as the processes of sediment

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accumulation and erosion need to be fully understood for the dates to be meaningful. Also the sediments may be subject to the ‘old carbon effect’, returning determinations that are considerably older than the event in question. Within archaeology, sampling issues pose similar challenges, in older literature it is often unclear as to whether samples were taken from secure contexts, which again raises the question of provenance – is the event in question actually being dated? Unidentified charcoal was frequently dated, which raises the question of the ‘old wood effect’, especially within the savanna landscapes of East Africa where *Acacia* is dominant, as it can potentially live for many hundreds of years.

Secondly, there is the issue of the precision of the dates. Rarely is it possible to obtain dates from conventional radiocarbon determinations alone that calibrate to a decadal scale (Blaauw et al., 2011; Stanley et al., 2003). The fluctuating nature of the radiocarbon calibration curve also means that there are periods of wiggles and plateaus, these can produce calibrated dates which span hundreds of years (Reimer et al., 2004, 2013). The period of 350–50 yr BP (cal AD 1600–1900) is one such period that can prove problematic for the dating of sites in East Africa, especially those associated with historic agriculture, the introduction of imported crops and the caravan trade.

However, once issues of accuracy and precision are acknowledged then they can start to be addressed. This is through careful sample selection, combining multiple dating methods and using other stratigraphic information to constrain the calibrated date (using Bayesian statistical techniques) (Bayliss, 2009). The best palaeoenvironmental example from East Africa where this has occurred is the high-resolution record from Lake Challa on the Kenyan/Tanzanian border (Blaauw et al., 2011); here, not only were radiocarbon determination obtained on 168 samples, but these samples were paired with other radiocarbon or ^{210}Pb-derived determinations to test for any old carbon offsets. The calibrated dates were then constrained using Bayesian statistics to produce age estimates for the Holocene that ranged from approximately 50–230 yr (Blaauw et al., 2011). Whilst all

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palaeoenvironmental age-depth models are informed ‘best estimates’ of the chronology of the sediment being studied (Telford et al., 2004; Heegard et al., 2005; Parnell et al., 2011; Trachsel and Telford, 2017) and contain inherent uncertainties and temporal aggregations (Blaauw and Heegaard, 2012), the Lake Challa example demonstrates that it is possible to provide a much more precise chronology when multiple methods and techniques are applied to carefully selected samples.

Archaeologically, the use of Bayesian statistics to constrain calibrated radiocarbon dates is also starting to be used. This is clearly seen in the work in of Crowther et al (2016b) examining the introduction of Southeast Asian crops to East Africa. A total of 48 samples were selected for dating, these were chosen to avoid long-lived species, and they were subsequently modelled using Bayesian statistics to take into account the stratigraphic relationship between samples, and hence to produce a narrower estimated date range for when the introductions occurred.

In this review dates are expressed, where possible, in calibrated years BP, to maintain consistency. This review brings together dating information from archaeological and palaeoenvironmental sites in East Africa, in particular, bibliographic site information contained in the SM1-3. It remains a future project to recalibrate and re-interpret the currently available dates. The patchiness of available in-depth meta-data concerning radiocarbon samples, the variety of laboratory reporting styles (raw data, or normalised account for variation in the production of atmospheric radiocarbon), the variation in calibration curves (whether the northern hemisphere (Reimer et al., 2013), southern hemisphere (Hogg et al., 2016), or mixed curve (Crowther et al., 2016b) is used) means that the original publications should be consulted for any queries concerning dating.

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3.2 Environmental history from geoarchives

Our review identified 129 published and unpublished palaeoenvironmental records within East Africa, which are mapped on Figure 9 and a full table is presented in SM1. The palaeoenvironmental sites are also mapped above the present day physiographic landscape (Figure 10) and climate (Figure 11) of East Africa. A total of 66 sites spanned the entire 6000 year time period or longer, 75 sites covered 4500-3000 yr BP, 85 records covered 3000-1500 yr BP, and 128 covered 1500 yr BP-present (Figure 9). Chronological control varied by the type of geoarchive, but are dominated by radiometric dating (n=116 sites) and eight sites making use of incremental dating (coral and dendrochronology), three sites used palynostratigraphy or stratigraphy for temporal matching, and two sites used repeat imagery of the past few decades. Sections 3.2i to 3.2iv below provide descriptions and interpretation of the environmental changes by 1500 year time periods from 6000 years BP to present.

3.2i Environmental history 6000 to 4500 yr BP

Our review starts at 6000 yr BP, which is towards the later phase of the globally evident Holocene climatic ‘optimum’ and end of the African Humid Period (Shanahan et al., 2015). Climate in East Africa was generally slightly warmer and wetter than present with most ecosystems experiencing minimal and diffuse anthropogenic impacts (Bonnefille and Riolett, 1988). The mid-Holocene (8200–4200 yr BP (Walker et al. 2012)) is characterised by climate variability driven by natural processes and intensifying anthropogenic modifications towards the end of this period (Stott et al., 2000; Kaplan et al., 2011; Ruddiman et al., 2011, 2015). In eastern Africa, the moist forest biome followed a similar distribution to today (Jolly et al., 1998b). Palaeoecological records from East Africa suggest that aridity increased from the early Holocene as temperatures rose; Barker et al. (2011) propose that annual temperatures were around 2–3°C higher in the Holocene, compared to the glacial maximum. This increase in arid conditions can be seen in a pollen record from Lake Tanganyika, which shows a change in the

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catchment area of the lake from being forested to becoming drier, more open grassland from 5000 yr BP (Msaky et al., 2005). Using paired compound-specific isotope records, Tierney et al. (2010) also illustrate that a major change in vegetation occurred around Lake Tanganyika at 6200–5500 yr BP even though the main period of drying was thought to have occurred in the early Holocene. However, other records exist in East Africa that also suggest that a change in aridity occurred in the mid-Holocene. An example of this can be seen in lake level changes at Lake Turkana in northwestern Kenya, here the lake level is thought to have decreased by approximately 50m around 5300 yr BP. Whilst it continued to maintain this lowered level for much of the mid- to late-Holocene (Garcin et al., 2006) there is considerable variation in the magnitude of this reconstructed change due to the application of different proxies and dating controls (Morrissey and Scholz, 2014; Blosziers et al., 2015). For instance the diatom records from Lake Victoria (Nakintu and Lejju, 2016) indicates a phase of low precipitation, but moderate lake levels, between ca. 5,000-4,000 yr BP. The high abundance of *Aulacoseira granulata* and *A. ambigua*, indicates well-mixed (moderately deep) water, but low abundance of all diatoms and the presence of Cyperaceae phytoliths suggest low rainfall.

Detailed characterisation of this period is challenging as many sites throughout East Africa are characterized by sedimentary hiatuses around this time, and their scientific contribution can be overlooked. Difficult sediment archives are often perceived as negative results, undermined by reviewers and editors, and frequently remain unpublished, but are crucial for examining histories, particularly of semi arid ecosystems. Hiatuses in sedimentation are often regarded as a lack of information that should be simply delimited and negated, although it could be argued the presence of a sedimentary hiatus is one of the strongest palaeoenvironmental indicators within a sedimentary sequence, as it potentially indicates how the sedimentary basin responded to regionally recorded climatic and tectonic changes. The main problem in defining sedimentary hiatuses is determining whether they result from a lack of sediment accumulation or from post-depositional erosion of the sediment. In the case of Mubwindi Swamp, the hiatuses are thought to result from erosion, particularly as sediment erosion can be observed at present within the southern part of Mubwindi Swamp (Marchant et al., 1997; Marchant and Taylor 2000). The temporal placements of the hiatuses at Mubwindi Swamp reiterate this suggestion as they occur during periods of increased effective moisture availability throughout the region (Bonnefille, 1987), thus providing the mechanism necessary to erode *in situ* sediments, i.e. an increase in the hydrological budget. Due to the long hiatus in sedimentation at some of the sites, often much of the material laid down during the Holocene is missing. Equally, re-initiation of peat accumulation during the late Holocene (around 4000 yr BP) may have commenced as a consequence of gradual aridification or increased seasonality (section 3.2ii). Throughout western East Africa, there appears to be a slow, but sustained increase in the depth of sediment accumulated down the altitudinal sequence: no peat formed at the higher Kuwasenkoko Swamp, Rwanda (Hamilton, 1982) at 2340m OD, or at Muchoya Swamp, Uganda, at 2260m OD (Jolly et al. 1997), but an accumulation of 7-10m of peat was recorded at Ahakagyezi Swamp, Uganda (Taylor, 1990) at the slightly lower elevation of 1830m OD. This variation in the presence/absence of peat is thought to be a common response by peat formation throughout central Africa, where the rate of peat accumulation is determined by increased moisture and temperature at lower altitudes, thus facilitating increased growth rates and/or decreased decomposition. This altitudinal gradient reiterates the responsive nature of the sediment stratigraphies in isolating the forcing mechanisms responsible for environmental change in East Africa.

Interestingly, the lack of woody biomass in the present-day grassy savannas of East Africa, not only characterises them today, but would appear from both high and low altitude palaeoecological records to have begun around 5000 to 6000 yr BP, coinciding with an increase in dry-season aridity (Barker et al., 2011; Nelson et al. 2012). The spread of drier forest types than previously present was widespread after about 6000 yr BP, probably in response to greater seasonality (Stager and Mayewski, 1997), possibly resulting from poleward extension of the migration of the ITCZ (Nicholson, 1994).

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On the coast of East Africa, sea levels are thought to have risen dramatically following low stands of the last glacial period (Prendergast et al., 2016). Sea levels reached a mid Holocene highstand, of up to 3.5 m above present mean sea level, by 4500 yr BP followed by subsequent falls to the present level in the late Holocene (Punwong et al., 2017). Sea level change is critically important to coastal societies and some mid Holocene archaeological sites (and also older Pleistocene ones) are now under water. Sea level variability impacts low-lying areas, such as deltas and mangrove forests (Punwong et al., 2013a), and is important to saltwater intrusion of surface and groundwater, as well as storm risk and consequences.

3.2ii Environmental history 4500 to 3000 yr BP

This time slice is largely included within the late-Holocene (from 4200 yr BP Walker et al. 2012), which in East Africa is marked by a relatively abrupt shift toward arid conditions characterised by higher temperatures, reduced rainfall and or a more seasonal environment (de Menocal, 2000) that was particularly pronounced at approximately 4000 yr BP when lake levels fell sharply (Gasse, 2000; Marchant and Hooghiemstra, 2004). Kiage and Lui (2006) present a summary evidence of this abrupt shift from a number of sites around region including the Lake Bogoria (Kenya) pollen sequence, which from 4500 yr BP shows a sharp decline in high altitude forest pollen from taxa such as *Hagenia abyssinica, Hypericum, Stoebe* and Ericaceae, and increases in taxa such as *Podocarpus, Juniperus, Acacia* and *Dodonaea*, which are more drought tolerant (Vincens, 1986). Similarly, on Mount Kenya and Mount Elgon sharp increases in *Podocarpus* occurred after 4500 yr BP and 3500 yr BP, respectively (Street-Perrott and Perrott, 1988; Hamilton, 1982). These increases mark the onset and establishment of dry conditions in the region, which is also seen in the low abundance of Panicoid grass cuticles at Sacred Lake on Mount Kenya during the mid to late Holocene, thought to indicate a shift in the seasonality of rainfall and/or fire (Wooller et al., 2000, 2003). Another record from Mount Kenya investigating the isotopic character of the sediments from Lake Rutundu indicates a very rapid rise in C_3 grasses about 4500 yr BP that is relatively short lived (Ficken et al., 2002) and similarly may derive from a sudden change in the precipitation regime. In

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Rwanda and Burundi, Jolly et al. (1997) suggest that within tropical montane forests taxa that are drought more tolerant, for example *Podocarpus*, increased in abundance after 4100 yr BP.

Moving southwards, this wide-scale ecosystem response corresponds with an abrupt climate event recorded in the ice core record from Mount Kilimanjaro, Tanzania. This is represented by a visible dust layer 30mm thick that has been interpreted as a desiccation episode in the early part of the late Holocene on the basis of its chemical signature and the correspondence of a possible hiatus in the accumulation of the ice (Thompson et al., 2002). Lake level records from Lake Rukwa, Tanzania (Talbot and Livingstone, 1989), also indicate that dry phase occurred at around 3000 yr BP. The outflow from Lake Kivu, Rwanda, to Lake Tanganyika (Burundi) was interrupted from about 3500 yr BP with lake levels lowered by about 75 m; this altered the salt balance in Lake Tanganyika and changed the resultant diatom flora (Haberyan and Hecky, 1987). Again, this phase of aridity can be seen in the Lake Kivu catchment, around 3200 yr BP a reduction in forest taxa occurred that coincided with an expansion of the savannah, without any indication that people were responsible for this change (Ssemmanda and Vincens, 1993). Moving northwards again, the level of Lake Turkana in northern Kenya also decreased to a minimum at around 4600 yr BP (Owen et al., 1982) with $\delta^{18}O$ isotope data indicating a new environmental regime in the lake from 4000 yr BP (Halfmann and Johnson, 1988; Halfmann et al., 1994); this is likely to be reflective of the aridity extending beyond the study area of this review, because Lake Turkana drains Southern Ethiopia. Lastly, moving out to the coast, mangrove records indicate that a lower sea level existed until approximately 3200 yr BP (Punwong et al., 2013a, 2017), which coincides with the East African dry event prior to this time. Thus, an abrupt dry event during c. 4500–3500 yr BP can be clearly identified across East Africa and beyond (Street-Perrott and Harrison, 1985; Street-Perrott and Perrott, 1988; Talbot, 1988; Elenga et al., 2000; Barker et al., 1999; Bonnefille and Chalié, 2000; Talbot and Laerdal 2000; Marchant and Hooghiemstra, 2004; Kiage and Lui, 2006), and has been associated with a decline in the base flow of the White Nile (Talbot and Brendeland, 2001).

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3.2iii Environmental history 3000 to 1500 yr BP

Variation in the carbonate content of sediment cores from the northern part of Lake Turkana, indicates that several arid events occurred between c. 2200 yr BP and 1700 yr BP (Halfman et al., 1994; Morrissey and Scholz, 2014). A lake-level reconstruction for Lake Tanganyika based on fossil ostracod assemblages suggests that its lowest level of the past 2500 years occurred between 2200 yr BP and 2000 yr BP (Alin and Cohen, 2003). Conversely, a high-resolution record of diatom-inferred conductivity (dissolved-ion content) from northern Lake Tanganyika (Stager et al., 2009) displays little evidence of this drought episode. Instead, the record shows decreased mean water-residence time over the past 3300 years, implying higher lake levels and a general trend of climatic wetting throughout this period. In the central Kenya Rift Valley, the deep Crescent Island Crater basin of Lake Naivasha, last stood dry c. 2200 yr BP (Verschuren, 2001). At Sacred Lake on the lower slopes of Mt. Kenya, high (less depleted) values in plant leaf waxes indicate increased aridity shortly before 1700 yr BP (Konecky et al., 2014). In western Uganda, peak %Mg levels of calcite deposited in Lake Edward point to a distinct century-scale phase of intense evaporation centred on c. 1900 yr BP (Russell and Johnson, 2005); this evidence for pronounced regional aridity has also been recorded at three nearby Ugandan crater lakes (Russell et al., 2007). Kiage and Lui (2006) have suggested that from 2500 yr BP a steady decline in tree cover, seen in pollen profiles, can be linked with a coeval increase in evidence for human activity, and that increased sedimentation rates are indicative of erosion caused by land clearance for agriculture. Examples that are given include the presence of *Elaeis guineensis* (wild oil palm) pollen grains found within the Lake Masoko sediment record (Vincens, 1989a); recycling of tree pollen within sediments with high accumulation rates at Lake Tanganyika (Masky et al., 2005) and coeval deforestation Batongo and Katenga mires in Uganda (Morrison and Hamilton, 1974; Taylor, 1990) in Uganda. Whilst these are signs of deforestation, disturbance and change, in the absence of further distinct human indicators or archaeological evidence, assigning a human cause to this disturbance is not possible. This is further supported by evidence for climatic change from Lake Challa, near

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Mount Kilimanjaro, where a shift to generally low values of the Branched to Isoprenoid Tetraether (BIT) index from bacterial cell-wall lipids have suggested a period of reduced rainfall between 2000 and 1800 yr BP (Buckles et al., 2016). On the coast of East Africa, a higher sea level was recorded after 3200 cal yr BP until around 2000 cal yr BP before starting to fall below the present level until approximately 1400 yr BP (Punwong et al., 2017); this fall in sea-level also co-incides with period of reduced rainfall seen at Lake Challa. Clearly this was a period of pronounced climate variability, with considerable regional differences, and a time when people may, or may not, have initiated or accentuated environmental change; despite this uncertainty, a period of extreme aridity does seem to have centred around 2000 yr BP.

Following this episode of apparently intense drought, much of East Africa appears to have experienced a transition to slightly wetter conditions between c. 1800 and 1500 yr BP. At Lake Naivasha this is evidenced by the refilling of the previously dry basin, followed by a relative highstand lasting until 1400 yr BP (Verschuren, 2001). A higher lake level at this time is also indicated by a low ratio of nearshore versus offshore diatom taxa in the sediment record of northern Lake Victoria (Stager et al., 2003; Stager et al., 2002). Similarly, reduced Mg values of calcite in Lake Edward for the period 1800 to 1600 yr BP (Russell and Johnson, 2005) suggests wet conditions on the western shoulder of the East African plateau, while at Lake Tanganyika, a contemporaneous humid phase is dated to between c. 1750 and 1450 yr BP (Stager et al., 2009).

Despite extensive forest clearance, as recorded on the mountains of Burundi, Rwanda, Tanzania, and Uganda (Bonnefille and Riolett, 1988; Taylor, 1990; Jolly et al., 1997) some quite large tracts of forests remained intact. For example, a precursor of the present Bwindi-Impenetrable Forest remained forested while the surrounding region was extensively cleared. Why some areas were cleared and others not is difficult to decipher. One possibility is that there may have been some degree of protection imparted by forest dwelling communities likely to have been present at the time, such as a precursor of the modern BaTwa pygmies,

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that restricted expansion of agricultural land (Hart et al., 1996). Currently there has been insufficient archaeological research on this time period or relevant ethnographic work, in these montane contexts, to allow us to even begin to understand how people might have perceived and used/avoided certain forested areas. However, the palaeoecological records do inform us that by approximately 2000 yr BP agriculture had spread within the western highlands of East Africa, and that areas of forest had been afforded 'protection'; this protection has continued to the present day, now under the guise of National Park legislation (Section 5.3).

3.2iv Environmental history from 1500 cal yr BP to present

The number of available palaeoenvironmental records covering the past 1500 years to present is greater than for the earlier time periods. Perhaps as a consequence, this increased wealth of data records a highly variable climate with quite a range of responses, although very large geographic knowledge gaps still remain. Variable climate has been seen at Lake Naivasha, Kenya where using preserved waterfleas (*Daphnia*) as proxies for lake level, it has been demonstrated that the lake fluctuated from a shallow pond-like existence to a "mega-lake' extending approximately 150-250 km^2 a total of eight times over the last 1800 years (Verschuren, 2001, Mergeay et al. 2011); these fluctuations indicate periods of reduced precipitation and drought. Further south, the record from Lake Tanganyika (Alin and Cohen, 2003) suggests increasingly wet conditions between 1200 and 1000 yr BP, while to the north in Lake Turkana, Mohammed et al. (1996) interpret the pollen record from this period as reflecting lower lake levels.

Ryves et al. (2011) suggest there is substantial evidence for a widespread arid phase around 1000 to 800 yr BP across the East African region, citing records from large lakes such as Lake Naivasha (Verschuren et al., 2000), Lake Emakat (Ryner et al., 2008), Lake Victoria (Stager et al., 2005) and Lake Edward (Russell and Johnson, 2005); and from smaller basins such as Lake Kitagata (Russell et al., 2007). Ryner et al. (2008) suggest that this dry phase before 800 yr BP

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also coincides with drier conditions at Lake Naivasha (Verschuren et al., 2000; Lamb et al., 2003) and Lake Edward (Russell and Johnson 2007). In addition, a prolonged dry phase from 1250 to 550 yr BP has been recorded in the sediment record from Lake Masoko (Barker et al. 200; Gibert et al., 2002; Vincens et al., 2003). The pollen data from Kasenda, Uganda (Ssemmanda et al., 2005) further supports this period of aridity, with a decline forest taxa around 1100 to 1000 yr BP being attributed to this dry phase. Limited burning during the period ca. 1050-950 yr BP in the Lake Simbi area, and during the longer period ca. 1100 to 850 yr BP in the Naivasha area, may both reflect the wider region's generally dry conditions (Verschuren and Charman, 2008) with widespread fuel limitation (Colombaroli et al., 2014) across the drier savannas of eastern equatorial Africa. It must be emphasized that such ecosystem transitions are challenging to assign cause and effect as this also coincides with the rise of political complexity, and consequential intensification of human activities, in western Uganda (Taylor and Marchant 1996; Taylor et al., 1999). In western East Africa lake records from western Uganda (Russell and Johnson, 2007, Russell et al., 2007; Mills et al., 2014) and Lake Tanganyika (Cohen et al., 1997; Alin and Cohen, 2003) record a humidity maximum from c. 800 to 500 yr BP, followed by sustained dry conditions. The high-resolution %Mg record from Lake Edward suggests that regional aridity at that time was comparable to that of climax drought conditions during the globally-expressed Medieval Climate Anomaly (Russell and Johnson, 2007). A similar pattern is shown by the 700-year biogenic silica (BSi) record from Lake Malawi (Johnson et al., 2001), where humidity peaked at 500 yr BP, after which aridification set in, culminating in severe drought around 200 yr BP (Crossley et al., 1984; Owen et al., 1990). Lake Bogoria in the Kenya Rift Valley reached a high level between 600 yr BP and 400 yr BP, followed by a more modest highstand around 250 yr BP (De Cort et al., 2013).

In the central Kenya Rift Valley, abrupt wetland formation at Loboi swamp is dated to 750 yr BP (Ashley et al., 2004; Driese et al., 2004). Available high-resolution, well-dated lake-sediment records distributed over the region suggest that, after this common initial stage of

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lake transgression, notable spatial differences developed in the amplitude and timing of hydroclimate variability. In easternmost East Africa, relatively humid conditions continued through the main phase of the global Little Ice Age time span (Verschuren, 2004). Whilst at Lake Naivasha, this 500-year period of relatively moist climate was interrupted by two episodes of lake-level decline at 650 and 350 yr BP, respectively (Verschuren et al., 2000; Verschuren, 2001). These multidecadal drought events were prominent enough to be recorded in regional vegetation (Lamb et al., 2003). Ryner et al., (2008) note that the wetter conditions prevailed at 800 yr BP at Lake Emakat (Tanzania) and Lake Edward (Uganda), whilst Lake Naivaisha (Kenya) and Lake Tanganyika (Tanzania) both record wetter conditions occurring later. The records from Lake Malawi, Tanzania (Johnson et al., 2001) also suggests wetter conditions prevailing from c. 700 yr BP, and Lake Victoria (Stager et al., 2005) shows evidence of a shift from drier to wetter conditions shortly after c. 700 yr BP. A study of diatom and midge remains from Lake Naivasha sediments suggests that the climate of East Africa was largely warmer and drier than today from 1000 to 630 yr BP (Verschuren et al., 2000), a period known as the Medieval Climate Anomaly (MCA). At Lake Challa, there is a fairly well-defined post-MCA shift to wetter conditions c. 700 yr BP followed by a period with substantial variability in BIT-index values (Buckles et al., 2016) - where sustained high BIT-index values suggest increased water levels - at Lake Challa this occurred between c. 430 and 330 yr BP. This is consistent with the Little Ice Age in East Africa, which is thought to be manifest as a predominantly wet climate during its main phase (Tierney et al., 2013), from 680–100 yr BP (Verschuren et al., 2000).

Overall, during the Little Ice Age, environmental conditions were generally wetter from 630 to 100 yr BP, but interrupted by prolonged droughts at 560–580, 390–325 and 190–160 yr BP, as seen at Lake Naivasha (Verschuren et al., 2000). East Africa appears to have shared a similar climate history over much of the last millennium, with dry phases at 800–700 yr BP and 200 BP and wetter phases around 600 and 250 yr BP, the exception to this, is a dry period recorded across western Uganda between 600 and 500 yr BP, which is the reverse to that

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observed to the east, and the south (Tierney et al., 2008; 2010; 2011). However, with the dominant drought periods noted at Lake Naivasha tantalizing connections have been made that link them to oral traditions of droughts (cf. Webster, 1979; Verschuren et al., 2000). On the basis of the oral history, drought-induced famine and political unrest, have been suggested as the reasons for large-scale migrations occurring in the three drought periods around 560–580 (Wamara drought), 390–325 yr BP (Nyarubanga drought), and 190–160 yr BP (Lapanarat-Mahlatule drought) (Verschuren et al., 2000). However, as the temporal and spatial precision of the drought reconstructions from the oral history are questionable, such connections are of limited quantitative value and would benefit from further cross-disciplinary research. Equally, of far more importance for understanding these relatively short-term climate fluctuations across the region is ensuring that the chronological information associated with the evidence for droughts is robust, and that it is both as precise and accurate as possible, as this period is notoriously hard to date using traditional radiocarbon methods alone (see section 3.1ii).

If we turn to look at fire activity in the palaeoenvironmental record, we can see a mixed picture of climate-driven fire activity and human-induced activity, however, long-term palaeoecological records have shown that fire is generally more responsive to climate variability than has been previously thought, as most studies were based on satellite observations, which suffer from the disadvantage of only recording short-term responses, not the longer-term climatic responses (Sankaran et al., 2005; Staver et al., 2011; Lehmann et al., 2014). Fire in the catchment of Lake Simbi, Kenya, seems to have been limited during the wettest episodes of the last millennium, as can also be seen in western Uganda (Colombaroli et al., 2014). However, conditions in the Lake Simbi catchment were never wet enough to allow wooded savanna to outcompete grasslands, implying that fire was sufficiently frequent to exert a positive feedback, impeding the encroachment of woody plants (Cochrane et al., 1999). At Lake Emakat, Tanzania, an increase in charcoal fragments c. 700 yr BP is contemporary with enhanced sedimentation suggesting in-wash associated with increased

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erosion (Ryner et al., 2008). The increase in sediment may also be linked to the increasing number of charcoal fragments 700–500 yr BP, in that the surrounding slopes may have become subject to increased erosion after stabilising vegetation has been had been burnt away. Frame et al. (1975) also propose that the present vegetation mosaic of woodland and bush in the Lake Emakat catchment is a result of extensive forest clearings by early agropastoralists in the Crater Highlands. This sedimentary and vegetation evidence, when combined with evidence from linguistic and archaeological sources (Sutton 1971, 1993; Fosbrook 1972; Ehret 1999, 2001), may point to an expansion of human population levels from c. 700 yr BP in northern Tanzania, however this link is currently unproven. At Lake Duluti (Öberg et al., 2012, 2013) burning was generally limited during both the wettest (ca. 600-400 yr BP) and driest episodes (ca. 800 to 730 and 200-150 yr BP; Stager et al., 2005) of the past millennium, which considering that fire only becomes more prevalent in wetter periods when people are involved, notably from 300 yr BP(Colombaroli et al., 2014), it would appear that climate was driving the fire regime at Lake Duluti. Coastal areas of East Africa show a low sea level low was present between 1400-100 yr BP (Punwong et al., 2017). However, over approximately the past 100 years there have been moderate sea level rises until the present day that probably relate to global sea-level rise during the last century (Stocker et al., 2013).

Although the Little Ice Age continued from 630 to 100 yr BP, people become a dominant factor in shaping palaeoenvironment records from 300 yr BP, therefore it is worth examining this more recent period (300–Present) in its own right. The leaf-wax δD time series from Sacred Lake on Mount Kenya attests to high lake level conditions between c. 300 yr BP and 130 yr BP (Konecky et al., 2014). Wetter conditions around 300 yr BP gave way to a widespread arid phase from 150 to 100 yr BP (Ryves et al., 2011), which had the effect of desiccating many of the lakes in the region (Bessems et al., 2008); however, from around 150 yr BP, these dry conditions were followed by a wetter phase. A general pattern of substantially increasing lake levels in the nineteenth century (150–50 yr BP) (Verschuren et al., 2002; Bessems et al., 2008), was followed by a period of wet, but more stable, conditions

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in the 20th century (50 to -50 yr BP) (Russell and Johnson 2007; Bessems et al., 2008), especially in the later half of the century (Present to -50 yr BP) (Ryner et al., 2008). Superimposed on these general patterns are shorter events, such as the period of increased rainfall across East Africa during AD 1860–1880 (90–70 yr BP) (Nicholson, 1996b), which may have also caused a dramatic rise in Lake Duluti, Tanzania, seen to occur around 50 y r BP, potentially turning an area of swamp in an open water lake (Öberg et al 2012). Wetter conditions are also attested to at the archaeological site of Munsa, where, after a period of prolonged drought upto 300 yr BP (that was seen across the region e.g. Nicholson, 1996b; Taylor et al., 1999; Robertshaw and Taylor, 2000; Verschuren et al., 2000; Thompson et al., 2002; Alin and Cohen, 2003; Robertshaw et al., 2004) forest expansion began to occur again between 300 yr BP and 100 yr BP. However, using records from Lake Baringo and two shallow crater lakes in western Uganda, the combined evidence suggests that average mid-19th century, from 100 yr BP, climate conditions were relatively dry, and that the 19th century was drier, on average, than the 20th century (Nash et al., 2016). Following the dry period at the beginning of the 19th century (Stager et al., 2005; Bessems et al., 2008), when also the level of Lake Simbi was low, biomass burning increased from ca. 80 yr BP (1870 AD) and peaked in the first decade of the 20th century. The dry phase noted at Lake Simbi is largely coeval with the wider East African dry phase, that occurred between approximately 150 to 100 yr BP and is seen in many of the regional records (Nicholson, 2000; Verschuren et al., 2000; Bessems et al., 2008, Ryner et al. 2008). The water levels of Lake Tanganyika and Lake Rukwa, established from historical and geographical information, were low until 160 yr BP (Nicholson, 2001). In the central Kenya Rift Valley, very low water levels and/or elevated salinity is dated to between 130 and 110 yr BP (Verschuren et al., 2000) and the shallow Lakes of Nakuru and Elementeita stood completely dry (De Cort et al., 2013).

In contrast to the generally ‘wetter’ historical period from 300-50 BP that was initially described above, intense dry conditions also appear to have punctuated this period, especially in the period around 150 to 100 yr BP. However, due to, local and regional differences, lags in

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response time of vegetation and water levels, and the general lack of precision in radiocarbon dating in this period; accurately detecting and dating these events, may or may not be possible in the palaeoenvironmental records, which leaves the potential for a slightly ‘blurred’ interpretation of climate from these records alone. A more precise, and potentially more accurate form of information about conditions for this period comes from historical sources. This reduction in water availability between 150 to 100 yr BP likely contributed to a famine dated to 120 yr BP in eastern Africa (Hartwig, 1979) that has been claimed to have triggered extensive population migrations. Nash et al. (2016) note that historical records from Burton (1860) and Krapf (1860) describe famine and drought occurring from 130 to 110 yr BP in the Pangani Valley, Tanzania and in Mombasa, Kenya. The “Great Ethiopian Famine” from 62–58 yr BP (1888-1892 AD) is thought to have cost the lives of one third of the country's population, however the famine was not purely restricted to Ethiopia, records from northern Tanzania, suggest as many as 40–75% of the pastoralist Maasai communities may have also lost their lives for the same reason (Iliffe, 1987). Nash et al (2016) suggest that this dry period began around 165 yr BP (AD 1785), and using this date as a point of comparison, it can be seen Nicholson and Yin’s (2001) water-balance model that rainfall within the catchment of Lake Victoria was roughly 13% below the 20th century mean between 165 and 115 yr BP, again broadly falling with the 150 to 100 yr BP dry phase/drought period. It is important to bear in mind, nonetheless, that ‘droughts’ and ‘famines’ are not directly equivalent entities, the former being natural phenomena while the latter are well-known to be primarily (or at least partially) social, economic and/or political creations (e.g., Ball, 1976; Scrimshaw, 1987; Vaughan, 1987; Maddox, 1990; McCann, 1990), and equally, within the palaeoenvironmental literature it is only when a dry period is associated with the potential to affect people that the discourse changes from apparently neutral terms such as ‘dry periods’ or ‘aridity’, to ones that are more socially loaded, for example, ‘drought’ and ‘famine’.

Historical and palaeoclimatic records show that there was a major drought in this area in the late 19th century (Gillson, 2015). Data from Lakes Victoria, Stefanie and Naivasha show a

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sharp fall in lake level in the late 1890s (Nicholson, 1996a). The Maasai know this period (120-100 yr BP) as ‘Emutai’ – to wipe out (Saitoti and Beckwith, 1980; Waller, 1988). Epidemics of bovine pleuropneumonia (BPP) and rinderpest killed cattle and wildlife in many areas in 1883–1891, and this was quickly followed by an epidemic of smallpox that devastated the human population in 1892 (Saitoti and Beckwith, 1980). Cattle raiding between different ethnic groups and between different sections of the same groups began shortly after the onset of rinderpest, and continued raiding of stock and crops exacerbated the social fragmentation precipitated by the smallpox epidemic. Drought followed, and the rains failed completely in 1897 and 1898. At this time, rinderpest reappeared and persisted, spreading south beyond the Zambezi river and resulting in severe famine across large areas of eastern and southern Africa by 1899, no doubt exacerbated within the context of developing antagonism between European settlers and many African communities (Ofcansky, 1981; Waller, 1985).

Following the onset of the colonial period (ca. 100 yr BP), human impact further intensified and resulted in major vegetation changes. Rainfall during the 1950s was well above average throughout the subtropics of both hemispheres, but the equatorial latitudes were comparatively dry. The inverse of this pattern prevailed during the 1960s, with exceptional rainfall in 1961 (Conway, 2002) leading to peak river discharge and peak levels for Lake Albert (Beuning et al., 1997; Sutcliffe and Parks, 1999), Lake Victoria (Kendall, 1969; Sene and Plinston, 1994), Lake Naivasha (Åse et al., 1986) and Lake Tanganyika (Nicholson, 2000) in 1963–1964. In the far eastern Sahel and eastern Africa, drought appears to have become more frequent and more intense during the same period (Graef and Haigis, 2001; Funk et al., 2013, Hoell and Funk, 2014; Nicholson, 2014). During the years 2008–2011, rainfall was 30–75% below average over the Horn of Africa, Kenya and most of the Sudan. Between July 2010 and June 2011 the situation was even more severe, with rainfall being at least 50–75% below average over nearly half of the drought-stricken region (Nicholson, 2014). Following the 2008-11 drought in eastern Africa, Kenya has seen a spectacular transgression of its Rift Valley lakes. By September 2013, lakes Naivasha, Nakuru and Bogoria had risen significantly, while

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Lake Baringo had reached levels not experienced since (at least) the early 1900s (Onywere et al., 2013). These examples appear to be part of a general trend towards increased interannual variability of rainfall over East Africa (Hastenrath et al., 2007, Hastenrath et al., 2010 and Kijazi and Reason, 2009).

3.3 Evidence for human change across the East African landscape

The ability of any particular landscape to support a human population depends on its capacity to produce carbohydrates and proteins (Bailey and Headland, 1991; Barnes and Lahm, 1997; Headland and Reid, 1989). The challenge of making accurate inferences about human history is extremely demanding and should not be underestimated - it requires the integration of archaeological, historical, genetic and linguistic data alongside palaeoenvironmental evidence (e.g., Gray and Atkinson, 2003). As with the synthesis of information derived from the accumulated sediments, a range of techniques is combined to reconstruct how cultures and societies have changed through time. This range of evidence varies from direct analysis of past occupation layers revealed by archaeological investigations and associated artefacts such as pottery, to documentary evidence. For example, traditionally in archaeology, ceramic artefacts have been used to establish patterns of regional and temporal succession of pottery styles, which are then used to trace the movements and interactions of different cultural groups, an intellectual history reviewed for East Africa by Ashley and Grillo (2015). However, this approach has been widely critiqued as archaeologists have long realised the limits of equating “pots and peoples” (Kramer, 1977; Lane, 2015a) and thus of using material culture as a proxy for identity and, by extension, migration (Ashley et al., 2016). Increasingly, alternative approaches have been taken to examining past population movements and interactions in East Africa, including technological analyses and geochemical sourcing of artefacts (e.g., Goldstein and Munyiri, 2017; Merrick and Brown, 1984), stable isotope analyses (e.g., Kiura, 2008; Chritz et al., 2015; Janzen, 2015), and modern DNA from people (e.g., Tishkoff et al., 2007; Henn et al., 2008; Tishkoff et al., 2009; Ranciaro et al., 2014) and livestock (e.g., Hanotte et al., 2002; Gifford-Gonzalez and Hanotte, 2011). These and other analyses show that the

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Holocene cultural record of East Africa is not characterised by neatly bounded developmental stages: rather, the human landscape of East Africa over the past six millennia was characterized by highly fluid economic and social “mosaics,”: landscapes of interaction between people with distinct subsistence strategies and cultural traditions (Kusimba and Kusimba, 2005; Crowther et al., 2017). This is exemplified by the fact that sites previously classified as terminal (Holocene) Late Stone Age (LSA), and those classified as Iron Age (IA, typically subdivided into the Early and Later Iron Age - EIA and LIA, respectively), two ostensibly distinct chronological and cultural stages, are often in fact contemporaneous with one another and found in the same geographic area (e.g. Ambrose, 1984; Helm et al., 2012). Indeed, in some cases the occupants of sites previously categorized as LSA or IA on the basis of their associated material culture and subsistence evidence are now known to have interacted (Shipton et al., 2013; Crowther et al., 2017). Assertions as to the date of a particular site based on artefactual evidence should thus be treated with caution, particularly within the older literature, and it is now clear that there is tremendous heterogeneity across space and time that defies these categorical definitions.

While studies of Holocene stone-using foraging and pastoralist societies in eastern Africa are documented primarily through archaeological evidence (reviewed below), studies of iron-using farming communities have relied much more heavily on the fields of historical linguistics (e.g., Vansina, 1984, 1995, 1999; Grollemund, 2015), and increasingly, modern population genetics (e.g., Tishkoff et al., 2009; Patin et al., 2017), in order to trace the spread of both farmers, and of Bantu languages, across the continent. Our understanding of this so-called ‘Bantu expansion’ has evolved from a vision of a neat “package” of crops, iron technology, and Bantu-language speaking peoples, to a disentangling of these distinct factors and their archaeological, linguistic, and genetic signatures, which are now understood not to move in tandem (as discussed by, for example, Hiernaux, 1968; de Maret 1985, 2013; Scheinfeldt et al., 2010; Crowther et al., 2017). Archaeology and especially archaeobotany have traditionally played a more limited role in our understanding of the *spread* of farming (but see Russell et

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al., 2014), which may be partially due to the lower visibility of these sites relative to those of stone-using peoples. A lack of archaeobotanical research in the region until recently (Giblin and Fuller, 2011; Walshaw, 2015; Crowther et al., 2016, 2017), is nevertheless also a significant factor.

Although the amount of data from archaeological studies has greatly increased, many gaps remain. These gaps in some cases reflect fashions in academic research, and in others result from pragmatic issues like ease of site access from major roads or settlements; factors that equally affect the distribution of palaeoenvironmental data, as discussed in Section 4 below. The coverage of archaeological surveys is certainly not comprehensive, as reflected in large blank areas on maps of site distribution (Figure 11), and is biased towards better-investigated regions, time-periods, and forms of evidence (like pottery or stone tools), with a ratchet effect whereby discoveries in one study area and dating to a particular time period tend to prompt additional searches for the same. The Pastoral Neolithic (PN) period, for example, is particularly well-known from the Central Rift Valley of Kenya, whereas the Early Iron Age (EIA) is better-documented in the Lake Victoria Basin and along the Indian Ocean coast; whether this reflects true distributions (and is thus informative about human choices), or results from sampling patchiness, is difficult to ascertain on present evidence. It is worth reiterating, however, that designations formerly regarded as distinct cultural-historical entities — terminal LSA, PN, and EIA — at least partially overlap in space and time, and distinctions between them are primarily based upon inferred subsistence and material culture traditions.

Recognisable pollen types related to human activities can also be a very useful addition to direct archaeological information, but pollen records are often a poor proxy for relatively subtle changes in vegetation (Marchant et al., 2004). An additional source is the modern biodiversity of plants used in agriculture, such as bananas and plantains: studies of the genetics of living specimens (and names given to them) can reveal histories of domestication and the rate, direction and timing of spread (Rossel, 1995). The cultivated crops commonly

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found in East Africa have distinct origin centres (reviewed by Fuller and Hildebrand, 2013; Crowther et al., 2017), with pearl millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*) originating in West Africa, finger millet (*Eleusine coracana*) most likely coming from the Ethiopian highlands, and sorghum (*Sorghum bicolor*) possibly from northeastern Sudan (Harlan et al., 1976; Harlan, 1993). Exotic crops such as Asian rice (*Oryza sativa*), banana (*Musa* spp.), Asian yam (*Dioscorea alata*), and taro (*Colocasia esculenta*) arrived via Indian Ocean exchanges (Boivin et al., 2013; 2014; Crowther et al., 2016). Macrofossils of maize (*Zea mays*) have been recorded from the Pare Mountains (Tanzania) and Lake Naivasha (Kenya) from approximately 250 yr BP (Finch et al., 2016), on the Laikipia Plateau (Kenya) by c. 200 yr BP (Taylor et al., 2005), and Munsa Swamp after c. 170 yr BP (Lejju, et al. 2005), indicating an exceedingly rapid spread of this crop from the New World to the Indian Ocean coast, from where it spread inland, presumably along established caravan trade routes. Tracing the histories of such plants is crucial as they can be intimately associated with human populations (e.g., Crowther et al., 2016). Evidence cited for food production and type of subsistence falls primarily within four categories; i) botanical and faunal remains from archaeological sites, ii) vegetation records obtained from perennially wet areas, iii) settlement characteristics including deposits of, for example, animal dung, and iv) genetic evidence from living crops and their wild ancestors (Neumann and Hildebrand, 2009; cf. Piperno et al., 2002). Other information on past human activity comes from a range of impacts and influences on the present-day ecological composition of vegetation communities.

Information on past human activities is often derived from sedimentary sequences based upon the assumption that major changes in human activities will impact upon the sediments by altering catchment conditions. Such records are often particularly sensitive to recording the environmental effects of human populations, particularly in sedimentary basins, since these both contain resources that attract human populations (water; deep soils) and allow for the accumulation of deep sediment sequences. Nevertheless, it may be that human actions are not commuted to the sedimentary record - an absence of human indicators does not

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mean humans were absent - but we should be wary of assuming that the onset of soil erosion, for example, can be readily equated with vegetation clearance, with all the attendant consequences such assumptions can have (e.g. Heckmann, 2011; for discussion see, e.g., Lane, 2009). Studies of sedimentary sequences from East Africa in general have tended to rely on relatively few proxy indicators of human impact such as certain pollen and diatom types, and the abundance of charcoal (Lejju et al., 2005; Rucina et al., 2010; Finch et al., 2016; Hawthorne et al., 2017). Fire, for example, is now recognised as an important agent of vegetation dynamics in tropical rainforests with humans clearly playing a major role in the distribution of vegetation communities on a global scale (Haberle and Chepstow-Lusty, 2000; Haberle et al., 2001). Thus, it is often assumed in East African palynology that the introduction of agriculture, in the absence of direct indicators such as pollen from domesticated plants, is marked by evidence of forest clearance and burning (e.g., Rucina et al., 2010; Finch et al., 2016).

This assumption may hold for some activities, but shifting cultivators often make use of natural forest gaps or move with sufficient regularity to allow forest recovery (e.g. Fairhead and Leach, 1996), and indeed some forms of agriculture could be said to promote tree cover, such as low intensity cultivation of oil palm (*Elaeis guineensis*), or the protection of trees to provide shade to crops grown within so-called ‘forest gardens’ (e.g. Stump and Tagseth, 2010). In other parts of the world, hunter-gatherers/foragers are also known to have used fire as a vegetation management tool (e.g., Head, 1996; Lightfoot et al., 2013).

This having been said, a reliance on charcoal as an indicator of human presence within landscapes can be problematic, as it ignores natural vegetation dynamics and the mass of evidence showing both that vegetation burns naturally and that fires are an important natural part of ecosystem change. For example, the Ahakagyezi and Muchoya swamps in southwest Uganda have yielded sedimentary records that extend into the last glacial period: samples from the entire span of sediments recovered have been analysed and each one has contained

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a significant amount of charcoal (Taylor, 1990, 1993). Indeed, on the basis of the charcoal record from Muchoya, fires appear to have been every bit as common at the end of the last Ice Age as they are today. Down-core fluctuations in charcoal abundance at Rusaka Swamp also show a similar pattern (Mohammed et al., 1996).

Pollen, similarly, can be a relatively blunt tool to trace human impacts: samples from Ahakagyezi Swamp suggest that 'regenerating' and 'stable' patches of forest co-existed throughout the Holocene (Taylor, 1993). There are a number of possible reasons for unexpectedly weak signals of human activity in pollen records. First, incompatible or loose chronologies may mean that researchers are looking for evidence in the wrong part of the sedimentary column. Second, some past societies may indeed have trodden lightly on the landscape, particularly where population densities were low and/or populations were highly mobile.

While it has long been argued that low population densities and/or high levels of mobility would also make pastoralist groups hard to see archaeologically (Smith, 2008), in fact a growing body of evidence demonstrates that pastoralist activities can be detected, often through micromorphological and/or geochemical approaches, as well as through analysis of microfaunal communities (Shahack-Gross et al., 2008; Muchiru et al., 2009; Weissbrod, 2011; Petek, 2015; Boles and Lane, 2016; Lane, 2016). Indeed, past generations of East African pastoralists left highly visible traces across the landscape, in the form of abundant stone tools and animal bone middens, as well as less visible but detectable traces of dung and ceramic scatters.

Of equal relevance to discussions of the detectability of change is the issue that human-induced alterations in some vegetation types, such as humid rainforest, may simply remain hidden in sedimentary records because the change was not sufficient to induce a change in the proxy. A good example of this is 'closed' (or amplifier) lakes in semi-arid parts of the

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region, since although these are the preferred locations for reconstructing past variations in effective precipitation, the nature of the ecosystems surrounding these lakes mean that the palaeoenvironmental proxies recorded in lake sediments may be very insensitive to change. Such systems might be sensitive to relatively small fluctuations in rainfall, therefore, but they may not record human impacts of low intensity. Indeed, it should be remembered too that the relevant part of the sediment column may be missing, either as a result of non-deposition or post-depositional erosion. Thus, sedimentary evidence, as with other sources of data, should be used with caution – an approach that will be adopted within this review.

The evidence for human change across East Africa will be presented in a series of steps that are identical to those of the environmental information, in order to enhance comparability. It should nevertheless be reiterated that the archaeological record does not fit easily into a series of stages, and especially for the latter half of this six-millennia period, mosaics of foragers and food producers, and later also including urban dwellers, defined the landscape (Kusimba and Kusimba, 2005).

3.3i Archaeological history from 6000 to 4500 yr BP

At the opening of our six-millennia review, the East African landscape was occupied by fishers and foragers associated with Late Stone Age (LSA) lithic technological traditions. While often viewed as indistinct, there is in fact tremendous diversity amongst Holocene LSA sites, both in terms of technological variability, and the settlement and subsistence strategies of their occupants. A key challenge to understanding this variability is the poor temporal resolution that characterizes much of Holocene archaeology in the region. In fact, there are extremely few radiocarbon dates falling within the 6000-4500 BP range (see SM2). Whether this reflects sampling patchiness, or a true decrease and/or dispersal in populations, remains to be understood. In this section, we discuss fishing and foraging traditions that both predate, and are thought to continue into, the sixth and early fifth millennia BP. Naturally, this review highlights the best-researched areas, and will regrettably overlook others where few or no

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sites have been documented. This patchiness may reflect research histories, rather than true distributions of people and their cultural traditions in any given window of time.

In the Turkana Basin, fishing communities are documented from as early as the Pleistocene-Holocene transition and are associated with almost exclusively aquatic fauna, bone points or harpoons, and at some sites, small numbers of ceramics (for reviews, see Stewart, 1989; Yellen, 1998; Prendergast and Beyin, in press); recently, a series of human remains recovered at Nataruk was interpreted as evidence of violent intergroup conflict amongst fisher-foragers of this era (cf. Stojanowski et al., 2016). Given that lake levels drop dramatically beginning c. 6000 yr BP (Garcin et al., 2012; Wright, 2014), one might expect such settlements to disappear. Unfortunately, radiocarbon dating remains seriously limited for the early Holocene sites, both in terms of contextual association and the materials dated, as discussed by Beyin et al. (2017). On current evidence, there are indeed very few fishing settlements extending beyond 6000 yr BP, other than isolated radiocarbon dates from GaJi3 at Koobi Fora (Barthelme, 1985) and Bb-14 at Lothagam Hill (Yamasaki et al., 1972). These fall into the sixth or early fifth millennia BP, as do some of the U-series dates on skeletal remains from the Nataruk "massacre" (Lahr et al., 2016). Whether these dates accurately reflect activities at these sites is open for debate, though we know that aquatic resource exploitation occurred in the Turkana Basin in the past two millennia (Robbins, 1980, 1984), continuing until today (e.g., Sobania, 1988). Concomitant with the mid-Holocene drop in lake levels, beginning as early as c. 5000 yr BP, this area also witnessed the arrival of the first livestock herders of East Africa. We discuss this phenomenon further below.

Additional LSA fisher-forager communities are found in the early to middle Holocene elsewhere in eastern Africa. Occupation levels with bone harpoons and fish remains at Ishango near Lake Rutanzige (Edward) in D.R. Congo (Brooks and Smith, 1987; Brooks et al., 1995) and at Gamble's Cave near Lake Nakuru in Kenya (Leakey, 1931) are both potentially Late Pleistocene in age rather than early-mid Holocene as originally thought. However, around

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Lake Victoria there are numerous sites dating to c. 8000-2000 yr BP, all sharing a type of ceramic known as Kansyore, as well as an aquatic subsistence focus and a quartz/quartzite-based lithic technology (Seitsonen, 2010). Kansyore sites are found in Uganda, Kenya, and Tanzania, nearly always near the shorelines or palaeoshorelines of Lake Victoria, or along its tributaries (reviewed by Dale and Ashley, 2010; Prendergast, 2010). Kansyore pottery has also been found in contexts associated with fishing in northwestern Uganda (Schmidt, 1997), and in rockshelters in grasslands and near a soda lake (Eyasi) in northern Tanzania, associated with foraging but little to no fishing (Mehlman, 1989; Prendergast et al., 2007; Prendergast, 2011). In these instances, occupations with Kansyore ceramics appear indistinct from roughly coeval aceramic LSA occupations at these and other sites in the region. The Kansyore chronology is problematic, and notably most sites fall on either side of the c. 6000-4500 yr BP window, raising the question of if and why there might be a hiatus in otherwise relatively unchanged ceramic and aquatic exploitation traditions. However, a handful of Kansyore occupations, including at Mumba Rockshelter where ceramics were directly dated, fall into this timeframe (Prendergast et al., 2014).

Away from lakes and rivers, foragers occupied rockshelters, and presumably undetected open-air sites, in the plains and highlands of East Africa throughout the Holocene (for a review, see Kusimba, 2013). The best-documented areas for Holocene LSA occupations are the Central Rift Valley of Kenya (Ambrose, 1982, 1984); Lukenya Hill in southern Kenya (Gramly, 1975; Bower and Nelson, 1978; Kusimba, 2002); the southeastern plains and coastal hinterland of Kenya (Abungu and Mutoro, 1993; Kusimba et al., 2005; Helm et al., 2012; Shipton et al., 2013); and the highlands and some lowland lake basins of north-central Tanzania (Inskeep, 1962; Odner, 1971; Masao, 1979; Mehlman, 1989; Prendergast et al., 2013). Some of these sites have dated samples falling within the 6000-4500 yr BP window, but the majority fall on either side of this gap. Superficially, many of these occupations seem similar: they are documented in rockshelters, sometimes with paintings that may or may not be associated; they share LSA lithic technologies, which have been little studied (but see

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Ambrose, 1984; Mehlman, 1989; Barut, 1994; Wilshaw, 2016); and their subsistence strategies include hunting of mainly large- and medium-sized game (Mehlman, 1989; Prendergast, 2011; Prendergast et al., 2013), though in more forested locations, trapping of smaller game was important (e.g., Ambrose, 1984; Marean, 1992). While other components of the modern hunter-gatherer diet do not preserve (honey) or have not been systematically sought (plants), it is likely that animal foods at prehistoric sites were part of a much broader diet.

The paucity of radiocarbon dates for both fishing and terrestrial hunting sites in the 6000-4500 yr BP window is notable, especially because many of the subsistence and technological traditions observed in the early Holocene are also observed in the later Holocene, and in one case (Kansyore) there are also very strong ceramic similarities on either end of this gap. At one site, the “Eburran” hunter-gatherer shelter of Enkapune ya Muto in the Central Rift Valley, this hiatus is very well documented within a long series of earlier and later dates, and might be attributable to site abandonment for higher altitudes as conditions became drier (Ambrose, 1998). At other sites, however, so few dates are available that it is difficult to know whether the gap c. 6000-4500 yr BP represents a sampling error or a true hiatus. What we can say is that on current evidence, it seems that populations at this time were living lightly on the landscape, employing subsistence strategies that are not expected to involve major vegetation clearance.

3.3ii Archaeological history from 4500 to 3000 yr BP

Beginning c. 5000 yr BP, East Africa witnesses the first appearance, and initially slow spread, of food production, as well as a continuation of fishing and foraging activities described above. This marks the beginning of the Pastoral Neolithic era (c. 5000 - 1200 yr BP; for reviews, see Bower, 1991; Gifford-Gonzalez, 2005; Marshall et al., 2011; Wright, 2014; Lane, 2013a; Lane, 2013b). Unlike other world areas, mobile livestock herding of cattle (*Bos taurus*), sheep (*Ovis aries*) and goat (*Capra hircus*), aided by donkeys (*Equus asinus*), preceded sedentary farming in much of prehistoric Africa (Marshall and Hildebrand, 2002). Increasing aridity in the Sahara

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during the mid-Holocene may have been the driving force leading to the southward movement of pastoralists into East Africa (Maslin, 2016). In this region, domestic caprine and cattle remains first appear in the Turkana Basin c. 4500-4000 yr BP at the site of Dongodien (GaJi4), and possibly at neighbouring GaJi2 (Marshall et al., 1984), and are associated with “Nderit” ceramics and LSA lithic technology. Elsewhere around Lake Turkana, from c. 5000 - 4000 yr BP, direct evidence of herding is present but scarce, and Nderit ceramics have been taken as a proxy for pastoralist communities. However, the scarcity of livestock remains likely reflects a lack of extensive excavation at habitation sites like Dongodien, rather than a true absence of evidence. Increased research at megalithic mortuary sites around Lake Turkana, many of which also have Nderit pottery, have clarified their chronology and more firmly link them to mobile pastoralism (Hildebrand and Grillo, 2012; Grillo and Hildebrand, 2013); at the site of Jarigole, clay livestock figurines may offer additional support (Nelson, 1995). Importantly, these megalithic mortuary sites, which were constructed relatively rapidly around the Turkana Basin, never extend beyond this area, despite finds of Nderit ceramics in central and southern Kenya and possibly into northern Tanzania (Gifford-Gonzalez, 1998). This slow start to the spread of pastoralism has been attributed to zoonotic diseases, aridity, and the presence of indigenous foragers or other social factors (Marshall, 1990; Gifford-Gonzalez, 2000; Marshall et al., 2011). The appearance of mobile herding around Lake Turkana coincides with dropping lake levels (Grillo and Hildebrand, 2013; Wright et al., 2015), and, as noted above, is possibly accompanied by a reduction in fishing sites and diversification of fishing strategies (Stewart, 1989), though this may be an artefact of uneven archaeological sampling. Fish remains continue to appear at sites with livestock, but barbed bone points and exclusively aquatic diets appear to all but disappear in the mid-Holocene arid period.

South of Lake Turkana, mobile herders appear in isolated occurrences throughout the fourth millennium BP, but direct evidence (i.e., livestock remains as opposed to proxies like Nderit pottery) is slim (Wright, 2014). At the Eburran forager site of Enkapune ya Muto in the Central Rift Valley, caprines appear in an otherwise wild faunal assemblage beginning possibly as early

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c. 4500-4300 yr BP and become common at the site by c. 3700-3200 yr BP (Ambrose, 1998). At Wadh Lang'o, a Kansyore site with later occupation phases near Lake Victoria, caprines and cattle appear after c. 4000 yr BP, again being minor components of otherwise fisher-forager assemblages (Prendergast, 2010); the same is true in the Kansyore horizons at the multi-period sites of Usenge 3 at c. 3500 yr BP (Lane et al., 2007) and Gogo Falls, where dating of domesticates is problematic (Robertshaw, 1991; Karega-Munene, 1993). Thus, the initial southward spread of livestock seems to be patchy and involving the agency of existing (fisher-)forager groups. Also in the early fourth millennium BP, forager occupations are well-documented, especially in the Rift Valley and adjacent highlands. It is remarkable that many of the Holocene LSA occupations of central Tanzania have radiocarbon dates primarily clustering around c. 4000 yr BP (Odner, 1971; Masao, 1979; Mehlman, 1989; Mjema, 2008; Prendergast et al., 2013; Prendergast et al., 2014). Given the small number of dates, this could be a sampling issue, but it remains a notable trend.

A recent review of the radiocarbon dating evidence suggests that, aside from the exceptions noted above, there are no sites with livestock beyond Turkana that predate the end of the fourth millennium BP (Grillo and Prendergast et al., in press). While Nderit pottery, like that of the Turkana Basin in the fifth millennium BP, does appear at multiple Kenyan sites (Gifford-Gonzalez, 1998, 2005), and possibly as far south as Lake Eyasi in Tanzania (Mehlman, 1989), these findings are scattered and not clearly associated with livestock. True PN sites, marked by abundant livestock remains, as well as novel ceramic styles and stone bowls, do not appear until after c. 3000 yr BP. This late date may be due to a heavy reliance at PN sites on bone apatite, a notoriously unreliable material for dating, as well as numerous problems of contextual association (Collett and Robertshaw, 1983). More recently obtained dates from PN sites in southeastern Kenya (Wright, 2005) and northern Tanzania (Prendergast et al., 2014; Grillo and Prendergast et al., in press) slightly predate the c. 3000 yr BP mark; re-dating more northerly sites is thus essential to reassess the tempo of the spread of herding. Indeed, the opening up of grasslands in Kenya and Tanzania after c. 3500 yr BP, as Rift Valley lakes shrank

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or disappeared altogether and forests receded, may have helped facilitate the spread of pastoralism, and this seems a more likely starting point for the spread of the PN (Lane, 2013a).

In summary, the period c. 4500-3000 yr BP is best characterized as one in which foragers and (in the Victoria Basin) fisher-foragers dominated the landscape, with livestock herding being mainly confined to the Turkana Basin, other than isolated occurrences. The latter seem to reflect a trickle, possibly involving the agency of foragers, of livestock moving south. One therefore assumes a marginal and highly localized impact upon vegetation that might be associated with grazing. However, renewed efforts at radiocarbon dating, and further palaeoecological work, have the potential to change this narrative.

3.3iii Archaeological history from 3000 to 1500 yr BP

The third millennium BP is characterised by the fluorescence of specialized pastoralism across much of East Africa, while foraging and fishing communities also continued to thrive, in some cases interacting with in-migrating herders. This widespread dispersal into the Rift Valley and grasslands of central and southern Kenya, and ultimately into Tanzania, is frequently viewed as a response to ameliorating climatic conditions, with rainy seasons becoming biannual, but rainfall itself less predictable (Marshall, 1990, 2000; Marshall et al., 2011). Both the number of PN sites, and the extent of research on them (particularly in central and southern Kenya), has enabled a relatively good understanding of the material culture, subsistence strategies, settlement patterns, and mortuary traditions of specialized herders of this era (Lane, 2013a; Lane, 2013b). These studies have enabled two broad groupings of the PN, both dating to c. 3000-1200 yr BP (Ambrose, 1984; Robertshaw, 1988). Elementeitan sites, found in geographically restricted areas of southwestern Kenya, are defined by distinctive and relatively uniform material culture and by consistent access to particular obsidian sources. By contrast, Savanna Pastoral Neolithic (SPN) sites are both more geographically widespread – from northern Kenya to northern Tanzania – and more variable in terms of ceramics, obsidian sources, and settlement patterns. It has been suggested that SPN heterogeneity could reflect

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localized adaptations to increasingly unpredictable rainfall and grazing conditions (Marshall et al., 2011). It must be emphasised that the distinctions between traditions both within the SPN, and between the SPN and Elmenteitan, remain fuzzy, as do distinctions between these and later Pastoral Iron Age (PIA) traditions, discussed in the following section, which date to c. 1900-1300 yr BP (Lane, 2013a, 2013b).

While the spread of specialized pastoralism is the most distinctive phenomenon of the 3000-1500 yr BP window, it is also spatially restricted: to date, no unambiguous PN settlements have been found near the Indian Ocean coast, for example, nor further west than the Nyanza area of eastern Lake Victoria. While recent discoveries extend the distribution of the PN southward (Prendergast et al., 2013), there is still no evidence that stone-using herders penetrated into central-southern Tanzania, despite strong genetic and, more debatably, archaeological arguments for connections between eastern and southern African prehistoric herding communities (e.g., Macholdt et al., 2014; Pickrell et al., 2014; Ranciaro et al., 2014; Russell and Lander, 2015).

Given this restricted distribution of early herders, it should be no surprise that interactions amongst people with different subsistence strategies and, presumably, group identities, were a defining characteristic of this era. It is also possible that fluidity in individual and group subsistence strategies, perhaps on a seasonal basis, results in sites that archaeologists interpret as evidence of interaction. Indeed, at the PN site of Prolonged Drift in central Kenya, seasonal pursuit of large migratory mammals, alongside herding, is well documented (Gifford et al., 1980). In the Turkana Basin, two post-Nderit ceramic traditions – Turkwel and Ileret – are associated with pastoralists who also consumed fish, and small sites associated with fisher-foragers have also been documented at this time (Robbins, 1984; Barthelme, 1985). However, dating and additional understandings of these sites remain limited. Turkwel ceramics are also documented from around Lake Baringo (Petek, 2015), where they have recently been dated to c. 1650-1500 yr BP at Oltioki (unpublished data, Nik Petek). In the

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Victoria Basin, Kansyore ceramics continue to be used until at least 2000 yr BP, and are associated with fishing, hunting, and increasingly, livestock keeping. Two sites – Gogo Falls and Wadh Lang'o – also have substantial Elmenteitan occupations lasting until c. 1700-1500 yr BP, with technological discontinuities in stone tool and pottery manufacture from Kansyore to Elmenteitan levels perhaps marking the arrival of specialized pastoralists from elsewhere. However, unlike their counterparts away from Lake Victoria, the Elmenteitan stock-keeping inhabitants of Gogo Falls and Wadh Lang'o hunted and fished substantially (Marshall and Stewart, 1995; Lane et al., 2007; Prendergast, 2010). While this was initially seen as an adaptation to more closed, tsetse-infested environments, recent isotopic work suggests the presence of open grasslands around Victoria-Nyanza during Elmenteitan occupations c. 2000 - 1500 yr BP (Chritz et al., 2015). Meanwhile, at rockshelters in the highlands of Kenya and Tanzania, the presence of domestic fauna alongside LSA lithics and limited numbers of ceramics may indicate temporary occupation of these environments by herders, or perhaps more likely, the incorporation of livestock into forager lifeways. Such zones of interaction are particularly well documented in the Central Rift Valley of Kenya (Ambrose, 1984) and the Eyasi Basin in northern Tanzania (Mehlman, 1989; Prendergast and Mutundu, 2009; Prendergast, 2011).

The spread of specialized pastoralism may have resulted in substantial but localized effects on vegetation and microfaunal communities, as indicated by a number of ecological and ethnoarchaeological studies (e.g., Shahack-Gross et al., 2003, 2004, 2008; Muchiru, 2008; 2009; Weissbrod, 2013; see also Boles and Lane, 2016). These studies highlight how pastoralist settlements can shape local ecodynamics - such as soil nutrient redistribution as a product of grazing-corralling cycles - with the implication that, for archaeologists, such effects offer investigative proxies for the ephemeral material residues associated with mobile communities. While methodologies for recognising and interpreting these ecological effects in the deep past are still in development, heterogeneity in soils and vegetation communities has been successfully linked to pastoralism at the PN site of Sugenya in southwestern Kenya, c.

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2000 yr BP (Shahack-Gross et al., 2008).

This window of time is marked by yet another arrival of food producers, in this case the makers of Urewe ceramics, which appear at sites in lacustrine and riverine environments around the Victoria Basin in Uganda, Tanzania, and Kenya, as well as in more forested and highland areas in Rwanda and Burundi (Desmedt, 1991). The earliest of the Urewe sites appear west of the lake beginning c. 2500 yr BP (e.g., Posnansky, 1969; Van Grunderbeek, 1992; Reid 1994), reaching the northeastern side (Nyanza) around c. 1800-1500 yr BP (e.g., Leakey et al., 1948; Lane et al., 2006; Ashley, 2010). In Nyanza, Urewe contexts frequently overlie Kansyore and/or Elmenteitan horizons, and contact between foragers, herders, and these newly arrived food producers is hypothesized (Robertshaw 1991; Lane et al., 2007; Ashley 2010), with the possible periodic formation of more stable cultural and economic frontiers between them (Lane, 2004). On the west side of Lake Victoria, there is also evidence for some degree of continuity between LSA and Urewe occupations (Reid, 1994). At some Urewe sites, there is evidence for metallurgy (e.g., Childs and Herbert, 2005; Schmidt, 1980; Schmidt and Childs, 1995), and it has been inferred, together with paleoecological data (see above), that iron production resulted in major changes to vegetation. For example, Giblin et al. (2010) describe a human burial at the site of Kabusanze, Rwanda, wherein finely-crafted iron objects, including jewellery were found in direct association with Urewe ceramics, also finely-made. The authors speculate that the craft specialisation this indicates may be related to agricultural expansion and food surplus during the early second millennium BP (see also Schoenbrun, 1998).

Even in the absence of evidence for metallurgy, Urewe ceramics are commonly taken as proxies for iron-working farming populations. This is also true of other Early Iron Age (EIA) ceramic traditions, thought to be related to Urewe: Kwale ware (Soper, 1967) is found at sites along the coast and coastal hinterland, occasionally in association with evidence of ironworking; a more poorly-defined variant, Lelesu, is taken as a marker of the EIA in north-

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central Tanzania (Mehlman, 1989). All of these EIA ceramics are traditionally linked with farming migrants whose origins lie in equatorial west-central Africa, the hypothesized homeland of Bantu languages. Such assertions were made in the absence of rigorous chronological and archaeobotanical evidence. However, it is now recognised that this so-called “Iron Age package” of Bantu languages, along with African cereals and iron technology, was not tightly packed at all, and that the physical migrations of people, and the disseminations of words, ideas, technologies, and crops, would have varied in tempo and scale (for recent linguistic and archaeological assessments, see Grollemund et al., 2015; de Maret, 2013; Crowther et al., 2017).

Archaeobotanical and archaeofaunal data from Early Iron Age sites, in both the Great Lakes region (Lane et al., 2007; Prendergast 2008; Giblin and Fuller, 2011) and along the coast in Kenya and Tanzania (Pawlowicz, 2011; Crowther et al., 2016a; Crowther et al., 2017), are now helping to disentangle subsistence, material culture, and identity. Unfortunately coastal EIA sites, compared with Middle Iron Age (MIA) sites, discussed below, have poor bone preservation, preventing a full discussion of subsistence strategies. An exception to this is Juani Primary School, where faunal and botanical data point to a strong marine orientation, with occupants reliant on shellfish and fish, with only occasional hunting and no unambiguous evidence of animal husbandry nor farming securely associated with EIA contexts (Crowther et al., 2016a), despite the presence of Kwale ware. In the Victoria Basin, fauna are well preserved at several sites with Urewe ware, and in each case there is little change from the mixed hunting, fishing, and herding strategies that were previously common in this area in association with Kansyore and Elmenteitan ceramics (Lane et al., 2007; Prendergast, 2008). Historical linguistic data further suggest that by the end of this period early Bantu-language speakers settled in the area had developed an integrated farming regime that included yams, oil-palm, a type of bean, and perhaps cowpea and Bambara groundnut among the root crops cultivated, and had also adopted sorghum and pearl millet and perhaps finger millet from neighbouring groups further north (Schoenbrun, 1993, 1998). The appearance of new terms

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around 1500 yr BP for ‘field’, ‘to weed’ and ‘to open land by clearing trees’, as well as terms for milking and bleeding cattle, also point to the development of additional agricultural and herding practices associated with an increasing domestication of the landscape (Schoenbrun, 1993).

3.3iv Archaeological history from 1500 yr BP to present

The past 1500 years in East Africa have been a remarkable time of economic and social change, with a dramatic increase in both the extent and intensity of agriculture, as well as the development of urban centres; the amplification of existing long-distance exchange networks; and the introduction of new actors and items of exchange. These developments have major implications for land cover change. While mosaics of people reliant upon fishing, foraging, herding, and farming define this era (Kusimba and Kusimba, 2005) - and to some extent continue to the present day - there is no doubt that over time, foraging populations shrank and agropastoral populations expanded. Environmental change has been a major driver of population movements within the past half-millennium, bringing new pastoral groups (such as the forebears of the Maasai) to the region and thus shaping ecological and social dynamics at the local level. During the last few centuries and particularly during the colonial era, resource extraction, the trafficking of enslaved people, agricultural commercialization, and infrastructure development were all important drivers of land cover change and, more broadly, of long-term environmental transformation.

Fishing remains are common in both the Lake Turkana and Lake Victoria Basins during the last two millennia BP, as seen at sites with Turkwel ceramics like Lopoy and Apeget (Robbins, 1980, 1984), and, as noted above, at sites with Urewe ceramics like Wadh Lang’o and Usenge 3 (Lane et al., 2007; Prendergast, 2008). In all of these sites, faunal remains attest to mixed herding-hunting-fishing economies, with herding varying widely in importance. While iron-using agropastoralists extended across much of East Africa during the Middle Iron Age (MIA; c. 1300-900 yr BP), the arid Turkana Basin appears to have been largely unaffected by the spread

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of both iron working and farming, and today the economic mainstays remain drylands mobile pastoralism (including camel pastoralism) and fishing.

Around the Lake Victoria Basin, iron-working communities became both numerous and intensive. Ultimately, in some areas these developed into increasingly complex societies and eventually states, as seen in Buganda, Rwanda, and Buhaya (Berger, 1981; Reid, 1994; 1996; 2013; Robertshaw, 1997; Robertshaw and Taylor, 2000; Schoenbrun, 1998). Distinct changes occur in the archaeological record to the west of Lake Victoria from around 1000 yr BP. These include the appearance of new ceramic styles, characterised by a preference for various kinds of roulette decoration along with changes in vessel form and size (Ashley, 2010), the rapid spread of which may even be indicative of the expansion and intensification of trade and exchange around Lake Victoria (Reid, 2013). Historical linguistic data point to a virtual 'explosion' of new terms associated with banana cultivation around the same times as these material developments, and also in the terminologies of herding and pastoralism (Schoenbrun, 1998), pointing to further elaboration and sophistication of food production strategies in the Great Lakes region. There is material evidence also for growing specialisation, including salt production at Kibiro on the eastern shores of Lake Albert (Connah, 1996), and in cattle herding at sites such as Ntuusi (also spelled Ntusi), occupied around 950-450 yr BP, situated in Mawogola, south-western Uganda.

Extending over c. 100 ha., but with deposits rarely more than 20cm in depth apart from two large mounds of occupation debris, Ntuusi was the focal point in the Mawogola landscape for almost five hundred years, and can be seen as being linked to an extensive network of smaller sites in the vicinity (Reid, 1994-1995). Faunal remains from Ntuusi indicate a focus on cattle herding from the initial establishment of the site onwards. Reconstructed mortality profiles indicate that most livestock were slaughtered at an extremely young age—a practice that would have been possible only with the existence of large herds (Reid, 1996, 2013). Storage pits, numerous grinding stones, some reaping knives and two clusters of carbonised sorghum

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attest to the importance of agriculture, that likely also included banana plantations, alongside cattle. The presence of a combination of working debris and finished ivory objects also highlights the significance of elephant hunting locally (Reid, 2015).

Based on the material evidence from Ntuusi, establishment of the site appears to mark the beginnings of a ranked society and socio-political complexity in this part of East Africa, laying a base from which various kingdoms later developed. A feature of some of the immediate political successors of Ntuusi was the construction of a series of deep encircling trenches around the central part of the occupation area, extending over several kilometres at some sites, as exemplified at Bigo bya Mugenyi (13km north of Ntuusi on the Katonga river), and at the site of Munsa in the more forested areas of western Uganda. Although massive, the configuration of these earthworks does not suggest they were principally defensive in nature, and they may well have served more political and symbolic roles associated with marking centres of power and ritual authority (Robertshaw, 2010; Reid, 2013). Although cattle dominate the faunal remains recovered from excavations at both Munsa and Bigo, the presence of several large grain storage pits at Munsa emphasise the importance of crop cultivation for at least some of these capital sites (Robertshaw, 1987), alongside the maintenance of banana plantations. The scale of the earthworks also point to an ability to pool the labour of fairly large groups and sufficient surplus production to feed this workforce, with likely environmental consequences. As noted above, for example, the pollen record and other environmental proxies for the period point to widespread forest disturbance and increased burning associated with this settlement phase (Taylor, et al., 2000; Lejuu, et al., 2005).

On current evidence, the earthwork sites appear to have been abandoned around 300-250 yr BP. Archaeological survey data also suggest a change from nucleated toward more dispersed settlement patterns at the village and homestead levels of the settlement hierarchy (Robertshaw, 1994). New capitals for the kingdoms of Bunyoro, Nkore and Buganda emerged,

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and reports compiled by the first Europeans to visit the Great Lakes kingdoms in the nineteenth century indicate that their capitals were sizeable settlements housing several thousand inhabitants, and structured by distinct spatial divisions based on class/occupation. However, a great many of these settlements were fairly short-lived, often occupied for less than a decade (Reid, 2013). Coupled with the preference for using wood, mud and thatch for house construction, and the damp, warm soils of the region, archaeological preservation, especially of the animal and plant remains that can provide information about insights into food production strategies and land use, is often poor. At present, only limited archaeological data are available concerning these capitals, with only two, the Nkore capital at Bweyorere and the Mpororo capital of Ryamurari, both occupied c. 350-250 yr BP, having been subjected to detailed archaeological investigation (Posnansky, 1968; Reid, 2013). These data are supplemented by a larger body of ethnohistorical information from linguistic, oral and documentary sources attesting to food-producing economies based on banana plantations and cattle herding (Schoenbrun, 1998) supplemented by arable cultivation of African cereal crops (Reid and Young, 2000). These same sources indicate continuing economic diversification, including specialised iron (Humphris, et al., 2009) and salt (Connah, 1996) production and kaolinite mining (Reid, 2003), and a flourishing regional exchange system, much of it by boat across and around Lake Victoria (Kenny, 1979). This period also witnessed growing political complexity, although not necessarily centralisation (Reid, R. 2003; Robertshaw, 2010), and by c. 200 yr BP aggressive military expansion of the more powerful states, especially Buganda (Reid, 2007), alongside greater religious and symbolic elaboration of kingship (Sassoon, 1983; Reid and MacLean, 1995). Various forms of enslavement, mostly for either internal domestic or agricultural purposes initially, but later also for external trade, are also well-attested across the interlacustrine region in both the oral and documentary historical sources for this period (Médard and Doyle, 2007).

On the eastern side of Lake Victoria, the archaeological characteristics of MIA farming and herding communities are poorly documented. Scattered traces are known from archaeological

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surveys around the lake margins and along the major rivers draining into the lake (e.g. Robertshaw, 1991; Lane, et al. 2006), and from material recovered from the upper horizons of excavated PN and EIA sites, such as Gogo Falls and Wadh Lang'o. Oral histories of the Luo, who are the main inhabitants of this area today and speakers of a Western Nilotic language, suggest that relatively small groups of clan-based, mixed farming-herding-fishing communities established themselves around the lake margins from around 560 yr BP in a series of phases, moving in from areas further north and west (Ogot, 1967; Cohen, 1983). According to these histories, settlement was initially around Got Ramogi Hill and Yala Swamp, before expanding across the Uyoma peninsula and southwards around the Winam Gulf and into what is now Migori County, SW Kenya by c. 300-200 yr BP (Ogot, 1967; Ochieng', 1974; Herring, 1979). A single archaeological site identified in these oral histories and containing roulette-decorated ceramics similar in form and design to ethnographically documented Luo pottery has been excavated. Known as Usare 1, the site comprises a series of three low occupation mounds with shell-midden deposits close to the current lake edge at the southern end of Asembo Bay. Dated to c. 430-300 BP, faunal remains recovered from the site suggest a mixed fishing and cattle-based herding subsistence economy (Lane, et al., 2006). Subsequently, the practice of enclosing individual homesteads and larger villages within earthen bank-and-ditch enclosures (*gunda buche* in the Dholuo language) became common in the areas north of the Winam Gulf, with over 60 examples now known (Odede, 2008) and likely many more have been destroyed by farming since the early twentieth century. Only one of these, Lwak, has been excavated. Finds from the site suggest a mixed agropastoral economy, with a similar range of crops (sorghum, millet, beans, maize) and livestock (cattle, sheep, goats, chicken) as described by the first European visitors to this area of western Kenya (e.g. Johnson, 1902). Intriguingly, the ceramics from the lowest levels of the ditches exhibit typological similarities to MIA pottery from the area, lending support to certain clan histories that suggest some enclosures were founded by the Bantu-language speakers the Luo encountered as they moved into the area.

South of the Winam Gulf, enclosures were typically built using drystone walling (*ohinga*, pl.

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ohingini, in Dholuo). The larger and better preserved of these contain one or more stone-walled livestock enclosure with traces of house-platforms and grain-bin foundations arranged concentrically around the inside wall (Lofgren, 1967). Some have drystone walls and droveways arranged in a spoke-like fashion around the main enclosure, creating a series of radiating agricultural plots. Stone terracing is also evident at some sites. Over 135 of these stone-walled enclosures are known. Nearest Neighbour and Cluster Analyses of their distribution and topographic setting, indicate a preference for hill-top and upper slope locations close (typically ≤ 3km) to a permanent water source (Onjala, 2003). They also tend to occur in distinct clusters, with the highest density around the site of Thimlich Ohinga, and elsewhere in Macalder district, Migori County. Thimlich Ohinga is the largest and best-preserved example, dated to c. 280-110 yr BP (Wandibba, 1986). Faunal remains from this site attest to the herding of cattle and small stock, with fish and wild game supplementing local diets. Grain-bin foundations, and upper and lower grinding stones indicate the importance of crop cultivation. By the late nineteenth century, quite a diverse range of crops were being grown. Johnson (1902, 787), for example, noted that the Luo cultivated sorghum, sweet potatoes, peas, eleusine, pumpkins, tobacco and hemp; there are also references to sesame, green gram, beans and speckled maize in some of the other documentary and oral sources. There is no supporting archaeobotanical evidence from these sites at present, however.

In the Rift Valley of Kenya and Tanzania, evidence of early farming is nearly absent, other than at the Pastoral Iron Age (PIA) site of Deloraine, c. 1200 yr BP. This site is remarkable for an apparently unique ceramic tradition as well as having, until recently, one of the few direct signs of agriculture in the form of a single finger millet grain (Ambrose, 1984; Harlan, 1992; Sutton, 1993; Sutton 1998a). This and neighbouring PIA sites, such as Hyrax Hill (Leakey, 1945; Sutton, 1987; Kyule, 1997) are interpreted as possibly emerging from later Elmenteitan communities, and later gave rise to a distinct form of permanent settlements known in the literature as "Sirikwa holes" or "hollows", after the depressions formed at their centre. The distribution of Sirikwa sites covered much of the Western Highlands of Kenya, extending into the central part of the Eastern Rift Valley as far as Lake Nakuru, with over 200 individual Sirikwa sites documented that together span the period from c. 750 to 150 BP (Sutton 1973; Sutton, 1987; Davies, 2013). Excavations have shown that Sirikwa sites comprised one or more individual homestead consisting of a central livestock enclosure around which were grouped a series of houses and other structures (interpreted by some as guard huts), with a single entrance into the enclosure that could be closed off (presumably at night and during times of conflict to protect the livestock and occupants from animal and human predators). The food-producing economy of these sites varied; in the drier areas of the Rift Valley, such as at Hyrax Hill and Lanet, more emphasis was placed on livestock herding, whereas sites in the wetter Western Highlands, as at Chemagel, more emphasis may have been placed on crop production (Posnansky, 1957; Sutton, 1993; Kyule, 1997), although much more systematic archaeobotanical, bioarchaeological and geoarchaeological research is needed at these sites to determine the range of crops exploited, the relative balance of herding versus cultivation and the overall nature of land use around these sites.

As noted above, in the central Eastern Rift Valley, traces of late PN Turkwell activity are quite widespread around the southern end of Lake Baringo. In contrast, diagnostic traces of PIA communities are relatively scarce, limited to inconclusive traces of settlement activity and to a few scatters of Lanet pottery (c. 1050-250 yr BP) and a single occurrence of Kisima ceramic (c. 500-250 yr BP) (Petek, 2015). Wetter than present conditions between c. 750-150 yr BP are suggested by various palaeoenvironmental records for the region, and it is possible that the consequent decrease in C4 grasses and an increase in woody and shrubby vegetation may have encouraged an expansion of tsetse flies, reducing the overall suitability of the areas around Lakes Baringo and Bogoria for livestock herding. A major dry spell centred around 350 yr BP resulted in a significant reduction in the size of Lake Baringo (Kiage and Liu, 2009), and is likely also to have had a significant impact on local livelihoods, possibly encouraging settlement abandonment and a shift to hunting and gathering (Petek and Lane, 2017). This was followed by another major drought of a sub-continental scale around 150 yr BP (Bessems

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et al., 2008), causing major socio-ethnic disruptions resulting in the formation of new ethnic groupings and both an animal and human depopulation of the Baringo basin until c. 120 yr BP (Anderson, 2016; Kiage & Liu, 2009). One of the new ethnic communities were the Il Chamus who, after the conditions ameliorated, practiced large scale irrigation farming on the lowlands south of Lake Baringo, though stock-keeping and hunting remained part of the economy (Anderson, 2002; Petek and Lane, 2017). They lived in densely settled villages with activities concentrated around nearby well-watered areas, expanding and intensifying their irrigation system between 130 and 70 yr BP due to the increasing population resulting from immigrant destitute pastoralists from the Central Kenyan Rift and Laikipia and due to the arrival and intensification of the caravan trade. The surrounding Baringo-Bogoria lowlands were seasonally utilised by various pastoralist groups such as Il Doijo and several Maasai sections (Anderson, 2002; Petek and Lane, 2017).

To the west of Baringo the end of the Sirikwa society appears to have led to the formation of what are now two distinct communities - the Pokot and Marakwet - in the Kerio Valley and northern Cherangani. Both communities appear to have first commenced land clearance and begun using irrigation around 250 yr BP (Davies and Moore, 2016), and both formerly used pottery styles suggesting a cultural affiliation with Sirikwa traditions (ibid.). Between c.200 and 150 yr BP the ancestors of the modern-day Pokot split into an agricultural and a pastoral faction, whereafter the agricultural Pokot expanded southwards from the drier lowlands to the well-watered highlands in the Cherangani hills (Davies, 2008), with the pastoral sections becoming more mobile and eventually employing rangelands that extended eastwards into Baringo and into what is now Uganda (Davies and Moore, 2016). Irrigation and the construction of terraces for homesteads and agricultural fields is a feature of crop production among the Marakwet and agricultural Pokot, but prior to c. 100 BP both communities had very dispersed settlement patterns based on individual households, and agricultural plots associated with these households are likely to have been relatively short-lived (Davies, 2008); a point that is essential in reconstructions of historic landcover since even ‘intensive’ systems

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of agricultural production need not lead to extensive or permanent land clearances. These agricultural communities in the Rift Valley occupied relatively niche locations, growing mainly finger millet, sorghum, leafy greens, and legumes (Davies and Moore, 2016; Petek and Lane, 2017). As the agricultural Pokot were moving south, the faction that would become the pastoral Pokot received a significant influx of immigrants from western Turkana and Karamoja in Uganda, likely due to the previously mentioned sub-continental drought. Though oral history records that most of the newcomers and the Pokot ancestors mainly practiced mixed subsistence economies, the community reorganised itself around a specialised pastoral lifestyle and a society centred around cattle, and rapidly expanded to exploit the patchily spread resources from Karamoja to the Leroghi Plateau and north of Lake Baringo by about 100 yr BP (Anderson and Bollig, 2016; Bollig, 2016; Bollig and Österle, 2013). About 50 yr BP, Il Chamus and Tugen would also become predominantly pastoral communities.

Vegetation conditions on the adjacent Laikipia Plateau to the east may have been more favourable for pastoralism over much of this period. Archaeological surveys and excavations indicate a significantly higher density of PIA surface scatters relative to PN remains (Siiriäinen, 1984; Causey, 2010; Lane, 2011), suggesting an increase in settlement across the Laikipia Plateau and the Ewaso Basin more generally. Charcoal and fungal spore records recovered from different palaeoenvironmental sampling sites on Laikipia Plateau point to increased burning and higher herbivore densities from c. 1650-650 yr BP, corresponding with a steady replacement of Afromontane vegetation by woodland and bushland taxa (including Capparis, Acacia, and Grewia) in the pollen record (Taylor et al., 2005; Muiruri, 2008), indicative of an expansion of open, disturbed savanna habitats typically associated with pastoral land use. Only a handful of sites for this period have been test-excavated. These include two large pastoral encampments: the Maasai Plains site near Loitigon Vlei in the northwestern part of the Plateau, occupied around 635-330 yr BP, and Maili Sita (also spelled Mili Sita) in the Lolldaiga Hills in the southeast, occupied c. 280-100 yr BP (Lane, 2011; Boles and Lane, 2016). Faunal assemblages from both sites indicate an emphasis on raising cattle and to a lesser

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extent sheep and goats, supplemented by hunting wild game. There is evidence also from different parts of the Ewaso Basin for localised iron smelting (Larick, 1986; Iles and Lane, 2015) using titanium-rich magnetite soils exposed through erosion, and indeed it may be significant in terms of ecological impact that the smelting techniques used were comparatively fuel-efficient (Iles and Martinón-Torres, 2009). Hunter-gatherers also continued to exploit this landscape, although competition for land and other resources suggests that these groups may have been increasingly encapsulated from c. 300 yr BP (Herren, 1987). Oral historical sources nevertheless indicate close interaction between some hunter-forager and pastoralist communities, with certain hunter-forager groups (or clans within groups) likely providing honey and pottery (Bernsten, 1976; Grillo, 2014) and perhaps also elephant ivory in return for livestock and other pastoralist products. Faunal remains recovered from excavations at Shulumai Rockshelter in the Mukogodo Hills suggest a hunting strategy oriented toward exploiting small species such as hyrax, dik-dik, and bushpig, supplemented by small numbers of domestic cattle and sheep or goats, with the eventual adoption of fully pastoral livelihoods and identity around 200 yr BP (Mutundu, 1999; Cronk, 2004).

Archaeological surveys and excavations in the Mara plains in southwest Kenya also attest to the dominance of pastoralism in this area (Robertshaw, 1990), despite the continuing human and livestock disease threats posed by tsetse fly. Changes in pottery styles link the area to PIA communities further north, while iron smelting was adopted by some sections of these communities (Siiriäinen et al., 2009). In the Lake Simbi area, western Kenya, pollen and other palaeoenvironmental data point to the practice of low-intensity, slash-and-burn subsistence agriculture, probably including some small-scale cattle herding, eventually giving rise to a mosaic landscape of small farm fields, pasture and regenerating natural vegetation (Lamb et al., 2003). In southeastern Kenya, around the Amboseli Basin and in the Taita-Tsavo area (Kusimba and Kusimba, 2005; Kusimba et al. 2005), similar mixed mosaics of farmers, herders and hunter-gatherers existed, and were linked through systems of reciprocal exchange and exploitation of different ecological niches and economic specialisation. Unusually, however,

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no evidence of iron production has been recovered in Amboseli despite extensive surveys (Foley, 1980; Anna Shoemaker, unpublished data), perhaps suggesting that the low-rainfall in the Amboseli basin and surrounding environs has always made this area marginal for crop production. As international demand for elephant ivory grew, initially around 450 yr BP from China and India, and subsequently from Europe and North America especially after c. 110 yr BP (Beachey, 1967), the Amboseli area may have experienced significant reduction in elephant numbers, although at present it is difficult to discern the scale and ecological impact of these extractions. A parallel increase in the demand for slaves to feed Red Sea and Indian Ocean markets over the same period likely also contributed to shifts in settlement locations to more defendable higher ground, as documented around Mt Kasiagau, Tsavo, and also probably caused disruption to local food-production economies (Kusimba, 2004).

The extraction of slaves and ivory from inland areas like Amboseli relied on the ability to provision trade caravans, and this was evidently achieved in northern Tanzania by skirting the well-watered highlands of the Usambara and Pare Mountains and of Mt Meru, Mt Arusha and Mt Kilimanjaro. Human occupation of these highlands has a long history, and although archaeological data is patchy it would appear – as one might expect – that communities always favoured the comparatively wet southern and eastern slopes and foothills of these mountains. On Kilimanjaro, for example, it seems from archaeological surveys and chance finds of artefacts that the north-western slopes were used by pastoralists in the period spanning 4500 to 2500 yr BP (Stump and Tagseth 2009), and indeed land-use in this area remained primarily seasonal grazing until the introduction of wheat farming in the twentieth century (Odner, 1971b). A variety of sources attest to farming on the southern and eastern slopes from at least 1000 BP. These include multiple finds of Iron Age pottery types (e.g. Odner, 1971b) that are commonly found elsewhere in association with agriculture (first Kwale ware and then Maore Ware from c. 1300 BP), as well as historical linguistic and oral historical evidence suggesting occupation in the early first millennium BP by the Maa-speaking Ongamo, who grew finger millet and sorghum, and raised livestock (Nurse, 1979; Ehret, 1984). The date

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by which bananas were introduced into these highlands is still unknown, but De Langhe et al. (1995) used the number of species variants now farmed on Kilimanjaro and the adjacent Pare Mountains to estimate local use of the crop since at least 1000 BP, while Montlahuc and Philippson (2006 63, citing Rossel, 1998) argue that the crop could not have been introduced until the area became incorporated into long-distance trade networks with the Indian Ocean and beyond after c. 1250 BP. The onset of soil erosion in the North Pare highlands from the early 2nd Millennium BP can, however, be plausibly linked to clearance of land of agriculture (Heckmann, 2009), and there is no reason to believe that similar small scale clearances for shifting agriculture were not also taking place in the other highland areas in the Eastern Arc Mountains. Increases in the scale and intensity of soil erosion in North Pare in the early first Millennium BP (Heckmann, 2009) correlates well with radiocarbon dates on some iron working furnaces on the lower footslopes of the mountains (Odner, 1971a; Iles et al. forthcoming), while the commencement of more severe soil erosion from c. 350 BP coincides with radiocarbon dates from a larger number of iron smelting and smithing furnaces from Pare, and with oral historical evidence from both Pare and Kilimanjaro suggesting that settlements and irrigation structures were already established at this time (see Stump and Tagseth, 2009 and references therein). Oral historical sources – in some cases with support from archaeological data – strongly suggest that similar process where taking place at about the same time in South Pare (Sheridan, 2002), Usambara (e.g. Feierman, 1990), and Meru (Spear, 1993); for an overview of which see Stump and Tagseth (2009). In very general terms then, land-use on the well-watered slopes of the highlands of northern Tanzania can be characterised as being based on the cultivation of grains and bananas since c. 350 BP, but it is not until the establishment of some degree of local political centralisation and the intensification of the caravan trade from c. 110 BP that the landscape started to resemble that of open fields and tree-shaded banana plantations evidenced today.

Farther to the south in Tanzania, elaborate terrace and irrigation systems are observed in the Manyara basin and at the base of the Crater Highlands, most notably at the site of Engaruka

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(e.g. Sutton 1984; Stump 2006; Westerberg et al., 2010). Radiocarbon determinations indicate that parts of the 2000 hectares of agricultural fields and associated settlements at Engaruka were in place by 650 yr BP (summarised in Westerberg et al., 2010), while historical sources demonstrate that the site was entirely abandoned by the 70 BP, and by inference abandonment probably occurred – likely gradually rather than by mass migration – in the period of c. 200 - 150 BP (Sutton, 2004). The construction of the field system and its attendant network of irrigation channels and canals were elaborate, with large parts built by capturing sediments eroded off adjacent high ground (Stump, 2006; Lang and Stump, 2017). This suggests severe soil erosion occurred in adjacent areas, with removal of vegetation being the likely trigger, though the extent of this removal and whether it had a human or climatic origin is the subject of on-going work. Attempts have been made to relate the development of the field and irrigation system to palaeoclimatic shifts evidenced from sediment cores from the nearby lake Emakat (Westerberg et al, 2010). Taken together the combined evidence from the site indicates an emphasis on cereals (Sorghum and Pearl millet), but the quantities and age profiles of animal bones recovered from excavations of the settlement areas (e.g. Robertshaw, 1986) suggests that some cattle and small stock were kept on or near the site, which in turn suggests the economy required access to grasslands outside the more intensively cultivated area.

Although in many cases not well dated, the use of irrigation and/or agricultural terracing was not restricted to the communities at Engaruka and those and in the highlands of northern Tanzania and the Kerio valley of Kenya; gazetteers and brief discussions of which are presented for this region and beyond in Adams and Anderson (1988), Grove and Sutton (1989) and Widgren (in press a and b). Most of these are small in scale and/or of low intensity until 150 BP or later, but are nevertheless significant for mapping both land-use and landcover, since it now seems increasingly clear that an economic focus on relatively intensive crop production required access to broader pastoralist resources, and indeed that highly specialised forms of pastoralism required regular contact with settled agriculturalists (e.g.

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Häkansson and Widgren, 2014).

On the coast and in the coastal hinterland, a large number of sites appear during the MIA, though some of these -- such as the above mentioned Juani Primary School site (Crowther et al., 2016a), and Mgombani in the hinterland (Helm, 2000) -- also had substantial EIA occupations. At these and other MIA sites such as Fukuchani and Unguja Ukuu on Zanzibar, there is clear archaeobotanical evidence for farming, mainly of African cereals such as sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), and finger millet (*Eleusine coracana*), as well as the cowpea (*Vigna unguiculata*) (Crowther et al., 2017). However faunal exploitation is highly variable from one site to the next, as recently reviewed by Quintana Morales and Prendergast (in press). For example, faunal remains from the Zanzibar sites point to a continuing marine orientation, with fish forming a key part of the diet, followed by hunting of terrestrial game, especially at Fukuchani; at Unguja Ukuu, management of caprines and chickens is a key part of the economy, alongside wild terrestrial and marine fauna (Prendergast et al., 2017). In contemporaneous contexts at Shanga, in the Lamu archipelago, domestic animals form the bulk of the diet (Mudida and Horton, 1996). Systematic archaeological surveys of several areas, including the area between Mombasa northward to Mida Creek, on the central Kenya coast (Helm, 2000), along the lower Pangani valley, NE Tanzania (Walz, 2010), around Kilwa (Wynne-Jones, 2007) and Mikindani (Pawlowicz, 2011) in southern Tanzania, and on Pemba (Fleisher, 2003; Kessey 2003) all indicate a trend toward an increasing density of rural settlements and the filling out of the landscape, likely due to demographic growth.

During the MIA and continuing into the Later Iron Age (from c. 900 yr BP), urban centres (commonly known as stone towns, an allusion to coral-rag architecture) develop along the coast and islands, where they served as important entrepôts for the exchange of goods from the interior to the coast, and from the coast and islands to the broader Indian Ocean maritime world (Horton and Middleton, 2001; Boivin et al., 2013; Wynne-Jones, 2016). This trade is

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evident in the arrival of new crops, including Asian rice (*Oryza sativa*), mung bean (Vigna radiata), and coconut (*Cocos nucifera*). While Asian crops appear during the MIA at sites such as Unguja Ukuu on Zanzibar (Crowther et al., 2016b; Crowther et al., 2017), on Mafia (Crowther et al., 2014) and Tumbe on Pemba (Walshaw, 2015), they -- and especially rice -- become more abundant after c. 900 yr BP, as evidenced, for example, at Chwaka on Pemba (Walshaw, 2010, 2015). Apart from this localised shift towards rice agriculture, sites remain mostly dependent on local crops, and on small-scale agriculture and household-level production. This suggests a relatively circumscribed area of farmed land around the towns, which would account for the regionality of subsistence practices in coastal towns, drawing on local crop regimes and practices (Walshaw 2015).

Settlement growth is consistent, although not evenly spread, along the coastal strip throughout the MIA and LIA. From c. 900 yr BP to 400 yr BP many hundreds of sites with coral architecture are known from Somalia to Mozambique. Many were very small, and their ‘urban’ status might be a matter of debate, but overall the settlement pattern reflects a consistent trend towards permanent, settled, life along this strip. There are certain centres of population, notably on the offshore islands and archipelagos of the coast (Lamu, Zanzibar, Mafia, Kilwa). Here, agricultural land beyond the town (and on the mainland opposite coastal island groups) would have been drawn into cultivation; although archaeological evidence for this is slight, the agricultural hinterland of coastal settlement is well documented historically and may have been based on a slave economy (Vernet, 2015). Overall, this would have contributed to a transformation of the coastal strip, with the large-scale clearance of coastal forests and increasingly dense settlement as the LIA proceeded. As urban centres developed, faunal evidence for increasing ratios of domestic stock and chickens point to the intensification of food production within the towns (reviewed by Quintana Morales and Prendergast, 2017), but also perhaps to the development of regional procurement networks. Specialized fishing technologies are employed to catch larger and more dangerous prey, including sharks, in open waters (Quintana Morales, 2013) as a more explicitly maritime socio-

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cultural orientation also emerged (Fleisher et al., 2015).

The relationship between this coastal urban development and interior regions of East Africa remains poorly understood, particularly with regard to economic intensification or changes in land use and labour relations (Lane 2010, 2014). A handful of studies have explored the inland networks to which coastal towns were connected and a variety of relationships of trade and production have been documented. Yet all have demonstrated continuity of land use, regional population and subsistence practices. The Tana Valley of northern Kenya (Abungu and Muturo, 1993), the Pangani Valley of northern Tanzania (Walz, 2010), and the deep hinterland of Mikindani in southern Tanzania (Pawlowicz, 2012), were all occupied throughout the MIA and LIA by village communities practicing small-scale agriculture; each was connected with the urban development of the coast periodically or continuously, but without significant effect on subsistence practices. In southern Kenya research has found evidence for foragers and agriculturalists connected with the coast in a ‘mosaic’ of peoples and practices (Kusimba et al., 2005).

In 453 yr BP, the Portuguese explorer Vasco da Gama’s small flotilla entered the Indian Ocean and sailed up the East African coast before crossing to India (Russell-Wood, 1998). This event ushered in a period of coastal domination, and yet along many parts of the East African coast the presence of the Portuguese would have been hardly noted, if at all, by the vast majority of the local population. Other, non-Western, non-African powers and actors also played active roles in shaping the economies and social dynamics of the East African coast over the next 500 years – including the Ottoman Empire in the 16-17th centuries, Omani Sultanates in the 17th-19th centuries, and various Indian merchants and financiers who had long been engaged in trade along the East African seaboard (Pearson, 2005; Alpers, 2013). The material traces of a Portuguese presence on the East African coast are also quite limited. On Zanzibar, trading posts (*feitorias*), that were simultaneously warehouses, markets and customs offices, were established during the sixteenth century at Mvuleni, Fukuchani, and at the Gereza in Stone

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Town, where a cruciform church was built. Another church survives almost intact in Malindi, which was closely allied to the Portuguese, who also established an unfortified *feitoria* here and erected a stone cross to commemorate their landfall (Finneran, 2002). Their main settlement, however, was on Mombasa Island, which became their centre of political authority and commercial operations after 1590 (Kirkman, 1974; McConkey and McErlean, 2007). Unfortunately, little is known archaeologically about either the colony settlement known as 'Gavana' that the Portuguese established just north of Fort Jesus, or the local town of Tuaca, on the south-western tip of the island, which was occupied from at least the twelfth century and is believed to have been abandoned in the sixteenth century after the arrival of the Portuguese.

The establishment of small Portuguese enclaves may well have further encouraged a degree of commoditization of food production in coastal areas so as to supply growing urban communities and passing ships. However, the available Arab and early modern European sources indicate that surplus food production for regional exchange was already established prior to the arrival of the Portuguese. Perhaps the most significant, albeit long-drawn out, consequence of the establishment of a Portuguese presence on the east African coast (unlike in Mozambique, where their influence on local economies was rather more substantial), was the introduction of North American domesticates, particularly maize and tobacco, but also other crops such as potatoes and sweet potatoes, although the timing, rate and directions of their spread in East Africa remains under-researched. Even less is known regarding the introduction of New World diseases, especially syphilis and polio, among local populations, although their impacts were far less than the well-documented devastation caused by the introduction of Old World diseases into the Americas.

The assumption of Omani political and economic control over the coast strip from c. 210 yr BP until the establishment of European colonial rule over the region, seems to have had a greater impact on land use in the coast region. The combined consequences of an increased demand

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for supplies of elephant ivory and slaves (Beachey, 1967; Sheriff, 1987) seem also to have created a more profound shift in interior landscapes. The most obvious material traces of Omani authority comprise a number of forts constructed at strategic locations on the coast and offshore islands and their modifications to pre-exiting Portuguese forts (Pradines, 2004). In terms of land use, a significant change came with the development of plantation agriculture, notably for cloves in the Zanzibar archipelago (Croucher, 2014) and sugar on the mainland, with associated transformations in the nature and extent of slavery and slave raiding (Kusimba, 2004, 2014; Lane, 2013b), from c. 100 yr BP onwards. A further, and related factor was the growth and transformation of caravan trade during the nineteenth century, supplying increased demand for elephant ivory in Europe and North America (Coutu et al. 2016). The consequences of this trade were enormous, and the effects on elephant populations and ecologies have been widely discussed. Thorbahn (1979) and Håkansson (2004), for example, charted how the increase in ivory trade would have transformed interior landscapes as elephant stocks on the coast dwindled and traders travelled further inland. To some extent this has been confirmed by archaeological analysis of historical ivories, which suggest an absence of coastal elephants (Coutu et al., 2016). As elephant populations themselves have profound effects on ecologies, this could have led to an opening up of woodland across a large swathe of East Africa and might, in turn, have led to changes in agricultural practice as people exploited these new landscapes (Lane, 2010).

The caravan trade itself created new landscape regimes, as areas like the Lake Baringo region were turned over to crops to supply the caravan trade, by the Il Chamus group who has previously had a pastoralist economy (Anderson, 2002; Petek and Lane, 2017). Historical records also document an intensification of agricultural extraction around the newly created centres built along Tanzanian caravan routes, such as Tabora or Ujiji, based largely on a slave economy (Rockel, 2006). Yet the few archaeological studies that have explored these regions have also highlighted continuity (Wynne-Jones, 2010; Biginagwa, 2012). For example, caravan halts in the Pangani Valley have revealed evidence for continuity in local subsistence practices,

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based on a mixed economy of cattle, hunted fauna, and fishing, despite a growing engagement with coastal trade. The local Zigua communities do seem, however, to have been farming maize (Biginagwa, 2009).

4 Environmental-human interconnections: linking environmental and human variability

Humans have long distinguished themselves by using tools and technologies to shape East Africa's ecosystems so that today, like many places in the world, the landscapes of East Africa are imprinted with a legacy of past anthropogenic activity. There are numerous challenges to investigating the interaction between environmental and cultural change. One of the key challenges is apparent when we plot the palaeoecological and the archaeological sites together across Eastern Africa; we can see there is a large disconnect in the location of these (Figure 16). Indeed, there are only a few sites where the palaeoecological and the archaeological insights are from the same location. Most notable where there is coeval insights from the same location is Munsa in Uganda (Leijju et al., 2005, 2006): this site has yielded interesting insights into changing land use and the character of these including cultural transitions relating to crop types used, forest clearance methods employed, particularly the use of fire, and how the timing of some of these transitions appear to be synchronous with rapid phases of environmental change (Lejju et al., 2006; Robertshaw et al., 2004). However, this site has also attracted considerable controversy regarding very early evidence of the possible presence of banana (Fuller et al., 2011), particularly within the archaeological community (Fuller and Boivin, 2009; Neumann and Hildebrand, 2009). Other locations, where palaeoecological and the archaeological sites have been studied together have provided great insights, but are more diffuse. This is particularly well exemplified from the Lake Turkana catchment where the changing nature of the lake as it responded to environmental change has impacted directly on the cultural use of the catchment. For example, extensive lowering of lake levels during the mid to late Holocene exposed large previously inundated lake deposits (Garcin et al., 2012) that supported rich pasture and provided a conduit for the movement of pastoral communities into the East African region

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(Gifford-Gonzalez, 1998). A further example where this linkage has shown promise comes from Laikipia, where cores taken from the Loitigon Vlei floodplain were considered with respect to new and existing archaeological and historical data, including investigation of the nearby Maasai Plains archaeological site (Taylor et al., 2005). The study linked vegetation change and evidence of burning during the last millennium to pastoralist landscape modification with the aim of extending pasture and epizootic control, and suggested that prolonged spells of aridity might have fostered the expansion of stock-based production in the region.

As mentioned above, the spatial disconnect between palaeoecological and archaeological sites mitigates against direct comparison between the evidence for environmental and cultural history and, as such, the ensuing descriptions entail a degree of uncertainty. In keeping with the presentation of the palaeoenvironmental data and the evidence on human history, the interconnections between the two sources of information will also be presented within the same time periods.

4.1i Environmental-human interconnections 6000-4500 yr BP (Figure 16A and 16E)

After the early Holocene warming and associated rise in lake levels (Stager et al., 1997; Stager and Johnson, 1997; 2000; Verschuren et al., 2010), the period from 6000-4500 yr BP marked a change to more arid conditions (see Section 3.2). This change has been seen through a transition in vegetation from forests to open grassland, and also directly through shoreline reconstructions at Lake Turkana where a significant lowering of the lake levels occurred at around 5300 cal yr BP (Garcin et al., 2012). The archaeological record for the early part of this period is generally scarce with the majority of finds consisting of evidence of harpoon bone and fish bones around the lakes in the region (Phillipson, 1986, 1988, 2005). Garcin et al. (2012) note that the main mid-Holocene cultural transition appears to be closely related to the timing of the documented ~ 50 m fall in lake water-level in the Turkana Basin from around 5300 yr BP. They suggest that the shrinking of the lake exposed large areas (~ 10,000 km^2) of

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silts conducive to the grazing of animals, which in turn, coincides with the beginnings of pastoralism in the area. However the radiocarbon dates from the earliest archaeological evidence for pastoralism at the sites around Lake Turkana, e.g., Dongodien (GaJj2), Koobi Fora Ridge (GaJj2) (Owen et al., 1982) and FwJj5 (Ashley et al., 2011) suggest that there was an initial lag following this pronounced environmental change and then a gradual take-up of pastoralism in relation to this newly available land. This potential of a temporal lag is further supported by Tierney et al.'s (2013) observation for the Tanganyika basin whereby the terrestrial ecosystem has an inertia or resilience in responding to climatic stress, and vegetation change appears to have contributed to abrupt hydrologic change; although there are uncertainties due to dating precision and intercomparison. Whilst a general trend towards a warmer and drier environment occurred in East Africa from this period onwards, vegetation change was often nonlinear, highly variable spatially and appears to have been dependent on specific ecosystem resilience to aridity at the local and regional scale (Willis et al., 2013).

The environmental and archaeological evidence for this period would suggest that people were reacting to the changing availability of resources as the climate changed, albeit slowly and after an initial lag. For the period 6000-4500 yr BP, archaeological research has focused around lakes (Figures 12 and 16) (Barthelme, 1985; Karega-Munene, 1993; Beyin et al., 2017). How people responded to the increasing aridity in areas away from large bodies of water is largely unknown, and whether this spatial clustering is real or a result of targeted fieldwork is an area for future investigation.

4.1ii Environmental-human interconnections 4500-3000 yr BP (Figure 16B and 16F)

Around 4000 yr BP a distinct drying phase occurs in the ice core evidence from Mount Kilimanjaro (Thompson et al., 2002), which is also correlated to similar events across tropical Africa (Marchant and Hooghiemstra, 2004) between 4100-4300 yr BP. A major drying event around 4200 yr BP has been widely detected and dated, and linked to a series of droughts that were responsible for events such as mass extinctions on Mauritius (de Boer et al., 2015).

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Archaeologically, during this period we see an expansion of pastoralist activity (Coughenour and Ellis, 1993). However, there is a significant caveat to assessing the impact that severe drought events may have as the palaeoenvironmental and archaeological records may not be well enough resolved (in terms of chronology and sampling) to detect these short-term, but intense, events**.** Where it has been possible to examine the impact of this, it has been within a closed island system and with animals who are not able to escape those conditions (e.g., de Boer et al., 2015), whereas people will arguably move to new areas. Whilst we may be seeing this with the expansion of pastoralism in East Africa at this time, as pastoral populations expanded farther southwards from an increasingly dry Sahara, finding the direct chronological and environmental link between people and the climatic events is still elusive.

4.1iii Environmental-human interconnections 3000-1500 yr BP (Figures 16C and 16G)

Evidence suggests that the general drying of the climate seen in the preceding periods continued during 3000-1550 yr BP. Simultaneously during this time there is a cultural shift, where we start to see evidence of iron working within the region, initially to the west of lake Victoria (e.g., van Grunderbeek et al. 1982, 2001; Schmidt, 1997a). This technological shift is of particular importance when discussing the relationship between people and their environment, because it is arguably the first time that people affected the environment around them as much as climate had done in preceding periods. This human impact on the vegetation is often assumed to have been caused by the need for fuel in the iron production process (Bayon et al., 2012; Bostoen et al., 2015) and the forest clearance for building and agricultural expansion to support a [rapidly] growing population (Taylor et al., 1990). Evidence for these causal effects is extremely limited, however, and the direct impact from iron smelting was probably minimal, the real link to deforestation being that iron arrives with farming and enables vegetation clearance for agriculture. Charcoal assemblages from excavated iron working sites in Buhaya, to the west of Lake Victoria show a change from exploiting wet forests that were known to have grown on the edges of the water around

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1950-1750 yr BP, however, by 1550 yr BP this had changed to taxa associated with secondary regrowth and swamp areas; a change also loosely corroborated in the pollen record (Schmidt, 1997b). Another example can be seen from the Pare Mountains in northern Tanzania, where increased erosion is recorded in the sedimentary records from 2000 yr BP, which correlates well with the arrival of agriculture and ironworking in the area (Heckmann 2011; Heckmann et al., 2014). Pare was a centre of iron production from at least from at least c. 1100 yr BP and several iron smelting and smithing furnaces in North Pare have been excavated. Archaeometallurgical research on samples recovered from these sites suggest that the industry was relatively fuel efficient, despite some variations in raw materials selection and smelting technologies over time. More critically, it is clear from the geoarchaeological studies that soil erosion had been initiated prior to the intensification of smelting activity that nevertheless continued well into the modern era (Iles et al., in press).

In the examples above, the benefits of multi-proxy studies are made clear, especially when these include evidence of both cultural activities and environmental change and more so when there is direct evidence of environmental exploitation by people through the charcoal and geoarchaeological record. More often than not, we are left with only one of those types of evidence and forced to make inferences to nearby studies that can be of a very different context. This can and does lead to heated debates about causes of environmental change (e.g., Maley et al., 2012; Bayon et al., 2012). How we bring datasets together to determine the ecological consequences of human activities in different environmental settings - whether these datasets are in close proximity to each other or over larger areas - is a wider issue (Marchant and Lane, 2014).

4.1iv Environmental-human interconnections 1500 yr BP to the present (Figures 16D and 16H)

The evidence from both the archaeological and palaeoecological records (with the addition of historical evidence for the later part of this time period) is most numerous and for the latter

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most complete and at the highest resolution than for any other period under review here. Regardless of this increased body of evidence, the environment of the past 1500 years is characterised by a highly variably hydroclimatic regime (Nash et al., 2016). In the more western sectors of the East African plateau, the driest conditions of the entire Holocene seem to have been registered already around 2000 years ago, followed by a modest long term wetting trend since then (Nash et al., 2016). Lake levels fluctuated by 10s of meters over decadal timescales. In addition to inundating or exposing low-lying areas around the numerous East African lakes, this hydrological change also resulted in expansion and contraction of swamp forest (Rucina et al., 2010). In addition to mean change in hydrology it is most likely this period of climate variability was characterised by shifts in seasonality of rainfall that would have, as today, impacted on farming communities. Pastoral populations would have been able to buffer their livelihoods against this climate variability and change by migrating to new pasture (Waller, 1985); such a system of transhumance would have been severely challenged under periods of rapid onset of aridity. One such period associated with large-scale movement of cattle and culture is associated with the arrival of the ancestor's of the Maasai into East Africa from more northerly locations. It is thought the Maasai's ancestors and their cattle migrated into East Africa in the 16th century (Galaty, 1993) - a period of relatively dry climate as recorded across the East African region from Lake Turkana to Lake Tanganyika (Nash et al., 2016). This ability of pastoralists to migrate in response to environmental challenges has been increasingly curtailed, especially by processes of land enclosure, protected area expansion and rangeland fragmentation, culminating in the situation today of limited grazing options and enhanced vulnerability (Pfeifer et al., 2012). Sedentary farming communities would also have to cope with this period of climate variability and shifts in seasonality of rainfall. This coping ability would have been helped by an ever expanding number of crop types initially based on African domesticated tubers and cereals, supplemented by a wide range of leafy greens and arboreal species, with increasing exploitation of non-African domesticates introduced from across the Indian Ocean and, post-Columbus, the Americas (Fuller and Hildebrand, 2013). These last two locations have

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provided the source for two of the most common staple food crops across the region - maize and plantain bananas (McCann, 2007). In addition to bringing in new crops, contact with the Americas and an increasing influence of global traders fueled the exploitation of the region initially focused on slaves and ivory, between c. 500 yr BP and 50 yr BP (Alpers, 1975; Austen, 1988; Beachey, 1967; Sheriff, 1987). As well as resulting in a significant reduction in the size of East African elephant populations from the millions to the tens of thousands (Milner-Gulland and Mace, 1991), which in turn would have had a number of ecological consequences (Håkansson, 2004, 2007; Lane, 2010), the caravan routes associated with the trade provided conduits for the passage of new crops, technologies, the movement of people and wealth, the restructuring of labour, and the transition to a service food-producing economy (Koponen, 1988). This transition may have resulted in extensive agricultural expansion focused along the main trade routes from the coast through to the interior of the East Africa, as has been argued by Håkansson (e.g. 2004). It should be emphasised that the recent period has not just been characterised by increasing human impact. For example, a extensive Rinderpest famine around 120 yr BP known to have decimated pastoral herds and the lives of their pastoral communities, resulting in a relatively depopulated and green landscape that provided an atypical impression of what East Africa was like to early colonial governments (Kjekhus, 1996).

Over the past century there has been a growing population across East Africa (Klein Goldwinke, 2010), some of this indigenous, but also as a result of large influx of immigrant populations. These increasing mobile flows of people, goods and services, combined with population growth and associated land use changes have led to a general degradation of the landscape including stripping of vegetation and major soil erosion (e.g., Snelder and Bryan, 1995; Johansson and Svensson, 2002). Intensive agriculture was introduced, for example, to the Loboi Plain and the Amboseli about 50 years ago, and cultivation has increased as more of the population has switched to subsistence farming. This seems to be a common trend throughout East Africa as traditional transhumance practices, increasing climate variability, and access into markets have made a sedentary farming a more profitable livelihood.

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4.2 Temporal and spatial gaps in the data and ensuing impact on extrapolation.

Geographic gaps in sampling effort also need to be addressed, and in some cases, new exploration of geoarchives adjacent to archaeological sites is necessary to assess their palaeoenvironmental potential in areas with no lacustrine or palustrine deposits. Rather than just producing new research findings from the different disciplines, it is time to pause and identify innovative trans-disciplinary projects that integrate archaeology, paleoethnobotany, archaeozoology, physical geography and ecology (Eggert, 2005). The palaeoecological record shows that there is a fairly even spread of sites across all four periods albeit with an increased number of sites towards the most recent period (Figures 9 and 16A-D). The number of archaeological records increases quite dramatically with an increase in the number of sites towards the present day, particularly along the coast (Figure Figure 12 and 16E-H). Interestingly, for both the archaeological and the palaeoecological sites, the distribution is concentrated in certain locations - for the latter this follows where suitable coring locations / sedimentary archives exist, which tends to be around lakes and swamps and does not change through the analysis presented here. For archaeological sites there is a concentration along the coast, along the present-day road network and around key locations (Figure 15) whereas large areas, such as southern Tanzania and northeastern Kenya, remain relatively under explored. The archaeological evidence does however show a change in the location of sites through time - notably on the coast there is an expansion as the Swahili trade developed with the Middle East and trans-Indian Ocean locations (Wynne-Jones, 2016). Whilst this may represent the choices of people in the past, we should keep in mind it is potentially also reflecting the choices of people in the present as well. These choices may reflect themes that are currently of interest to the research team and also choices of publication method. There are considerable numbers of artefacts produced by the practicalities of conducting fieldwork, with many reported sites being close to present day road networks (Figure 15). Particularly interesting sites may have had multiple studies conducted on them; for example Engaruka was first visited by L.S.B. Leakey on his way to Olduvai in 1935 and then worked on by a

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succession of scholars (e.g. Leakey, 1936; Sassoon, 1967; Sutton, 1978; Robertshaw, 1986; Sutton, 2004; Stump, 2006; Westerberg et al., 2010). There is also a difference in the visibility of the research: almost all of the palaeoecological and climatic research that has been undertaken in East Africa is dated and published in mainstream journals. Whilst the same can not be said of contemporary or historical archaeological research, a lot of work has been undertaken more locally and also by amateurs and antiquarians in the past, both of which are undated and unpublished, or not easily accessible in their current format, hence the need for the creation of a digital database of archaeological sites and monuments for the region as a whole.

4.3 Harmonising datasets and interlinking databases

Data are presented in a multitude of ways and are stored in different real and virtual locations with independent structuring. Although this can improve visibility and local accessibility, it highlights the need for common standards and appreciation of the potential use and application for other disciplines and by non-specialists. The growth of archaeological and palaeoenvironmental data is rapidly increasing, with new techniques allowing previous interpretations and contexts to be revisited. This growth highlights the need and requirements for data archiving, accessibility, and on-demand visualisation of complex datasets for multiple end user audiences. The use of these data should not be exclusive to the realm of scientific enquiry, but should be made available to a broader audience in the private and public sectors, non-governmental organisations, and private citizens for research, context, policy and management guidance, entertainment, education and training (Courtney-Mustaphi et al., 2014; Keeso, 2014). Certain types of metadata and data that have yet to be thoroughly archived are at risk of disappearing or having reduced efficacy or scientific usefulness. The highly dispersed nature of these datasets covering East Africa means that previous syntheses (Mgomezulu, 1981; Ambrose, 1984; Courtney-Mustaphi and Marchant, 2016) and palaeoenvironmental databases (Marlon et al., 2016) remain incomplete and some are relatively static with few updates - a situation this current compilation from East Africa will

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aim to resolve for the region, and feed into the Global LandCover6K (Galliard et al, 2015a).

5 Application of perspectives on 6000 years of land use change across East Africa

One of the key rationales for conducting this review was to explore the linkages between our current understanding of land cover change and human interaction for the past 6000 years, and to examine the potential wider applications of such past insight into contemporary issues. Such potential application falls within a wide and increasing number of areas but we will focus on four diverse examples: developing methodologies for further understanding human/environment interactions, ecosystem and climate modelling, ecosystem services and biogeochemical cycling, and finally conservation and sustainable development. The range of topics have been chosen so as to highlight the potential breadth for the utility of these combined datasets, and the insights they can produce for a range of disciplines.

5.1 Developing methodologies and understanding of human environmental interactions

Clearly, understanding human interaction with environment change can be of relevance to society, politics and the economy, but to fully utilise these insights and incorporate them into future trajectories, we need to understand and integrate long-term perspectives (Crumley, 1994; Gillson and Marchant, 2014). We have shown above how sedimentary sequences can contribute to our wider understanding of environmental history in East Africa, especially for periods when the instrumental records are relatively short and incomplete. Although the utility of this work and the potential application is clear, we have also seen that at times the records appear to contradict one another, or can not provide the resolution of data that is needed to answer the question in hand. Further research is needed to more fully understand the processes that have led to the sediment formation (e.g. taphonomic processes), how we approach these records as researchers (e.g. addressing issues of sampling resolution and chronological control) and how we integrate these records with data, and into models, created by other disciplines.

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Clearly there are geographic gaps in sampling effort (note concentration of sites depicted in Figure 15) that also need to be addressed, and in some cases new explorations of geoarchives adjacent to archaeological sites are necessary to assess their palaeoenvironmental potential in areas with no lacustrine or palustrine deposits. A set of related challenges in dealing with archaeological and palaeoenvironmental data entails the differing chronological scales under consideration while trying to deal with the seasonal to annual response of farming communities and the decadal to centennial scale resolution of palaeoenvironmental study. This is often reflected in the different implicit meanings of commonplace phrases, such as 'long-term', 'sustainable' and 'resilient', which may be understood by scholars from different disciplines in quite different ways (Stump, 2010; Bollig, 2014; Lane, 2015b).

There are also practical challenges that need to be addressed, as well as methodological and conceptual issues. For instance, currently most pollen records have a temporal resolution >50 years that does not permit a thorough investigation of the timing and impact of changes due to human populations. However, by employing high resolution analysis in conjunction with robust chronology construction it should be possible to make interpretations at the scale of a human lifetime (Bayliss 2009), and to link records and engage with issues that are specifically relevant to historians, geographers and anthropologists (Harberle and Chepstow-Lusty, 2000). This is only achieved by the careful selection of samples initially, gaining a larger number of radiocarbon determinations, utilising other fine scale Pb^{210} and ^{137}Cs radiometric chronologies to the upper sections of cores (e.g., Ssemmanda et al., 2005; Gillson 2006; Finch et al., 2016) and employing predictive (as well as retrospective) Bayesian age-depth modelling techniques to provide more robust and precise estimates for radiocarbon determinations (e.g., Öberg et al., 2013; Courtney-Mustaphi et al., 2016).

To fully understand the interactions between environments and people a perspective that combines *in situ* site-specific studies and explores the spatial relationships with existing

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archaeology and palaeoecology insight is fundamental (Ekblom, 2012; Ekblom, et al. 2017). The mélange of information preserved in sedimentary cores can be complicated due to climate change and human activity operating in tandem; identifying cause and effect is highly challenging with current approaches. There is thus a pressing need in studies of late Holocene sediment cores for the careful selection of sites and for a full consideration of all factors that are likely to have affected the proxies and also forced change in the conditions within the catchment areas of sedimentary basins. Many new methods are available for use on sediment cores, but they currently remain the exception in East Africa, rather than the norm. These include, the analysis of plant macrofossils (Birks and Birks, 2000), grass cuticles, phytoliths (Alexandre et al., 1997), non-pollen palynomorphs (Ekblom and Gillson, 2010; Ejarque et al., 2011), and a suite of developing geo- and bio-chemical techniques through chemical archaeology (Crowther et al., 2017).

As documented in this review, there is an increasing amount of palaeoenvironmental and archaeological information from East Africa (Figure 15), and as the datasets continue to increase in both quality and quantity, it also becomes necessary to develop new theoretical models that are conceptualised to accommodate both types of information that are acceptable to all disciplinary perspectives (Bird et al., 2005), as well as the wider ontologies of the disciplines that produce the data, as they sit within both the sciences and the humanities (Mazzocchi, 2006). Will we never know exactly how people in the past perceived their environments, or the changes that occurred within them, but documenting the evidence of these complex interactions between people and the environment, understanding the mechanisms by which the signals of activity are recorded in the sedimentary records and working to theoretically combine different types of evidence (Richer and Gearey 2017) are some of the first steps to be undertaken before we can fully start to inform current and future responses to conservation and land-use strategies.

Towards this goal, a number of categorization schemes have been developed in order to map

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and quantify land use across space and time, whether on global (e.g. Morrison et al., 2016; Phelps and Kaplan, 2017; Widgren in press) or regional scales (Kay and Kaplan, 2015; Widgren in press). As part of the project *Mapping Global Agricultural History*, which aims to map agricultural development at the global scale during the last millennium (Widgren, 2010), Figure 19 presents a slightly revised excerpt from a continental map covering sub-Saharan Africa published by Widgren (in press). Here, the focus is not on land cover *per se*, but on the delimitation of the dominant global agricultural systems in the sense of Whittlesey (1936) and Grigg (1974). Land use/land cover within each polygon can thus be varied, but at a general level there is co-variation between type of agricultural system and land use/land cover. Within this project seven such broad categories of agricultural systems have been identified globally (1-7) (Widgren, in press). The category "Extensive or undifferentiated agriculture" (3 on Figure 19) refers on the one hand to areas where agriculture is known to have been extensive (e.g. slash-and-burn), but also to areas where agriculture is known to have existed, but its character is not yet documented. Further subdivisions of these seven categories have been made for Africa (Widgren, in press).

Similarly, the ACACIA project (Kay and Kaplan, 2015) is working at the sub-Saharan scale and is combining archaeological data from published studies to produce categories and maps of land use at different time periods. These categories and maps will then be used to drive the human element in coupled human-environment models that are presently additive and do not represent the pulsed, and sometime rapid, nature of change (Figure 20). Preliminary classification relied on existing socio-cultural categorizations and showed how the land use footprint of a society can be quantified at various scales based on their diet, technology, and economy (Kay and Kaplan 2015). Subsequent work has looked at the specific effects and terminology used to describe pastoral societies (Phelps and Kaplan 2017), and focusing on mapping specifically agricultural livelihoods in West and western Central Africa (Kay et al., in prep), although the methodology used and many of the categories could easily be applied in East Africa. An emphasis in this work has been to acknowledge the multi-scalar nature of the

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data and how this impacts on the ensuing reconstruction. For example, the presence of a particular domestic crop in a region does not mean that the only land use was farming. Many of the livelihood categories incorporate farming to varying degrees, and the evidence indicates that there was a mosaic of livelihoods, and therefore land uses, present in the landscape at any one time. By approaching the human-environment interaction in this way, it is hoped that a better understanding will be gained about how humans have not just responded to, but also influenced the environments of sub-Saharan Africa over the last several thousand years.

5.2 Linking palaeoinfomatics with Climate and ecosystem models

In addition to improving our ability to reconstruct and understand the processes of past environmental change, and to explain mechanisms that might be responsible for such variability, there are many potential benefits of combining data-based with model-based interpretations of change (Jolly et al., 1998a). An understanding of past environmental history is crucial for both providing context into regional climate change assessments through to validating global and regional climate model simulations when these are hind-cast (Braconnot et al., 2012). Africa is cited by the Intergovernmental Panel on Climate Change as a continent where proxy-based climate reconstructions are currently too limited to support regional climate change assessments (Masson-Delmote et al., 2013); with the increasing desire for long-term regional climate models, this makes the need for proxy evidence of environmental change even more pressing. Climate models are *the* tools used to understand the future climate of the Earth. There are some 18 General Climate Models (GCMs) used throughout the world that have been developed by different governmental institutions, such as the Hadley Centre in the UK; NASA, GFDL, and NCAR in the USA; and JAMSTEC in Japan. Although these different climate models are based on physical laws of thermodynamics, how they are implemented and how they consider land surface feedbacks and ocean-atmosphere-land interactions varies considerably from model to model. As a consequence, regionally-specific temperature and precipitation reconstructions can vary tremendously across the various

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models and predictions, which tend to rely on multiple ensemble GCM outputs under different scenarios of Greenhouse gas concentration (Hitz and Smith, 2004; Monerie, 2012). Added to this are the numerous discrepancies between modelled and data-based views of past climate variability in East Africa. For example, changes in the African monsoon strength have long been a subject of considerable research interest (e.g. Harrison et al., 2001, 2003), with particular attention being given to the most recent period of maximum extension and intensity of the northern monsoon domain, the so-called African Humid Period, which took place between 14,800 and 5500 yr BP (*sensu* deMenocal et al., 2000), and which caused a 'greening' of the Sahara (Claussen and Gayler, 1997; Hoelzmann, 1992; Hoelzmann et al., 1998). Many modelling studies conducted in northern Africa currently underestimate the apparent amplitude of change during this period (Braconnot et al., 2012, Harrison et al., 2015; Perez-Sanz et al., 2014). Similarly, there is uncertainty about the rapidity of the expansion of the Sahara from the mid Holocene and the role that people may have played in this (Hoelzmann et al., 2001; Wright et al., 2017).

Progress towards improved modelling skills, and a better understanding of the mechanisms that drive abrupt changes in climate, should be expected from both the climate modelling and palaeoenvironmental communities as increasing use is made of palaeoclimatic data sets to provide context for anthropogenic warming (Braconnot et al., 2012; Clark et al., 2002). One of the current problems encountered when it comes to the application of modelled outputs has been a discrepancy between the observed and the predicted, this is because vegetation and climate often change in nonlinear fashion, instead being affected by cycles, pulses, and reversals caused by factors such as soil moisture, vegetation change and albedo feedbacks; and the relationship between the three (Friedlingstein et al., 2006; Ganopolski et al., 1998). One of the other key areas for future GCM development is to incorporate vegetation changes and how such changes may feedback to the climate system (Foley et al., 1998; Doherty et al., 2000; Richardson et al., 2013; Chevalier et al., 2017). Within Africa, rapid switching between wet and dry phases has been linked to positive feedbacks in the changes in vegetation, soil

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and albedo (Claussen, 1997; Claussen et al., 1999; Knorr et al., 2001; Friedlingstein et al., 2006). Additionally, increasing in land surface albedo, caused by anthropogenic vegetation change, can also produce similar feedback processes that ultimately result in climate change (cf. Kutzbach et al., 1996; Doherty et al., 2000). An East African example of the albedo effect can be seen in the conversion of savanna grassland mosaic to a semi-desert environment. This has resulted in significant changes to surface dynamic parameters such as albedo, surface roughness, leaf area index, and fractional vegetation coverage. Collectively, these have altered water and energy exchange between the ground surface and the atmosphere, which in turn has affected the timing and intensity of the monsoons (Lamb et al., 1989; Claussen, 1997; Claussen et al., 1999; DeMenocal et al., 2000).

Given this importance of land cover for influencing Holocene weather and climate patterns in East Africa, and the growing recognition that human activities are at least as important as climate in causing land cover change, especially over the last 3000-4000 years, there is a growing realisation that more comprehensive and thematically resolved information on human systems is required to drive the next generation of Earth System models. More and better data about how people have influenced African landscapes in the past will ultimately lead to an enhanced predictive capability and an improved match between model-based and data-based reconstructions of past climate and environments. At present, those Earth System models that take anthropogenic land cover change into account generally rely on simple model-based scenarios of a poorly defined single variable called “land use” from e.g., the HYDE or KK10 scenarios. These scenarios are generally additive views of land cover and population change that tend to do a poor job of reflecting the nature and magnitude of land use and anthropogenic land cover change, particularly in Africa. Indeed, a key rationale for the wider PAGES LandCover 6K initiative - into which the data behind this review will contribute - is to provide data-based global surfaces of land cover at 6000 yr BP, 500 yr BP (AD 1500) and 150 yr BP (AD 1800) relating respectively to the mid Holocene ‘optimum’, latest pre-colonial period, and the latest pre-industrial times. These global surfaces of land cover will then

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provide a data-based test of GCMs (Gaillard et al., 2015; Morrison in press).

As changes in land-use and land cover can significantly affect how the planet functions and in particular that they can cause changes in local and regional climates (Claussen and Esch, 1994; Chase et al., 1999) they both have implications for understanding how the ecosystem in the past, present and future has supported and can support human needs (Vitousek et al., 1997). An important aspect of the recent Framework Convention on Climate Change, hosted by the United Nations in Paris towards the end of 2016, was the development of plans to integrate climate change perspectives into new policies and programs that aim to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change. The currently anticipated changes to the planet's climate poses threats to biodiversity and natural resources, human health, food and water security, public health, natural resources and biodiversity (Swallow et al., 2009). Clearly models that investigate the impact of future change on our ecosystems, crop systems (Thornton et al., 2007), and the ensuing potential of nature-based solutions for development, have to be testable. As with the GCMs, the only temporal data to provide such a test of model performance are those data sets generated from the past such as presented here.

In addition to impacts from climate systems, changes in atmospheric composition are changing ecosystem-environment relationships. Under the present situation of increased CO_2 concentrations, there is increasingly 'closed' savanna, not primarily as a result of CO_2 fertilisation, but as a result of increased water-use efficiency and the ensuing growth rates (Midgely and Bond, 2015). In water-limited environments, such as savannahs, increases in atmospheric CO_2 concentrations can promote increases in plant water-use-efficiency, net primary productivity, and enhanced carbon storage (Midgely and Bond, 2015). Current GCM projections for East Africa suggest a climate that will be warmer and wetter, with enhanced net primary productivity, associated carbon storage, and increased runoff. All of which are likely to contribute to increases in both tropical broadleaved evergreen forests and tropical

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broadleaved rain-green forests (Doherty et al., 2010). Such a broad-scale prediction across a region of clear environmental and ecosystem complexity (Section 2.2) is clearly open to error, and many more regionally focused modelling approaches are needed to capture the range in spatial variability (Platts et al., 2015). It is clear from the palaeoenvironment data reviewed above (Section 3) that spatial variability and complexity existed in the past, with some areas getting drier and others getting wetter, and this is likely to continue in the future (Figure 21).

A variety of models are available to investigate individual species or ecosystem responses to climate change (Platts et al., 2013, 2015) and land use change (Jung et al., 2016). To date, one of the most popular methods for investigating the responses that plants have had to climate change has been species niche modelling, or bioclimatic modelling (Araújo and Peterson, 2012). Climatic envelopes are created by correlating the known distribution of the target species with various ecological and climatic parameters – the effect is to create a niche which represents the boundaries within which that species can survive. As the ecological and climatic conditions are both known for the present, to some extent the past, and can be predicted for the future, it allows hypotheses to be generated concerning how the species distribution may change in relation to climate change (e.g., Maiorano et al., 2013). Combining palaeoecological and metacommunity approaches has the potential to be a very fruitful combination to engage in a truly comprehensive analysis of the processes regulating ecological communities (Svenning, et al., 2013). For example, such a combination will allow us to understand transition mechanisms in savanna ecosystems: such as how they change from woodland to apparently stable grassland 'phases', how they can be resilient to disturbance and how the can persist over the long-term and still withstand disturbance (Li, 2002). Fire and/or herbivory, primarily by elephants, are usually the causes of disturbance that are responsible for the transition woodland to grassland savannah. However, transitions from grassland to woodland occur less frequently and more slowly (Bond and Midgley, 2000), relying primarily on recruitment events, and are likely to be hampered by browsing. In situations where factors such as disease or hunting affect herbivore numbers, the transition

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from grassland to woodland occurs more quickly (Dublin, 1995).

In addition to providing a data-based test for models, and providing an input of changed land surface to climate models, the long term perspective of land cover change presented here can be used to provide context for more contemporary analysis of land cover change. For example, over the past 50 or so years the timing, direction and rate of land cover change can be assessed by looking at remotely sensed images (Pfeifer et al., 2012). This study analysed land cover change across East Africa from two paired MODIS land cover images taken in 2001 and 2012, which clearly show the continued expansion of agriculture, particularly around the eastern shores of Lake Victoria (Figure 22) and the coastal strip of East Africa. Hence, perspectives brought together from past environmental and archaeological archives can provide spatially constrained, long term land cover and land use reconstructions that can be used to test models of vegetation and environmental change, and feed into fully coupled, next generation climate and Earth system models to provide a more comprehensive understanding of environmental-human interactions and how these change over time and across space.

5.3 Enhanced understanding of ecosystem services and biogeochemical cycling

Ecosystems and the services they provide (e.g., food, timber, water, carbon storage, nutrient cycling, soil formation etc.) are fundamental for future livelihoods (Rockström et al., 2009). This relationship between people and natural resources is particularly close across East Africa where people’s livelihoods connect strongly with their environment (Figure 23). It is therefore of critical importance to the management of ecosystem services – both in the present and in the future – to understand how they have, and do, vary temporally and spatially (Dearing et al., 2014). Challenges to this relationship come in the form of climate change, land-use transformation, population growth and migration, and complex local to global environmental policies. Population growth together with socio-economic development unavoidably results in resource competition between different land use requirements (e.g., agriculture, forest and

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biodiversity conservation, pastoralism, water provision and carbon sequestration). Compounding these biophysical challenges are challenges around developing and implementing workable Payment for Ecosystem services (PES) schemes that are often run at international (e.g., REDD+), national (e.g., Participatory Forest Management) and local (e.g., agri-environment accreditation) scales.

Human-induced land-use change can impact on the underlying ecosystem services, especially via altering biogeochemical cycles and the composition and distribution of ecosystems (Pagel and Mace, 2004). The integration of these long-term records into planning and ecosystems management tools is vital for the future provisioning of ecosystem services (Jeffers et al., 2015). An understanding of land-use change can support policies aimed at mitigating both the driving factors behind such change, and the behaviour of complex agro-ecosystems under changing conditions (de Koning et al., 1999). For example, in East Africa it is clear from palaeoecological and historical evidence (Section 3) that precipitation regimes can change suddenly and they are not synchronous across the region, therefore future adaptation planning would be wise to include provision for such variations (Shanahan et al., 2015). Impending changes in environment, population, land use, and economic development in the near future will dictate patterns of water supply and demand (Vörösmarty et al., 2000). Wetland environments have clearly figured prominently in East Africa throughout the last 6000 years and continue to be important to many societies: such environments are, and were, attractive areas within a landscape due to their high diversity in resources, high productivity and their reliable water supply (Nicholas, 1998). As population continues to grow, and as the regional climate seasonality becomes enhanced, there is increasing pressure on water supplies (Platts et al., 2015); this pressure is accentuated further as freshwater supplies become even more restricted due to pollution (Vorosmarty et al., 2000; Heathwaite, 2010). Jeffers et al. (2015) and Ekblom et al. (2017) identify palaeoecology as being ideally situated to address questions around vulnerability in water supplies under differing climate change scenarios, and also for potentially providing baseline information on water supply and quality.

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These issues are gaining increasing importance as government agencies around the world, but particularly in East Africa, become responsible for implementing legislation to ensure the reliable and clean water supplies exist and are maintained.

The recent study by Jeffers et al. (2015) also identifies three factors that underpin ecosystem services, changes in which will ultimately affect the provisioning of ecosystem services today, and in the future in East Africa. The three factors are the availability of nitrogen and phosphorous; plant biomass and soil. Understanding the history of both of these has been possible in other parts of the world through the use of palaeoecological proxies. Nitrogen levels in the environment are particularly elevated because of the use of fertilisers and crop farming strategies (example Figure 23F), and this is seen clearly as pollution in East African lakes (Sutton, 2011), which in turn reduces the ability of those lakes to provide ecosystem services. Using stable isotope analysis of nitrogen ($\delta^{15}N$) from the sedimentary record (Chapman et al., 2006) allows us to track pollution both spatially and temporally, and provides the wider community with a baseline for pollution control (Jeffers et al., 2015).

The second factor identified (Jeffers et al., 2015) - plant biomass – is linked to many ecosystem services that include climate regulation, protection from soil erosion, the provision of clean water and higher yields of timber and crops (Mace et al., 2012). Understanding how plant biomass fluctuates in relation to climate change is going to be of utmost importance for future scenario modelling and as payment for ecosystem services schemes (such as REDD+, Reducing Emissions from Deforestation and forest Degradation) increase across East Africa. These schemes rely on being able to model carbon drawdown and sequestration (Asner et al., 2010), which are then equated to a monetary value. Baseline information is required on what the potential of the forests to sequester and store carbon could be, particularly where many of the previously extensive forests of East Africa have been largely converted to agricultural land. For example, the Coastal Forests and Eastern Arc Montane Forests of Tanzania and Kenya are now restricted to a number of isolated pockets under protected area status. While

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we can see the impact of relatively recent (decadal) land cover changes through the remote sensing such as MODIS and other satellite-based Earth observation products (Figure 22), again a deeper perspective is really required to provide the full picture of the potential, and to enable this potential to be realised. For example, regarding the Eastern Arc Montane Forests, a Biodiversity Hotspot of global importance (Burgess et al., 1998b), the former palaeoecological extent of these ecosystems is thought to be some 80 to 90 % greater than their current extent (Willcock et al., 2016). There is still some way to go in refining schemes implementing payment for ecosystem services: for example, the effect of fire on carbon storage (Barlow et al., 2012) has not been taken into account, and given the clear palaeoenvironmental evidence on how these fire regimes have changed through time (Courtney-Mustaphi et al., 2017) and the recent increase in wildfires (Barlow et al., 2012), it is highly probable that changes to fire regimes is a significant factor across many East African landscapes (Hemp and Beck, 2001; Colombaroli et al., 2016; Hempson et al., 2017.

Soil underpins a number of ecosystem services, such as nutrient cycling and below ground carbon storage; it is also fundamental for agricultural provision and water supply (Jeffers et al., 2015). The palaeoenvironmental and archaeological records provide information that can inform and validate soil formation and erosion models. Analysis of soil formation is undertaken by examining fluctuations in the rates of soil evolution, seen through pedogenic changes over time. These pedogenic changes occur in response to local factors such as changes in vegetation cover and land use cover, and also in relation to climate change. An example of where pedogenic changes have been observed through detailed archaeological soil analyses comes from the site of Engaruka in northern Tanzania (Lang and Stump, 2017), here pedogenic changes have occurred through changes in land use practices, namely agriculture and irrigation. Lastly, erosion and influx of mineral organic matter can be inferred from soil analysis, but also from geochemical analyses (Hu et al., 2001). Human activities and climate change can accelerate soil erosion processes, which, in turn, are likely to produce an economic effect as productive agricultural land becomes lost and water quality declines.

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5.4 Understanding current biodiversity patterns and links to current conservation challenges

East Africa is world famous for the National Park network that brings in vital tourist revenue across the region. The Tanzania and Kenya Borderlands region is home to fourteen protected areas, that include the Amboseli, Masaai Mara and Serengeti national parks; these alone attract millions of visitors per annum with billions of US$ in associated tourist revenue that is vital to the national economies (Figure 24E). Climate change, and how this will impact on ecosystems, is highly uncertain, likewise, the associated impacts on biodiversity, protected areas and socioeconomic benefits are largely unknown. For example, within the Amboseli National Park in southern Kenya, the extensive drought experienced in 2008-2009 resulted in a 90% reduction in the wildebeest populations, and corresponding reductions in the populations of other ungulates (David Western, unpublished data; Okello et al., 2015). Despite this decrease in ungulates, carnivore populations increased at this time, however, in the absence of wild ungulates the domesticated livestock of the pastoral communities, such as cattle, sheep and goats, come under pressure instead (Manoa and Mwaura, 2016). In order to control this spiralling human-wildlife conflict, the Kenyan Wildlife Service spent approximately US$ 1,000,000 on 150 zebra from a private game reserve in Kenya to alleviate the pressure. Whilst this is clearly unsustainable into the future longer term, perspectives from the longer-term past may be able to guide more informed decisions in the future. One of the key findings from the work on the environmental histories of East African savannas has been the large and rapid fluctuations in wetlands, driven by regional hydrological variability. This variability has had massive impacts on water and grazing refuges during periods of drought, and will do so in the future as pressures on these resources intensify due to fragmentation and increasing human populations More broadly, whilst these hydrological fluctuations are now known about in general, the detail is lacking in many instances. We still need to understand the mechanisms and triggers for the origins of wetlands; how they are hydrologically sustained and how the climate can affect these fragile ecological systems. Whilst we do not know how most swamps are hydrologically sustained, they currently serve as a permanent freshwater source for animals and people, and as such are critical for maintaining biodiversity

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(Homewood and Lewis, 1987). Another example is that of spring-fed wetlands. These are vitally important resources in arid regions of East Africa, not only for providing cooking and drinking water, but also for providing materials for fodder, thatching roofs and for mat making. However, these spring-fed wetlands are increasingly being put under pressure as population increases (e.g., Thenya, 2001).

As these pressures continue to grow, there is a need for policies and practice to promote successful adaptation strategies. Before this can occur, an appreciation is needed about how people perceive climate change, their current adaptation measures, and other factors that may influence people's decisions to adapt their current practices. Again, salutary lessons can be learned from a historical perspective. Meeting, and addressing, the challenges that East African ecosystems face in a world of rising populations makes the need the understand to human-environment interactions (past, present and future) more pressing, particularly because it is only through people – from local communities to policy makers – that a sustainable mode of human-environment interaction will be desired, implemented and hopefully achieved. A longer-term perspective on land use change that also brings together conservation measures to assess the challenges to biodiversity conservation and to provide status assessments would be a helpful step forward. A good example of the utility of this long-term perspective is clear from our understanding of fluctuating elephant populations. After the ban on international trade in ivory from 1989 (Lemieux and Clarke, 2009) poaching dramatically declined. However, despite this relatively instant reduction, we still know relatively little about the effects of changing herbivore numbers, and there is still an urgent need for more data on long-term vegetation variability in response to changing herbivore densities. Gaining insight on this relationship would have the effect of improving our understanding of ecological processes in savannas; past distribution of elephant populations (Coutu et al. 2016); and their mobility patterns and geographical ranges (Coutu, 2015). And crucially, it could also provide a basis for future management decisions. We know today the significant impact that elephant populations have in maintaining open and grassland

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(Morrison et al., 2016), and that the impacts of these important 'ecosystem engineers' has been significantly curtailed through the wholesale removal of the elephant population from some areas, initially through the European and American-driven demands for ivory during the 19th and early 20th centuries, and now, owing to the recent upsurge in poaching and illicit trade in ivory, largely driven by Asian markets (Sommerville, 2016). Integrated, multi-sited, landscape historical and political ecologies of these trades and previous phases of forest and savannah elephant ivory extraction offer one model for addressing these challenges (Håkansson, 2004; Lane, 2010).

Understanding how people have interacted with their environments in the past, in particular in savanna landscapes that dominate the main areas of archaeological and palaeoecological work to date, is important today; but has been (and still is) a dynamic, complex and ever-changing interaction. But it is precisely these complex relationships that have shaped the productive and varied biome of savannahs that we see today. Inline with Fairhead and Leach's (2002) argument, it is only by understanding these landscape histories of savannahs that we can move beyond narratives of degradation to one where societies are interwoven with the ecosystem. This flattening of the heirarchy of knowledge construction allows the possibility for multiple voices within the landscape to be heard and recognised, including those from palaeoecology, archaeology and local communities (Richer and Gearey, in review). However, as a result of these complex interactions, the rate of change in savannah landscapes is potentially faster (Svenning et al., 2016) and more dramatic than we have witnessed before, as can be seen through events such as species extinctions (Maslin, 2016). Trying to gain clarity on the inter-linkages between societal and ecological processes, such as habitat fragmentation and human-animal conflict, is becoming increasingly pressing to ensure the livelihoods of people currently living in these landscapes (Marchant 2010).

Indeed, a more balanced view that biodiversity is part and product of complex and linked natural anthropogenic interactions (Pinedo-Vasquez et al., 2002) is crucial if we are to manage

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ecosystems in a future of uncertain change. For example, the diversity in resource use, cultural practices and the capacity of adaptations for social change are only rarely taken into account for conservation and development schemes (Pinedo-Vasquez et al., 2002). There is nevertheless a growing realisation that the idea of virgin rainforests, initially seen as largely ‘untouched’ by ‘native’ people, is a misnomer. Instead, the extent of, and potential relationships between, early populations and ecosystems, is supporting the realisation that humans have sculpted closed forest for millennia (Pearce, 1999). With long-term perspectives on human-ecosystem interaction we can modify our conservation and protectionist ethos to adopt more dynamic strategies for conserving biodiversity to accommodate the change that inevitably occurs in species ranges and environmental regimes over time (Tallis, 1991; Marchant, 2010). Conserving ecosystems and communities are they currently exist, or intervening to restore them to to a previous state, has become redundant. Instead, dynamic strategies are supported as these can allow for a type of conservation that accommodates climate change by embracing concepts that encapsulate networks and connectivity – as these can support fluidity and change (Hannah et al., 2002a). Given current climate projections (Platts et al., 2015), conservation institutions and approaches will fail if they do not factor in change as major component of the system. Equally, individuals, communities and societies will also need to be able to adapt and change, to reduce their vulnerability to climate change (Rayner and Malone, 1997). It is also the responsibility of the academic community to rethink how we research and communicate our understandings of climate change, and this includes challenging our current theories and models for working on issues surrounding climate change and how people and environment relate (Rayner and Malone, 1997; Marchant and Lane, 2014). An example of this is the debate about paved roadways through the Serengeti ecosystem (Dobson et al., 2010; Homewood et al., 2010; Fyumagwa et al., 2013) and development of new railways lines; both of which are long linear features that fragment landscapes and have varied socio-ecological benefits and impacts (Figure 25) (Hopcraft et al., 2015). One of the many ways that we can engage with the call to radically alter how we think about these issues is to again reiterate the importance of relevant and scientifically robust

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palaeoecological and archaeological records.

5.5 Further research

Understanding interactions between past ecosystem dynamics, movements of people and land use strategies is paramount if we want to understand the relationship between human societies and climate change; this requires going beyond individual site records that remain entrenched in only one discipline, and instead undertaking integrated landscape-scale research (Dillehay, 2002). It is such an approach that is the foundation of this paper. Characterising the emergence of a diversified agriculture and rapid spread of crops across East Africa is one of the most challenging research topics for the future (Neumann, 2005), and not only because the identification of pollen of indigenous cultivated crops is challenging, although this is certainly one area that needs addressing. Enhanced collaboration between the palaeoenvironmental and archaeological communities will help to provide an integrated perspective on this crucial period in the recent history of East Africa. And whilst landscape-wide studies are needed, there is a simultaneous need for high quality, high precision and high-resolution records within this (cf. Ssemmanda et al., 2005; Russell et al., 2007, 2009; Bessems et al., 2008). From a palaeoenvironmental perspective, one of the key locations to obtain the material for such analyses is from the so far largely untapped resource of small lakes and sedimentary basins. Once these sites have been identified, the next step is to provide a robust, accurate and precise chronology to their respective sequences. In the majority of case studies, the timing, frequency, magnitude and regional phasing of these events is poorly understood. There is thus a need, not only for more well-dated sequences, but for sample selection to be made intelligently using predictive modelling prior to sample submission, and for dating determinations to be further constrained using appropriate Bayesian methodologies. Whilst these methods do not provide ‘the answer’, they allow for us to gain a better understanding of temporal variation, which is vital in any understanding of climate conditions in eastern Africa.

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However, even when a robust chronology has been constructed, we are still need to disentangle the non-linear relationships between precipitation-fire-vegetation (Whitlock et al., 2010; Lehmann et al., 2014; Njokuocha and Akaegbobi, 2014) and also the feedbacks between them (Cochrane et al., 1999). This is especially important in East African savannas due to the difficult nature of assessing whether changes in precipitation or land use have caused the shift in fire regimes (Stocker et al., 2013). Similarly, there is also a need for an increased number of higher-temporal-resolution palynological studies within East Africa, particularly those that place an emphasis on multiproxy methodologies. Whilst we still need to devise new methods to aid in differentiating climatic and anthropogenic signals, the more information we have at our disposal to undertake this means that we can use this information in a Bayesian-like manner to begin to refine our interpretations and place more certainty on whether we are witnessing anthropogenic, climatic or mixed signals in the palaeoecological record.

6 Conclusions

Throughout our synthesis a wide body of information has been presented from two different schools spanning the environmental and human sciences and we have indicated the possible interrelationships between these independent findings. Holocene environmental conditions in East Africa have switched between different climate modes, and the only constant that can be identified is that of change. The tendency of climate to change relatively suddenly, often over the scale of a single generation, would have been highly noticeable to human populations, and may have afforded both difficulties or opportunities. We can not know how people perceived these climatic change in the past, but by the same measure, researchers worldwide have yet to fully consider the potential implications of the sudden environmental changes that would have occurred as the result of both climatic and anthropogenic drivers. Throughout this review we have identified patterns that exist in the current datasets and where the different types of evidence corroborate or contradict one another, and have highlighted how the lack of spatial or chronological resolution or contrasting resolutions between datasets hamper this

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effort. Although the amount of data, and the spectrum of techniques applied from these foci, has greatly increased over the last couple of decades, many gaps still remain and the evidence carries the historic legacy of being biased towards certain key sites and time periods; other areas and time frames may need to be targeted by new initiatives.

Integrating information from different disciplines, with independent ontologies, methodologies, vocabularies, and interpretative frameworks is not a straightforward task, but it if we can achieve it, it will enhance our understanding of past environmental change and how people have been enmeshed within this process. It is unlikely that this understanding will be fully realised, but in working towards it we need to apply the currently under-utilised theories, methodology and techniques that we have at our disposal; such as fungal spores, grass cuticles, seeds, geochemical analysis, charcoal and phytoliths (Alexandre et al., 1997). Changes and advances in theoretical positions, techniques, rigorous sampling of a greater number of sites, together with greater applications of GIS and Bayesian modelling may nudge the enquiry into new domains. However, the main concern is the shortcomings of our current explanatory strategy, which leaves many questions still remaining to be answered. These will hopefully be explored through new datasets and through further extrapolation of some of the datasets presented here.

Whilst pronounced waves of environmental change can be seen in the tropical belt, these only register very weakly at temperate latitudes. Understanding the differences in the intensity of these signals in different parts of the world may also help to understand some of the underlying global climate dynamics. In turn, this can help to enhance our predictions of future likelihoods of rapid climate change, and some of their associated societal impacts. More broadly, this underlies the need to move away from orthodox, Eurocentric, notions of human-environment inter-relationships (Morrison, in press; Richer and Gearey, in review) and to rethink the changing relationship between nature and humans in the past as well as in the future. This is especially the case as human action comes to modify, dominate or sometimes

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replace natural ecosystems, and with that comes the concomitant increase in vulnerability to climate changes or extreme events (Messerli et al., 2000). Certainly, a thorough understanding of past environmental cultural dynamics is crucial to contextualising the location of protected areas and forms of land management required today. The course of human history is closely coupled with that of the environment; the same holds true for the African continent's future. Indeed, the contribution of palaeoecology and archaeology is not to 'simply' reconstruct the past but to confront the present (Hassan, 2000). Additional insights from combining research from different disciplines may lead to a retrospective process to examine how well the individual disciplines are poised to answer future research questions.

The frequency of atypical weather extremes linked to anthropogenic global warming is projected to increase in frequency and magnitude. The disruption of traditionally predictable seasons, including increased frequency of extremes (droughts and floods) as seen throughout the world, has major implications for crop yields and livestock, and hence for the social structure of pastoralists and farmers (Brown, 1971). Creating knowledge and integrating past datasets into future planning and policy is a central output of this review: identifying a range of practices that may enhance community and ecosystem resilience and adaptive capacities (Holling, 1973) that could be incorporated into landscape planning and future scenarios is a crucial development. A better understanding of how people have responded to past environmental change, and how on-going adaptation measures have evolved, are vital if we are to craft visions, policies and programmes aimed at promoting successful adaptation to future environmental shifts and cultural changes. The datasets produced will also be crucial in providing data for building future scenarios based on the range of variability and potential threshold responses, and as a basis for decision making in land management, food production and security. Planning for the long-term sustainable use of natural resources requires a long-term perspective on human-ecosystem-environment 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. Whilst critical earth system boundaries

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have been identified and exceeded at the global level, most sustainability targets (e.g. SDGs) either remain unmet, or appear highly challenging to achieve. We contend this is in part because there is little synthesised knowledge of environmental, social and heritage interactions at the landscape or catchment, scale. Our cross-disciplinary socio-environmental review presents how East African social-ecological systems have responded to environmental and social shifts in the past, and will hopefully contribute to informing how ecosystems, people and wildlife will respond in the future.

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Table 1

ID	Site Name	Latitude	Longitude	Country	Geoarchive Type	Dating Technique	6000-4500	4500-3000	3000-1500	1500-Present	Citation	References
PE1	Derema Swamp	-5.116667	38.666667	Tanzania	Palustrine	Radiometric				x	Mumbi et al., 2014	Mumbi, C.T., Marchant, R. and Lane, P., 2014. Vegetation response to climate change and human impacts in the Usambara Mountains. ISRN Forestry, 2014.
PE2	Deva-Deva	-7.1222	37.620533	Tanzania	Palustrine	Radiometric	x	x	x	x	Finch et al., 2009	Finch, J., Leng, M.J. and Marchant, R., 2009. Late Quaternary vegetation dynamics in a biodiversity hotspot, the Uluguru Mountains of Tanzania. Quaternary Research, 72(1), pp.111-122.
PE3	Madumu	-4.966667	38.416667	Tanzania	Palustrine	Radiometric		x	x	x	Mumbi et al., 2014	Mumbi, C.T., Marchant, R. and Lane, P., 2014. Vegetation response to climate change and human impacts in the Usambara Mountains. ISRN Forestry, 2014.
PE4	Iringa	-7.816667	35.916667	Tanzania	Palustrine	Radiometric	x	x	x	x	Mumbi et al., 2008	Mumbi, C.T., Marchant, R., Hooghiemstra, H. and Wooller, M.J., 2008. Late Quaternary vegetation reconstruction from the eastern Arc mountains,

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												Tanzania. Quaternary Research, 69(2), pp.326-341.
PE5	Kitumbako	-7.145333	37.631333	Tanzania	Palustrine	Radiometric	x	x	x	x	Finch and Marchant, 2014	Finch, J. and Marchant, R., 2011. A palaeoecological investigation into the role of fire and human activity in the development of montane grasslands in East Africa. Vegetation History and Archaeobotany, 20(2), pp.109-124.
PE6	Mbomole	-5.116667	38.666667	Tanzania	Palustrine	Radiometric				x	Mumbi et al., 2008	Mumbi, C.T., Marchant, R., Hooghiemstra, H. and Wooller, M.J., 2008. Late Quaternary vegetation reconstruction from the eastern Arc mountains, Tanzania. Quaternary Research, 69(2), pp.326-341.
PE7	Mgundamvaha grassland	-7.3	36.23	Tanzania	Palustrine	Radiometric	x	x	x	x	Finch et al., 2014	Finch, J., Wooller, M. and Marchant, R., 2014. Tracing long?term tropical montane ecosystem change in the Eastern Arc Mountains of Tanzania. Journal of Quaternary Science,

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													29(3), pp.269-278.
PE8	Namelok	-2.70691	37.456199	Kenya	Palustrine	Radiometric			x	x		Rucina et al., 2010	Rucina, S.M., Muiruri, V.M., Downton, L. and Marchant, R., 2010. Late-Holocene savanna dynamics in the Amboseli Basin, Kenya. The Holocene, 20(5), pp.667-677.
PE9	Rumuiku	-0.118583	37.5611	Kenya	Palustrine	Radiometric	x	x	x	x		Rucina et al., 2009	Rucina, S.M., Muiruri, V.M., Kinyanjui, R.N., McGuiness, K. and Marchant, R., 2009. Late Quaternary vegetation and fire dynamics on Mount Kenya. Palaeogeography, Palaeoclimatology, Palaeoecology, 283(1), pp.1-14.
PE10	Unguja Ukuu	-7.7894391	39.3296844	Tanzania	Palustrine	Radiometric				x		Punwong et al., 2013c	Punwong, P., Marchant, R. and Selby, K., 2013c. Holocene mangrove dynamics from Unguja Ukuu, Zanzibar. Quaternary International, 298, pp.4-19.
PE11	Unguja Ukuu	-6.320833	39.377528	Tanzania	Coastal	Radiometric				x		Punwong et al., 2013c	Punwong, P., Marchant, R. and Selby, K., 2013c.

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												Holocene mangrove dynamics from Unguja Ukuu, Zanzibar. Quaternary International, 298, pp.4-19.
PE12	Unguja Ukuu	-6.320806	39.376472	Tanzania	Coastal	Radiometric		x	x	x	Punwong et al., 2013c	Punwong, P., Marchant, R. and Selby, K., 2013c. Holocene mangrove dynamics from Unguja Ukuu, Zanzibar. Quaternary International, 298, pp.4-19.
PE13	Unguja Ukuu	-6.318139	39.376778	Tanzania	Coastal	Radiometric	x	x	x	x	Punwong et al., 2013c	Punwong, P., Marchant, R. and Selby, K., 2013c. Holocene mangrove dynamics from Unguja Ukuu, Zanzibar. Quaternary International, 298, pp.4-19.
PE14	Northern Rufiji Delta	-7.789444	39.399722	Tanzania	Deltaic	Radiometric				x	Punwong et al., 2013b	Punwong, P., Marchant, R. and Selby, K., 2013b. Holocene mangrove dynamics and environmental change in the Rufiji Delta, Tanzania. Vegetation history and archaeobotany, 22(5),

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												pp.381-396.
PE15	Northern Rufiji Delta	-7.856944	39.340556	Tanzania	Deltaic	Radiometric	x	x	x	x	Punwong et al., 2013b	Punwong, P., Marchant, R. and Selby, K., 2013b. Holocene mangrove dynamics and environmental change in the Rufiji Delta, Tanzania. Vegetation history and archaeobotany, 22(5), pp.381-396.
PE16	Northern Rufiji Delta	-7.901944	39.251111	Tanzania	Deltaic	Radiometric				x	Punwong et al., 2013b	Punwong, P., Marchant, R. and Selby, K., 2013b. Holocene mangrove dynamics and environmental change in the Rufiji Delta, Tanzania. Vegetation history and archaeobotany, 22(5), pp.381-396.
PE17	Makoba Bay	-5.938972	39.205333	Tanzania	Coastal	Radiometric	x	x	x	x	Woodroffe et al., 2015	Woodroffe, S.A., Long, A.J., Punwong, P., Selby, K., Bryant, C.L. and Marchant, R., 2015. Radiocarbon dating of mangrove sediments to constrain Holocene relative sea-level change on Zanzibar in the

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												southwest Indian Ocean. The Holocene, 25(5), pp.820-831.
PE18	Makoba Bay	-5.939083	39.202806	Tanzania	Coastal	Radiometric	x	x	x	x	Woodroffe et al., 2015	Woodroffe, S.A., Long, A.J., Punwong, P., Selby, K., Bryant, C.L. and Marchant, R., 2015. Radiocarbon dating of mangrove sediments to constrain Holocene relative sea-level change on Zanzibar in the southwest Indian Ocean. The Holocene, 25(5), pp.820-831.
PE19	Makoba Bay	-5.939528	39.199889	Tanzania	Coastal	Radiometric	x	x	x	x	Punwong et al., 2013a	Punwong, P., Marchant, R. and Selby, K., 2013a. Holocene mangrove dynamics in Makoba Bay, Zanzibar. Palaeogeography, Palaeoclimatology, Palaeoecology, 379, pp.54-67.
PE20	Lomwe Swamp	-3.714722	37.672778	Tanzania	Palustrine	Radiometric				x	Heckmann et al., 2014	Heckmann, M., Muiruri, V., Boom, A. and Marchant, R., 2014. Human–environment interactions in an agricultural landscape: A 1400-yr sediment and pollen record from

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												North Pare, NE Tanzania. Palaeogeography, Palaeoclimatology, Palaeoecology, 406, pp.49-61.
PE21	Lomwe soil	-3.714958	37.674512	Tanzania	Soil	Radiometric			x	x	Heckmann et al., 2014	Heckmann, M., Muiruri, V., Boom, A. and Marchant, R., 2014. Human–environment interactions in an agricultural landscape: A 1400-yr sediment and pollen record from North Pare, NE Tanzania. Palaeogeography, Palaeoclimatology, Palaeoecology, 406, pp.49-61.
PE22	Kwasebuge (Shengena)	-4.292015	37.92284	Tanzania	Palustrine	Radiometric				x	Finch et al., 2016	Finch J, Marchant R, and Courtney Mustaphi CJ. 2016. Ecosystem change in the South Pare Mountain bloc, Eastern Arc Mountains of Tanzania. The Holocene.
PE23	Oblong Tarn	-0.145306	37.301707	Kenya	lacustrine	Radiometric	x	x	x	x	Karlén, 1985	Karlén, W. 1985. Glacier and climate fluctuations on Mount Kenya, East Africa. Zeitschrift fur Gletscherkunde und

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												Glazialgeologie 21: 195-201.; Johansson, L., & Holmgren, K. (1985). Dating of a moraine on Mount Kenya. Geografiska Annaler Series A. Physical Geography, pp.123-128.
PE24	Hausberg Tarn	-0.144304	37.30043	Kenya	lacustrine	Radiometric	x	x	x	x	Karlén, 1985	Karlén, W. 1985. Glacier and climate fluctuations on Mount Kenya, East Africa. Zeitschrift fur Gletscherkunde und Glazialgeologie 21: 195-201.; Johansson, L., & Holmgren, K. (1985). Dating of a moraine on Mount Kenya. Geografiska Annaler Series A. Physical Geography, pp.123-128.
PE25	Naro Moru Tarn	-0.165753	37.300383	Kenya	lacustrine	Radiometric	x	x	x	x	Johansson and Holmgren, 1985	Johansson, L. and Holmgren, K., 1985. Dating of a moraine on Mount Kenya. Geografiska Annaler. Series A. Physical Geography, pp.123-128.
PE26	Kuruyange Swamp	-3.565697	29.686807	Burundi	Palustrine	Radiometric	x	x	x	x	Jolly et al., 1997	Jolly, D., Taylor, D., Marchant, R., Hamilton,

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												A., Bonnefille, R., Buchet, G. and Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr BP: pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. Journal of Biogeography, 24(4), pp.492-512.
PE27	Ahakagyezi Swamp	-1.120967	29.842314	Uganda	Palustrine	Radiometric	x	x	x	x	Jolly et al., 1997	Jolly, D., Taylor, D., Marchant, R., Hamilton, A., Bonnefille, R., Buchet, G. and Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr BP: pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. Journal of Biogeography, 24(4), pp.492-512.
PE28	Mubwindi Swamp	-1.079253	29.755472	Uganda	Palustrine	Radiometric	x	x	x	x	Jolly et al., 1997	Jolly, D., Taylor, D., Marchant, R., Hamilton, A., Bonnefille, R., Buchet, G. and Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr BP: pollen records from

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												the interlacustrine highlands of Burundi, Rwanda and western Uganda. Journal of Biogeography, 24(4), pp.492-512.
PE29	Muchoya Swamp	-1.281767	29.811139	Uganda	Palustrine	Radiometric	x	x	x	x	Jolly et al., 1997	Jolly, D., Taylor, D., Marchant, R., Hamilton, A., Bonnefille, R., Buchet, G. and Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr BP: pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. Journal of Biogeography, 24(4), pp.492-512.
PE30	Sacred Lake	0.047598	37.527363	Kenya	Lacustrine	Radiometric	x	x	x	x	Olago et al., 1999	Olago, D.O., Street-Perrott, F.A., Perrott, R.A., Ivanovich, M. and Harkness, D.D., 1999. Late Quaternary glacial-interglacial cycle of climatic and environmental change on Mount Kenya, Kenya. Journal of African Earth Sciences, 29(3), pp.593-618.
PE31	Lake Nkunga	0.115639	37.594733	Kenya	Lacustrine	Radiometric	x	x	x	x	Olago et al., 1999	Olago, D.O., Street-Perrott, F.A., Perrott,

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												R.A., Ivanovich, M. and Harkness, D.D., 1999. Late Quaternary glacial-interglacial cycle of climatic and environmental change on Mount Kenya, Kenya. Journal of African Earth Sciences, 29(3), pp.593-618.
PE32	Sokorte Dika	2.3088	37.969195	Kenya	Lacustrine	Radiometric	x	x	x	x	Marchant et al., unpublished	
PE33	Lake Paradise	2.261338	37.934986	Kenya	Lacustrine	Radiometric				x	Marchant et al., unpublished	
PE34	Kiluli Swamp	0.133333	37.75	Kenya	Palustrine	Radiometric		x	x	x	Olago et al., 2004	Olago, D.D., Street-Perrott, F.A., Perrott, R.A. and Odada, E.O., 2003. Late Holocene sedimentology and palaeoenvironment of Kiluli Swamp, Mount Kenya. African Journal of Science and Technology, 4(2), pp.12-23.
PE35	Ziwani Swamp	-3.390177	37.788068	Kenya	Palustrine	Radiometric				x	Gillson, 2006	Gillson, L., 2006. A 'large infrequent disturbance'in an East African savanna. African Journal of Ecology, 44(4), pp.458-467.
PE36	Lake Challa	-3.316667	37.7	Kenya	Lacustrine	Radiometric	x	x	x	x	Blaauw et al., 2011	Blaauw, M., van Geel,

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												B., Kristen, I., Plessen, B., Lyaruu, A., Engstrom, D.R., van der Plicht, J. and Verschuren, D., 2011. High-resolution 14 C dating of a 25,000-year lake-sediment record from equatorial East Africa. Quaternary Science Reviews, 30(21), pp.3043-3059.
PE37	Loboi Swamp	0.365034	36.045882	Kenya	Palustrine	Radiometric				x	Ashley et al., 2004	Ashley, G.M., Maitima Mworia, J., Muasya, A.M., Owen, R.B., Driese, S.G., Hover, V.C., Renaut, R.W., Goman, M.F., Mathai, S. and Blatt, S.H., 2004. Sedimentation and recent history of a freshwater wetland in a semi?arid environment: Loboi Swamp, Kenya, East Africa. Sedimentology, 51(6), pp.1301-1321.
PE38	Lake Mahoma	0.344306	29.967045	Uganda	Lacustrine	Radiometric	x	x	x	x	Livingstone, 1967	Livingstone, D.A., 1967. Postglacial vegetation of the Ruwenzori Mountains in equatorial Africa. Ecological Monographs, 37(1),

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												pp.25-52.
PE39	Bujuku Lake	0.376584	29.893681	Uganda	Lacustrine	Radiometric	x	x	x	x	Livingstone, 1967	Livingstone, D.A., 1967. Postglacial vegetation of the Ruwenzori Mountains in equatorial Africa. Ecological Monographs, 37(1), pp.25-52.
PE40	Kabata Swamp	0.482374	30.277126	Uganda	Palustrine	Radiometric	x	x	x	x	Taylor et al., 1999	Taylor, D., Marchant, R.A. and Robertshaw, P., 1999. A sediment?based history of medium altitude forest in central Africa: a record from Kabata Swamp, Ndale volcanic field, Uganda. Journal of Ecology, 87(2), pp.303-315.
PE41	Kanderi Swamp	-3.363167	38.6725	Kenya	Palustrine	Radiometric				x	Gillson, 2004	Gillson, L., 2004. Testing non-equilibrium theories in savannas: 1400 years of vegetation change in Tsavo National Park, Kenya. Ecological Complexity, 1(4), pp.281-298.
PE42	Lake Emakat	-2.924921	35.831012	Tanzania	Tree rings	Radiometric				x	Ryner et al., 2008	Ryner, M., Holmgren, K. and Taylor, D., 2008. A record of vegetation dynamics

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												and lake level changes from Lake Emakat, northern Tanzania, during the last c. 1200 years. Journal of Paleolimnology, 40(2), pp.583-601.
PE43	Munsa Swamp	0.822362	31.308599	Uganda	Palustrine	Radiometric				x	Lejju, 2009	Lejju, J.B., 2009. Vegetation dynamics in western Uganda during the last 1000 years: climate change or human induced environmental degradation?. African Journal of Ecology, 47(s1), pp.21-29.
PE44	Lake Kimilili	1.096664	34.573625	Kenya	Lacustrine	Radiometric	x	x	x	x	Hamilton, 1987	Hamilton, A.C., 1987. Vegetation and climate of Mt Elgon during the late Pleistocene and Holocene. Palaeoecology of Africa, 18, pp.283-304.
PE45	Loitigon	0.737778	36.465556	Kenya	Fluvial	Radiometric	x	x	x	x	Taylor et al., 2005	Taylor, D., Lane, P.J., Muiruri, V., Ruttledge, A., McKeever, R.G., Nolan, T., Kenny, P. and Goodhue, R., 2005. Mid-to late-Holocene vegetation dynamics on the Laikipia Plateau, Kenya. The Holocene,

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										15(6), pp.837-846.
PE46	Maua Mire	-3.129586	37.431179	Tanzania	Palustrine	Radiometric	x	x	Kinyanjui et al., unpublished	
PE47	Lake Duluti	-3.387664	36.787957	Tanzania	Lacustrine	Radiometric		x	Öberg et al., 2013	Öberg, H., Norström, E., Ryner, M.M., Holmgren, K., Westerberg, L.O., Risberg, J., Eddudóttir, S.D., Andersen, T.J. and Muzuka, A., 2013. Environmental variability in northern Tanzania from AD 1000 to 1800, as inferred from diatoms and pollen in Lake Duluti. Palaeogeography, Palaeoclimatology, Palaeoecology, 374, pp.230-241.
PE48	Lake Duluti	-3.384416	36.787028	Tanzania	Lacustrine	Radiometric		x	Öberg et al., 2009	Öberg, H., Risberg, J. and Stabell, B., 2009. Morphology, Valve Ultrastructure and Stratigraphical Variability of Discostella Taxa in a Tropical Crater Lake, Northern Tanzania. Diatom Research, 24(2), pp.341-356.
PE49	Lake Duluti	-3.387664	36.787957	Tanzania	Lacustrine	Radiometric		x	Öberg et al., 2012	Öberg, H., Andersen,

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												T.J., Westerberg, L.O., Risberg, J. and Holmgren, K., 2012. A diatom record of recent environmental change in Lake Duluti, northern Tanzania. Journal of paleolimnology, 48(2), pp.401-416.
PE50	Maundi Crater	-3.174306	37.518278	Tanzania	Lacustrine	Radiometric	x	x	x	x	Schüler et al., 2012	Schüler, L., Hemp, A., Zech, W. and Behling, H., 2012. Vegetation, climate and fire-dynamics in East Africa inferred from the Maundi crater pollen record from Mt Kilimanjaro during the last glacial–interglacial cycle. Quaternary Science Reviews, 39, pp.1-13.
PE51	Mt Kilimanjaro north slope	-2.93199	37.231411	Tanzania	Soil	Radiometric	x	x	x		Zech et al., 2011	Zech, M., Leiber, K., Zech, W., Poetsch, T. and Hemp, A., 2011. Late Quaternary soil genesis and vegetation history on the northern slopes of Mt. Kilimanjaro, East Africa. Quaternary International, 243(2), pp.327-336.

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PE52	Enkongu Swamp	-2.704661	37.260777	Kenya	Palustrine	Radiometric			x	x	Githumbi et al., unpublished	
PE53	Esambu Swamp	-2.711913	37.554357	Kenya	Palustrine	Radiometric		x	x	x	Githumbi et al., unpublished	
PE54	Manguo Swamp	-1.105444	36.6329	Kenya	Palustrine	Radiometric	x	x	x	x	Githumbi, 2013	Githumbi, E.N., 2013. An ecological and palynological study of Manguo Wetland in Kiambu County, Kenya. Unpublished master's thesis. University of Nairobi, Nairobi, Kenya.
PE55	Enapuiyapui Swamp	-0.436467	35.79965	Kenya	Palustrine	Radiometric	x	x	x	x	Courtney Mustaphi et al., 2016	Courtney Mustaphi, C.J., Githumbi, E.N., Shotter, L.R., Rucina, S.M. and Marchant, R., 2016. Subfossil statoblasts of Lophopodella capensis (Sollas, 1908)(Bryozoa, Phylactolaemata, Lophopodidae) in the Upper Pleistocene and Holocene sediments of a montane wetland, Eastern Mau Forest, Kenya. African Invertebrates, 57, p.39-52.
PE56	Ewaso Narok Swamp	0.319504	36.596227	Kenya	Palustrine	Radiometric				x	Muiruri, 2008	Muiruri, V.M., 2008. Detecting environmental change and anthropogenic

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										activities on the Laikipia Plateau, Kenya. Masters degree. Earth Sciences Dept, Palynology section, National Museums of Kenya, Nairobi, and Dept of Botany, University of Free State South Africa.
PE57	Marura Swamp	0.243231	36.701858	Kenya	Palustrine	Radiometric	x	x	Muiruri, 2008	Muiruri, V.M., 2008. Detecting environmental change and anthropogenic activities on the Laikipia Plateau, Kenya. Masters degree. Earth Sciences Dept, Palynology section, National Museums of Kenya, Nairobi, and Dept of Botany, University of Free State South Africa.
PE58	Kyambangunguru peat bog	-9.370319	33.807111	Tanzania	Palustrine	Radiometric		x	Galka et al., 2015	Ga?ka, M., Bergonzini, L., Williamson, D., Majule, A., Masao, C. and Huguet, A., 2015. Macrofossil evidence of Late Holocene presence of Aldrovanda vesiculosa

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												L. in central-eastern Europe (Poland) and East Africa (Tanzania). Quaternary International, 386, pp.186-190.
PE59	WeruWeru 26	-3.121694	37.271583	Tanzania	soil	Radiometric	x	x	x	x	Schüler, 2012	Schüler, L. 2012. Studies on late Quaternary environmental dynamics (vegetation, biodiversity, climate, soils, fire and human impact) on Mt Kilimanjaro. PhD Thesis. Georg-August-Universität Göttingen, Germany
PE60	Lake Katinda	-0.221138	30.106413	Uganda	Lacustrine	Radiometric		x	x	x	Colombaroli et al., 2014	Colombaroli, D., Ssemmanda, I., Gelorini, V. and Verschuren, D., 2014. Contrasting long?term records of biomass burning in wet and dry savannas of equatorial East Africa. Global change biology, 20(9), pp.2903-2914.
PE61	Lake Naivasha	-0.775383	36.371464	Kenya	Lacustrine	Radiometric	x	x	x	x	Maitima, 1991	Maitima, J., 1991. Vegetation response to climate change in Central Rift Valley. Quaternary Research,

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												35, pp.234-245.
PE62	Lake Masoko	-9.333406	33.755589	Tanzania	Lacustrine	Radiometric		x	x	x	Gibert et al.,2003	Gibert, E., Bergonzini, L., Massault, M. and Williamson, D., 2002. AMS 14C chronology of continuous deposits from a crater lake (Lake Masoko, Tanzania): modern water balance and environmental implications. Paleogeography, Paleoclimatology, Paleoecology, 187, pp.307-22.
PE63	Lake Turkana	3.206667	36.228333	Kenya	Lacustrine	Radiometric		x	x	x	Halfman, 1987	Halfman, John D. 1987. High-resolution sedimentology and plaeoclimatology of Lake Turkana, Kenya. Unpublished PhD dissertation, Dept of Geology, Duke University.
PE64	Lake Turkana	2.716668	36.536669	Kenya	Lacustrine	Radiometric	x	x	x	x	Halfman, 1987	Halfman, John D. 1987. High-resolution sedimentology and plaeoclimatology of Lake Turkana, Kenya. Unpublished PhD dissertation, Dept of Geology, Duke

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PE65	Lake Turkana	2.553333	36.6	Kenya	Lacustrine	Radiometric			x	Halfman, 1987	Halfman, John D. 1987. High-resolution sedimentology and plaeoclimatology of Lake Turkana, Kenya. Unpublished PhD dissertation, Dept of Geology, Duke University.
PE66	Lake Turkana	3.765	35.926667	Kenya	Lacustrine	Radiometric	x	x	x	Halfman, 1987	Halfman, John D. 1987. High-resolution sedimentology and plaeoclimatology of Lake Turkana, Kenya. Unpublished PhD dissertation, Dept of Geology, Duke University.
PE67	Lake Turkana	3.936663	36.113334	Kenya	Lacustrine	Radiometric	x	x	x	Halfman and Johnson, 1988	Halfman, J.D. and Johnson, T.C., 1988. High-resolution record of cyclic climatic change during the past 4 ka from Lake Turkana, Kenya. Geology, 16(6), pp.496-500.; Halfman, J.D., Johnson, T.C., Showers, W.J. and Lister, G.S., 1989. Authigenic low-Mg calcite in Lake

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												Turkana, Kenya. Journal of African Earth Sciences (and the Middle East), 8(2), pp.533-540.
PE68	Lake Turkana	4.021667	35.991667	Kenya	Lacustrine	Radiometric			x	x	Halfman, 1987	Halfman, John D. 1987. High-resolution sedimentology and plaeoclimatology of Lake Turkana, Kenya. Unpublished PhD dissertation, Dept of Geology, Duke University.
PE69	Lake Victoria (Pilkington Bay)	0.299967	33.333341	Uganda	Lacustrine	Radiometric	x	x	x	x	Stager et al., 2003	Stager, J.C., Cumming, B.F. and Meeker, L.D., 2003. A 10,000-year high-resolution diatom record from Pilkington Bay, Lake Victoria, East Africa. Quaternary Research, 59(2), pp.172-181.
PE70	Lake Victoria	-0.9779	33.45534	Uganda	Lacustrine	Radiometric	x	x	x	x	Stager and Johnson, 2000	Stager, J.C. and Johnson, T.C., 2000. A 12,400 14C yr offshore diatom record from east central Lake Victoria, East Africa. Journal of Paleolimnology, 23(4), pp.373-383.
PE71	Tyndall Glacier	-0.151567	37.305309	Kenya	Ice	Radiometric				x	Mizuno and Nakamura, 1999	Mizuno, K. and Nakamura, T., 1999.

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												Succession of Alpine Vegetation in Relation to Environmental Changes around Tyndall Glacier on Mt. Kenya-Discovery of leopard's remains from Tyndall Glacier in 1997. JOURNAL OF GEOGRAPHY-TOKYO-, 108, pp.18-30.; Mizuno, K., 2005. Glacial fluctuation and vegetation succession on tyndall glacier, Mt Kenya. Mountain Research and Development, 25(1), pp.68-75.
PE72	Panga ya Kuumbi	-6.361113	39.5425	Tanzania	Cave	Radiometric	x	x	x	x	Prendergast et al., 2016	Prendergast, M.E., Rouby, H., Punnwong, P., Marchant, R., Crowther, A., Kourampas, N., Shipton, C., Walsh, M., Lambeck, K. and Boivin, N.L., 2016. Continental island formation and the archaeology of defaunation on Zanzibar, eastern Africa. PloS one, 11(2), p.e0149565.

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PE73	Lake Simbi	-0.367568	34.628954	Kenya	Lacustrine	Radiometric				x	Colombaroli et al., 2014	Daniele Colombaroli, Geert van der Plas, Stephen Rucina, Dirk Verschuren. 2016. Determinants of savanna-fire dynamics in the eastern Lake Victoria catchment (western Kenya) during the last 1200 years. Quaternary International.
PE74	Mount Kilimanjaro Glacier	-3.08	37.35	Tanzania	Ice	Stratigraphic	x	x	x	x	Thompson et al., 2002	Thompson, L.G., E. Mosley-Thompson, M.E. Davis, K.A. Henderson, H.H. Brecher, V.S. Zagorodnov, T.A. Mashiotta, P.-N. Lin, V.N. Mikhalenko, D.R. Hardy, and J. Beer, 2002. Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa. Science, Volume 298(5593), pp.589-593.
PE75	Gazi Bay forest	-4.418401	39.524468	Tanzania	Tree rings	Incremental				x	Verheyden et al., 2005	Verheyden, A., De Ridder, F., Schmitz, N., Beeckman, H. and Koedam, N., 2005. High-resolution time series of vessel density

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PE76	River Yala forests	-0.018776	34.215166	Kenya	Tree rings	Incremental				x	David et al., 2014	David, E.T., Chhin, S. and Skole, D., 2014. Dendrochronological potential and productivity of tropical tree species in western Kenya. Tree-Ring Research, 70(2), pp.119-135.
PE77	Ragati Forest Station	-0.58	37	Kenya	Tree rings	Incremental				x	Stahle et al., 2005	Stahle, D.W., Maingi, J., Munyao, M., 2005. Ragati Forest Station Nyeri District - VIKE - ITRDB KENY001 [data].
PE78	Malindi Marine Park	-3	40	Kenya	Coral	Incremental				x	Cole et al., 2004	Cole, J.E., Dunbar, R.B., McClanahan, T.R. and Muthiga, N.A., 2000. Tropical Pacific forcing of decadal SST variability in the western Indian Ocean over the past two centuries. Science, 287(5453), pp.617-619.
PE79	Lake Victoria (Sango Bay)	-0.863336	31.713277	Uganda	Lacustrine	Radiometric	x	x	x	x	Nakintu and Lejju, 2016	Nakintu, J. and Lejju, J., 2016. Environmental Dynamics of Lake Victoria: Evidence from

											a 10,000 14C yr Diatom Record from Napoleon Gulf and Sango Bay. Journal of Environmental Science and Engineering, 5, pp.626-637.
PE80	Lake Victoria (Napoleon Bay)	0.429024	33.236223	Uganda	Lacustrine	Radiometric	x	x	x	x	Nakintu and Lejju, 2016	Nakintu, J. and Lejju, J., 2016. Environmental Dynamics of Lake Victoria: Evidence from a 10,000 14C yr Diatom Record from Napoleon Gulf and Sango Bay. Journal of Environmental Science and Engineering, 5, pp.626-637.
PE81	Lake Albert	1.835	31.17	Uganda	Lacustrine	Radiometric	x	x	x	x	Beuning et al., 1997	Beuning, K.R., Talbot, M.R. and Kelts, K., 1997. A revised 30,000-year paleoclimatic and paleohydrologic history of Lake Albert, East Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, 136(1-4), pp.259-279.
PE82	Lake Tanganyika	-8.385863	30.96946	Tanzania	Lacustrine	Radiometric	x	x	x	x	Linginstone, 1965	Livingstone, D.A., 1965. Sedimentation and the history of water level change in Lake

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												Tanganyika. Limnology and Oceanography, 10(4), pp.607-610.
PE83	Lake Kivu	-2.046969	29.185875	Rwanda	Lacustrine	Radiometric	x	x	x	x	Haberyan and Hecky, 1987	Haberyan, K.A. and Hecky, R.E., 1987. The late Pleistocene and Holocene stratigraphy and paleolimnology of Lakes Kivu and Tanganyika. Palaeogeography, Palaeoclimatology, Palaeoecology, 61, pp.169-197.
PE84	Lake Baringo	0.632467	36.05745	Kenya	Lacustrine	Radiometric				x	Bessems et al., 2008	Bessems, I., Verschuren, D., Russell, J.M., Hus, J., Mees, F. and Cumming, B.F., 2008. Palaeolimnological evidence for widespread late 18th century drought across equatorial East Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, 259(2), pp.107-120.
PE85	Lake Bogoria	0.256462	36.102878	Kenya	Lacustrine	Radiometric				x	De Cort et al., 2013	De Cort, G., Bessems, I., Keppens, E., Mees, F., Cumming, B. and Verschuren, D., 2013. Late-Holocene and recent hydroclimatic

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												variability in the central Kenya Rift Valley: the sediment record of hypersaline lakes Bogoria, Nakuru and Elementeita. Palaeogeography, palaeoclimatology, palaeoecology, 388, pp.69-80
PE86	Lake Naivasha	-0.775383	36.371464	Kenya	Lacustrine	Radiometric	x	x	x	x	Richardson and Dussinger, 1986	Richardson, J.L. and Dussinger, R.A., 1986. Paleolimnology of mid-elevation lakes in the Kenya Rift Valley. Hydrobiologia, 143(1), pp.167-174.
PE87	Lake Elementeita	-0.4431	36.246814	Kenya	Lacustrine	Radiometric				x	De Cort et al., 2013	De Cort, G., Bessems, I., Keppens, E., Mees, F., Cumming, B. and 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, pp.69-80

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PE88	Lake Nakuru	-0.366669	36.083336	Kenya	Lacustrine	Radiometric				x	De Cort et al., 2013	De Cort, G., Bessems, I., Keppens, E., Mees, F., Cumming, B. and 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, pp.69-80
PE89	Lake Edward	-0.32864	29.695011	Uganda	Lacustrine	Radiometric	x	x	x	x	Russell et al., 2003	Russell, J. M., Johnson, T. C., Kelts, K. R., Lærdal, T., & Talbot, M. R. (2003). An 11 000-year lithostratigraphic and paleohydrologic record from equatorial Africa: Lake Edward, Uganda–Congo. Palaeogeography, Palaeoclimatology, Palaeoecology, 193(1), 25-49.
PE90	Lake Kitigata	-0.063933	29.975111	Uganda	Lacustrine	Radiometric			x	x	Russell et al., 2007	Russell, J.M., Verschuren, D. and Eggermont, H., 2007. Spatial complexity of

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												'Little Ice Age'climate in East Africa: sedimentary records from two crater lake basins in western Uganda. The Holocene, 17(2), pp.183-193.
PE91	Lake Kibengo	-0.083288	30.176303	Uganda	Lacustrine	Radiometric			x	x	Russell et al., 2007	Russell, J.M., Verschuren, D. and Eggermont, H., 2007. Spatial complexity of 'Little Ice Age'climate in East Africa: sedimentary records from two crater lake basins in western Uganda. The Holocene, 17(2), pp.183-193.
PE92	Kashiru Swamp	-3.466667	29.566667	Burundi	Palustrine	Radiometric	x	x	x	x	Bonnefille and Riollet, 1988	Bonnefille, R. and Riollet, G., 1988. The Kashiru pollen sequence (Burundi) palaeoclimatic implications for the last 40,000 yr BP in tropical Africa. Quaternary Research, 30(1), pp.19-35.
PE93	Rusaka Swamp	-3.43333	29.61667	Burundi	Palustrine	Radiometric	x	x	x	x	Bonnefille et al., 1997	Bonnefille, R., Riollet, G., Buchet, G., Icole, M., Lafont, R., Arnold, M. and Jolly, D., 1995.

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PE94	Kamiranzovu Swamp	-2.666751	29.083309	Burundi	Palustrine	Radiometric	x	x	x	x	Jolly et al., 1997	Jolly, D., Taylor, D., Marchant, R., Hamilton, A., Bonnefille, R., Buchet, G. and Riollet, G., 1997. Vegetation dynamics in central Africa since 18,000 yr BP: pollen records from the interlacustrine highlands of Burundi, Rwanda and western Uganda. Journal of Biogeography, 24(4), pp.492-512.
PE95	Lake Bunyoni	-1.296358	29.914179	Uganda	Lacustrine	Radiometric	x	x	x	x	Morrison and Hamilton, 1974	Morrison, M.E. and Hamilton, A.C., 1974. Vegetation and climate in the uplands of south-western Uganda during the later Pleistocene Period: II. Forest clearance and other vegetational changes in the Rukiga Highlands during the past 8000 Years. The Journal of

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												Ecology, pp.1-31.
PE96	Lake Kyasanduka	-0.289778	30.050167	Uganda	Lacustrine	Radiometric			x	x	Mills et al., 2014	Mills, K., Ryves, D.B., Anderson, N.J., Bryant, C.L. and Tyler, J.J., 2014. Expressions of climate perturbations in western Ugandan crater lake sediment records during the last 1000 years. Climate of the Past, 10(4), pp.1581-1601.
PE97	Lake Nyamogusingiri	-0.284583	30.012972	Uganda	Lacustrine	Radiometric				x	Mills et al., 2014	Mills, K., Ryves, D.B., Anderson, N.J., Bryant, C.L. and Tyler, J.J., 2014. Expressions of climate perturbations in western Ugandan crater lake sediment records during the last 1000 years. Climate of the Past, 10(4), pp.1581-1601.
PE98	Kitandara Lake	0.347999	29.886435	Uganda	Lacustrine	Radiometric	x	x	x	x	Livingstone, 1967	Livingstone, D.A., 1967. Postglacial vegetation of the Ruwenzori Mountains in equatorial Africa. Ecological Monographs, 37(1), pp.25-52.
PE99	Hobley Valley mire	-0.172331	37.324141	Kenya	Palustrine	Palynostratigraphy	x	x	x	x	Perrott, 1982a	Perrott, R.A., 1982a. A high altitude pollen

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												diagram from Mount Kenya: Its implications for the history of glaciation. Palaeoecology of Africa and the Surrounding Islands, 14, pp.77-83.
PE100	Small Hall Tarn	-0.15	37.35	Kenya	Lacustrine	Radiometric	x	x	x	x	Barker et al., 2001	Barker, P.A., Street-Perrott, F.A., Leng, M.J., Greenwood, P.B., Swain, D.L., Perrott, R.A., Telford, R.J. and Ficken, K.J., 2001. A 14,000-year oxygen isotope record from diatom silica in two alpine lakes on Mt. Kenya. Science, 292(5525), pp.2307-2310.
PE101	Simba Tarn	-0.148462	37.322271	Kenya	Lacustrine	Radiometric	x	x	x	x	Barker et al., 2001	Barker, P.A., Street-Perrott, F.A., Leng, M.J., Greenwood, P.B., Swain, D.L., Perrott, R.A., Telford, R.J. and Ficken, K.J., 2001. A 14,000-year oxygen isotope record from diatom silica in two alpine lakes on Mt. Kenya. Science, 292(5525), pp.2307-2310.

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PE102	Mount Satima mire	-0.346477	36.61424	Kenya	Palustrine	Palynostratigraphy	x	x	x	x	Perrott, 1982b	Perrott, R.A., 1982b. A postglacial pollen record from Mount Satima, Aberdare Range, Kenya. In: Amer. Quat. Assoc. Seventh Biennial Conference Seattle, June 1982. Program and Abstracts, 188 pp
PE103	Mau Narok forest	-0.666667	36	Kenya	Tree rings	Incremental				x	Krishnamurthy and Epstein, 1985	Krishnamurthy, R.V. and Epstein, S., 1985. Tree ring D/H ratio from Kenya, East Africa and its palaeoclimatic significance. Nature, 317(6033), pp.160-162.
PE104	Ngisonyoka forest	1.95	36.02	Kenya	Tree rings	Incremental				x	Wyant and Reid, 1992	Wyant, J.G. and Reid, R.S., 1992. Determining the age of Acacia tortilis with ring counts for South Turkana, Kenya: a preliminary assessment. African Journal of Ecology, 30(2), pp.176-180.
PE105	Lake Basotu	-4.369722	35.072778	Tanzania	Lake surface areas	Repeat imagery				x	Higgins et al., 2016	Higgins, L., Koutsouris, A.J., Westerberg, L.O. and Risberg, J., 2016. Surface Area Variability of a North-Central Tanzanian Crater Lake. Geosciences, 6(2),

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PE106	Lake Rukwa	-8.430072	32.820293	Tanzania	Lacustrine	Radiometric	x	x	x	x	Haberyan, 1987	Haberyan, K.A., 1987. Fossil diatoms and the paleolimnology of Lake Rukwa, Tanzania. Freshwater Biology, 17(3), pp.429-440
PE107	Lake Chibwera	-0.155148	30.141612	Uganda	Lacustrine	Radiometric				x	Bessems et al., 2008	Bessems, I., Verschuren, D., Russell, J.M., Hus, J., Mees, F. and Cumming, B.F., 2008. Palaeolimnological evidence for widespread late 18th century drought across equatorial East Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, 259(2), pp.107-120
PE108	Lake Kanyamukali	0.4	30.233333	Uganda	Lacustrine	Radiometric				x	Bessems et al., 2008	Bessems, I., Verschuren, D., Russell, J.M., Hus, J., Mees, F. and Cumming, B.F., 2008. Palaeolimnological evidence for widespread late 18th century drought across equatorial East Africa. Palaeogeography, Palaeoclimatology,

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												Palaeoecology, 259(2), pp.107-121
PE109	Kibwezi lava flow	-2.5	38.166667	Kenya	Soil	Radiometric				x	Saggerson, 1963	Saggerson, EP. 1963. Geology of the Simba-Kibwezi area, Geological Survey of Kenya, Report. No. 58, Nairobi.
PE110	Fungu Mrima reef	-8.017306	39.506669	Tanzania	coral	Incremental				x	Damassa et al., 2006	Damassa, T.D., Cole, J.E., Barnett, H.R., Ault, T.R. and McClanahan, T.R., 2006. Enhanced multidecadal climate variability in the seventeenth century from coral isotope records in the western Indian Ocean. Paleoceanography, 21(2), PA2016.
PE111	Malindi Marine Park	-3.295728	40.140336	Kenya	coral	Incremental				x	Nakamura et al., 2009	Nakamura, N., Kayanne, H., Iijima, H., McClanahan, T.R., Behera, S.K. and Yamagata, T., 2009. Mode shift in the Indian Ocean climate under global warming stress. Geophysical Research Letters, 36(23), L23708.
PE112	Mount Gahinga crater	-1.386793	29.645011	Uganda	Palustrine	Radiometric	x	x	x	x	McGlynn et al., 2014	McGlynn, G., Mooney, S. and Taylor, D.,

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											2013. Palaeoecological evidence for Holocene environmental change from the Virunga volcanoes in the Albertine Rift, central Africa. Quaternary Science Reviews, 61, pp.32-46.
PE113	Mount Muhavura crater	-1.382945	29.677894	Uganda	Lacustrine	Radiometric	x	x	x	x	McGlynn et al., 2014	McGlynn, G., Mooney, S. and Taylor, D., 2013. Palaeoecological evidence for Holocene environmental change from the Virunga volcanoes in the Albertine Rift, central Africa. Quaternary Science Reviews, 61, pp.32-46.
PE114	Lake Malawi (M98-1P)	-10.265	34.318333	Tanzania	Lacustrine	Radiometric	x	x	x	x	Johnson et al., 2002	Johnson, T.C., Brown, E.T., McManus, J., Barry, S., Barker, P. and Gasse, F., 2002. A high-resolution paleoclimate record spanning the past 25,000 years in southern East Africa. Science, 296(5565), pp.113-132.
PE115	Lake Malawi (M98-2P)	-9.976667	34.23	Tanzania	Lacustrine	Radiometric	x	x	x	x	Johnson et al., 2002	Johnson, T.C., Brown, E.T., McManus, J., Barry, S., Barker, P.

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												and Gasse, F., 2002. A high-resolution paleoclimate record spanning the past 25,000 years in southern East Africa. Science, 296(5565), pp.113-132.
PE116	Lake Malawi (M98-11-MC)	-10	34.25	Tanzania	Lacustrine	Radiometric				x	Johnson et al., 2001	Johnson, T.C., Barry, S.L., Chan, Y. and Wilkinson, P., 2001. Decadal record of climate variability spanning the past 700 yr in the Southern Tropics of East Africa. Geology, 29(1), pp.83-86.
PE117	Lake Malawi (MAL2A,B,C)	-10.017662	34.186012	Tanzania	Lacustrine	Radiometric	x	x	x	x	Scholz et al., 2011	Scholz, C.A., Cohen, A.S., Johnson, T.C., King, J., Talbot, M.R. and Brown, E.T., 2011. Scientific drilling in the Great Rift Valley: the 2005 Lake Malawi Scientific Drilling Project—an overview of the past 145,000 years of climate variability in Southern Hemisphere East Africa. Palaeogeography, Palaeoclimatology,

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												Palaeoecology, 303(1), pp.3-19
PE118	Lake Malawi (MAL1A,B,C,D,13P)	-11.293978	34.437218	Tanzania	Lacustrine	Radiometric	x	x	x	x	Scholz et al., 2011	Scholz, C.A., Cohen, A.S., Johnson, T.C., King, J., Talbot, M.R. and Brown, E.T., 2011. Scientific drilling in the Great Rift Valley: the 2005 Lake Malawi Scientific Drilling Project—an overview of the past 145,000 years of climate variability in Southern Hemisphere East Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, 303(1), pp.3-19
PE119	Lake Rutundu	-0.041197	37.463479	Kenya	Lacustrine	Radiometric	x	x	x	x	Coetzee, 1967	Coetzee, J.A., 1967. Pollen analytical studies in East and Southern Africa.. Palaeoecology of Africa, 3, pp.1-146.
PE120	Lake Kayanja	-0.275972	31.867722	Uganda	Lacustrine	Radiometric	x	x	x	x	Lejju et al., unpublished	
PE121	Kimana Swamp	-2.748833	37.515367	Kenya	Palustrine	Radiometric				x	Githumbi et al., unpublished	
PE122	Ormakau Swamp	-2.717633	37.456183	Kenya	Palustrine	Radiometric			x	x	Githumbi et al., unpublished	
PE123	Kibasira	-8.348496	36.271884	Tanzania	Lake surface	Repeat imagery				x	Hamidu et al.,	

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					areas						unpublished	
PE124	Lake Kasenda	0.432038	30.290342	Uganda	Lacustrine	Radiometric				x	Ssemmanda et al., 2005	Ssemmanda, I., Ryves, D.B., Bennike, O., Appleby, P.G., 2005. Vegetation history in west Uganda during the last 1200 years: a sediment-based reconstruction from two crater lakes. The Holocene 15, 119-132.
PE125	Lake Wandakara	0.416631	30.271169	Uganda	Lacustrine	Radiometric				x	Ssemmanda et al., 2005	Ssemmanda, I., Ryves, D.B., Bennike, O., Appleby, P.G., 2005. Vegetation history in west Uganda during the last 1200 years: a sediment-based reconstruction from two crater lakes. The Holocene 15, 119-132.
PE126	Kaisungor Swamp	1	35.466667	Kenya	Lacustrine	Radiometric	x	x	x	x	van Zinderen Bakker, 1962	van Zinderen Bakker, E.M. 1962. A late-glacial and post-glacial climatic correlation between East Africa and Europe. Nature, 194(4824), pp.201-203.
PE127	Lake Victoria (Napoleon Bay - Jinja)	0.448972	33.26875	Uganda	Lacustrine	Radiometric	x	x	x	x	Morgan and Lejju, 2012.	Morgan, A and Lejju J. 2012. Holocene climate and environmental history of Lake Victoria Basin - use of

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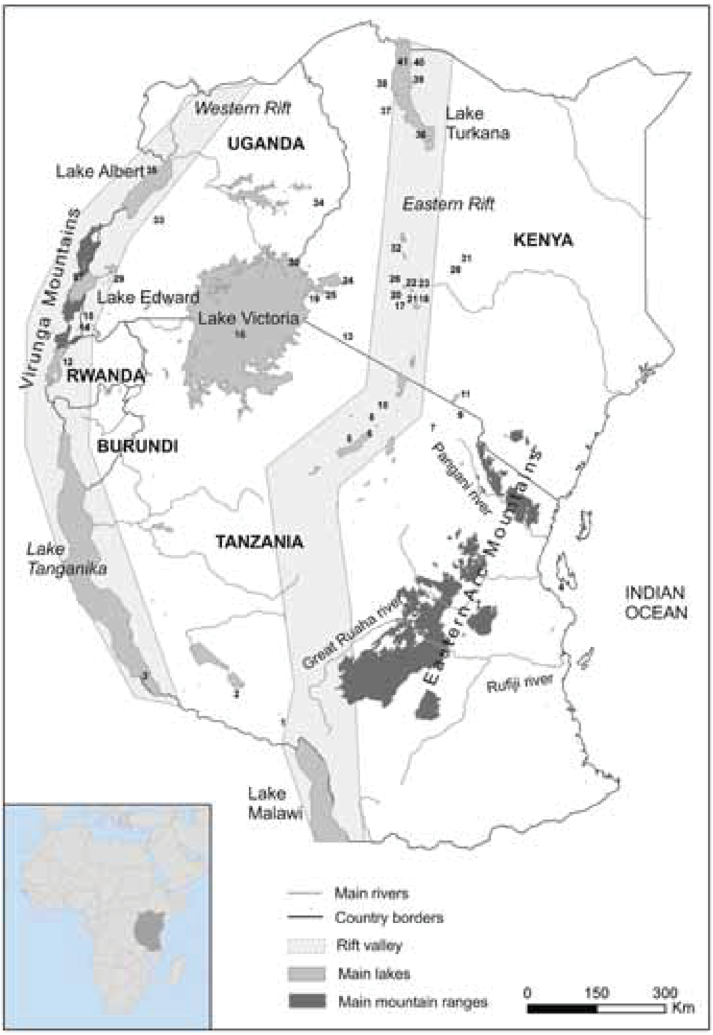
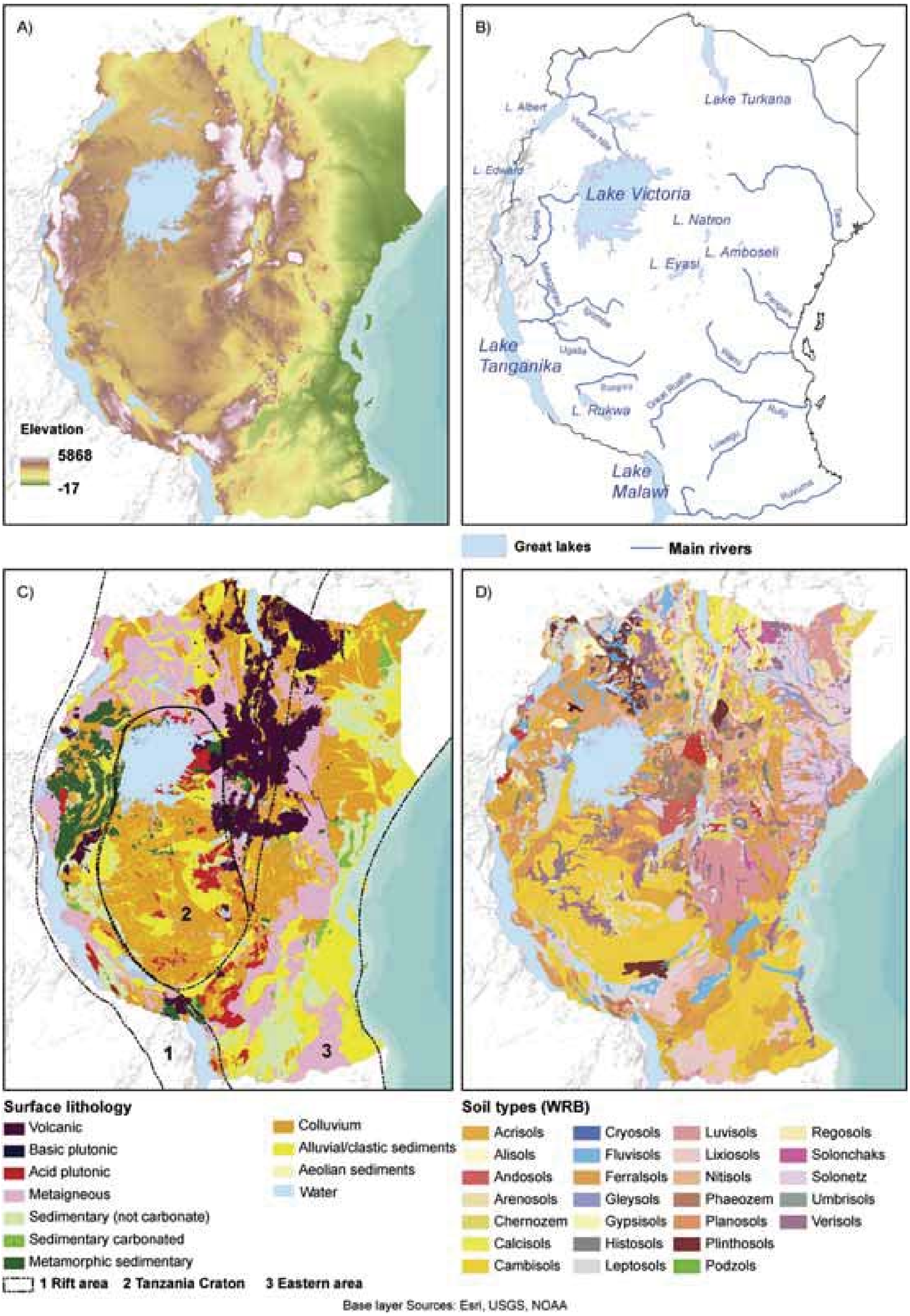
											biogeochemical proxies. LAP Lambert Academic Publishing.
PE128	Lake Victoria (Kagera)	-0.917222	31.774444	Uganda	Lacustrine	Radiometric	x	x	x	x	Morgan and Lejju, 2012.	Morgan, A and Lejju J. 2012. Holocene climate and environmental history of Lake Victoria Basin - use of biogeochemical proxies. LAP Lambert Academic Publishing.
PE129	Lake Victoria (Katonga)	-0.087056	32.089111	Uganda	Lacustrine	Radiometric	x	x	x	x	Morgan and Lejju, 2012.	Morgan, A and Lejju J. 2012. Holocene climate and environmental history of Lake Victoria Basin - use of biogeochemical proxies. LAP Lambert Academic Publishing.



Location
1. Lake Masoko
2. Lake Rukwa
3. Lake Tanganyika
4. Unguja Ukuu
5. Lake Eyasi
6. Mumba Rockshelter
7. Lake Duluti
8. Ngorongoro crater
9. Mount Kilimanjaro
10. Lake Emakat
11. Amboseli
12. Lake Kivu
13. Serengeti Masaai Mara
14. Muchoya swamp
15. Ahakagyezi swamp
16. Lake Victoria
17. Enkapune ya Muto
18. Lake Naivasha
19. Gogo Falls
20. Gamble's Cave
21. Prolonged Drift
22. Lake Elementeita
23. Aberdares
24. Wadh Lang'o
25. Lake Simbi
26. Lake Nakuru
27. Lake Edward (Rutanzige)
28. Mount Kenya
29. Lake Kibengo
30. Usenge
31. Sacred Lake
32. Lake Bogoria
33. Munsa
34. Mout Elgon
35. Lake Albert
36. Lake Turkana
37. Lothagam Hill
38. Lopoy
39. Jarigole
40. Dongodien
41. Koobi Fora

Figure 1



Base layer Sources: Esri, USGS, NOAA

Figure 2

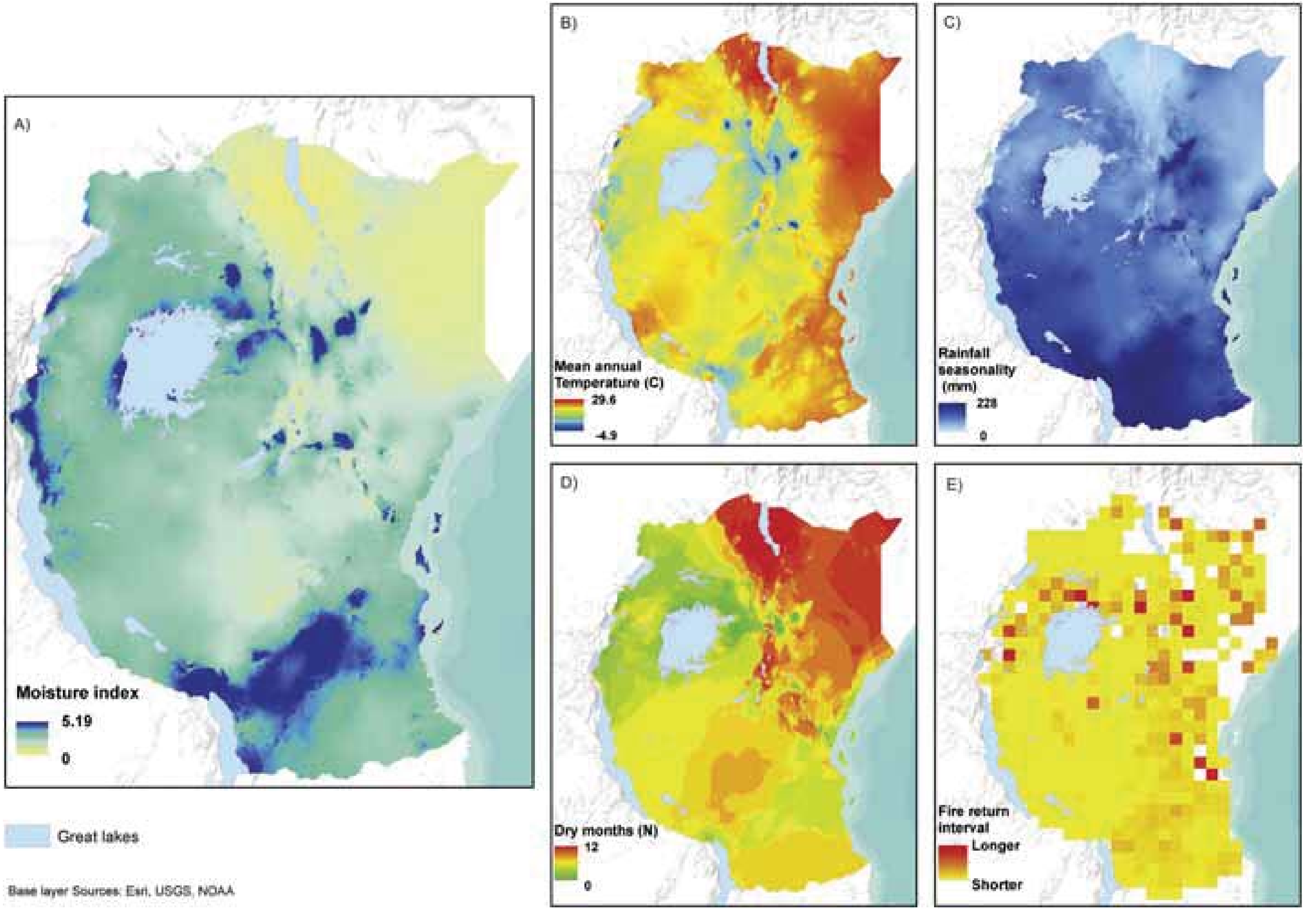
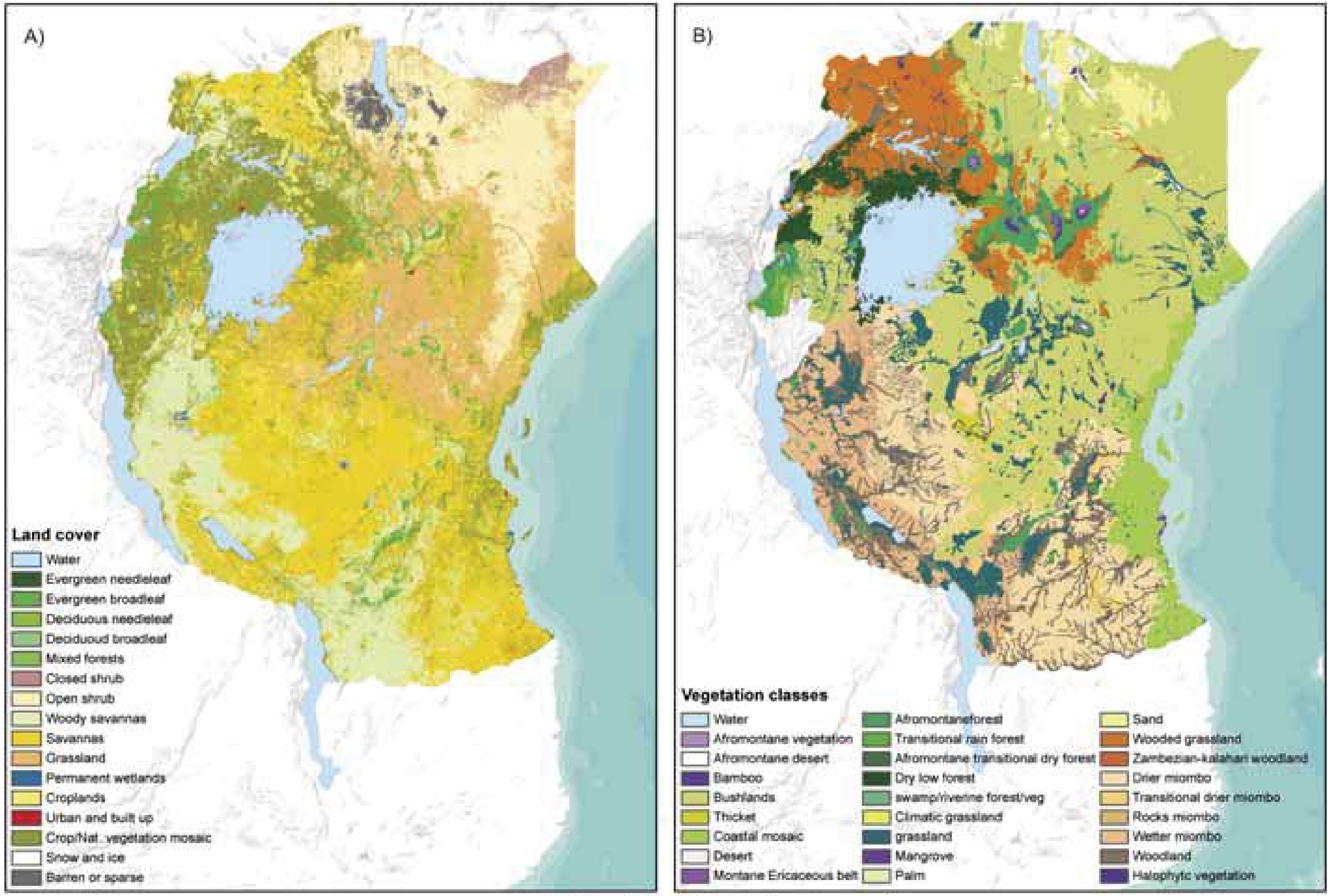

A)
Moisture index
5.19
0
Great lakes
Base layer Sources: Esri, USGS, NOAA
B)
Mean annual
Temperature (C)
29.6
-4.9
C)
Rainfall
seasonality
(mm)
228
0
D)
Dry months (N)
12
0
E)
Fire return
interval
Longer
Shorter

Figure 3



Base layer Sources: Esri, USGS, NOAA

Figure 4

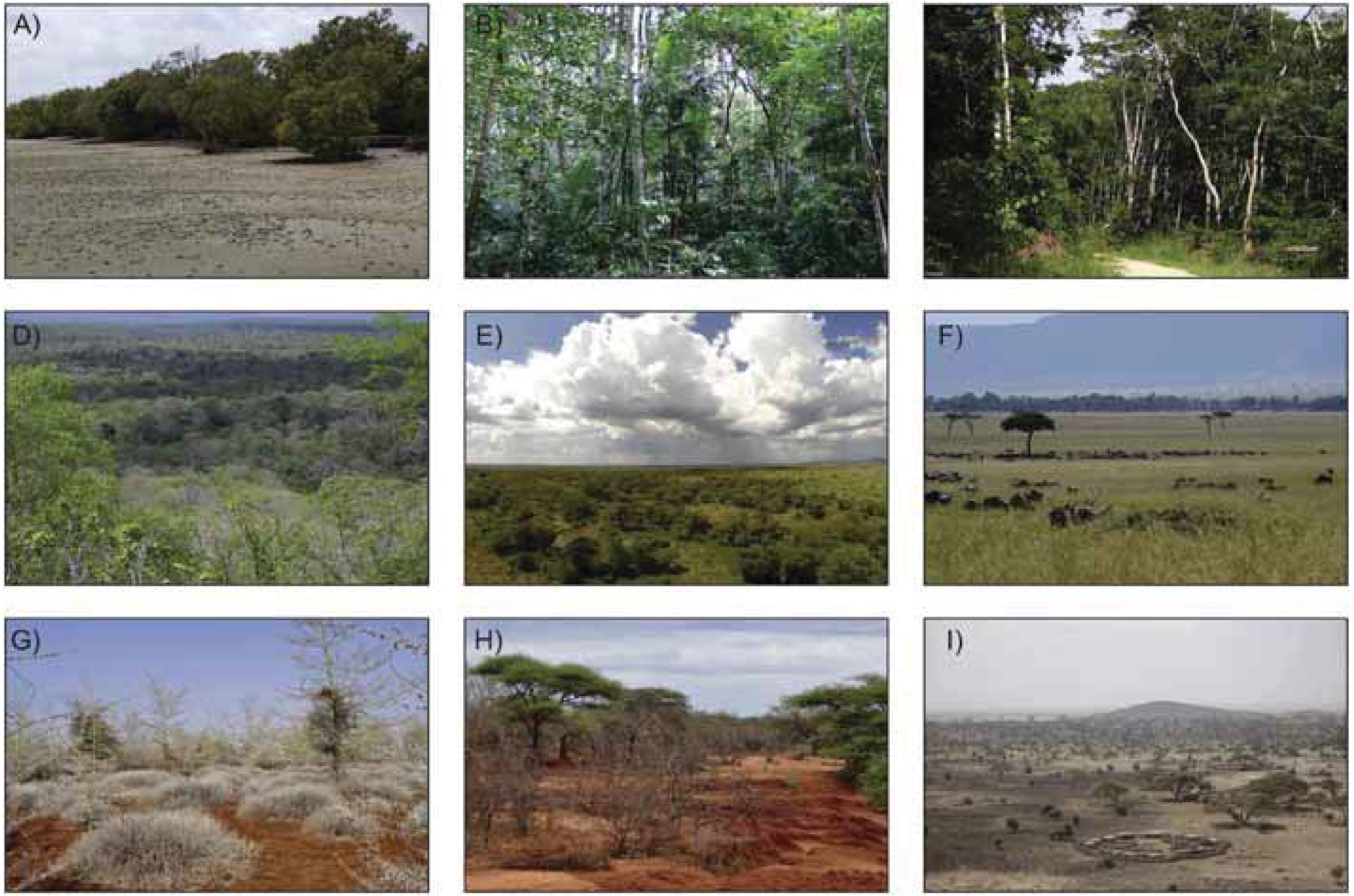


Figure 5

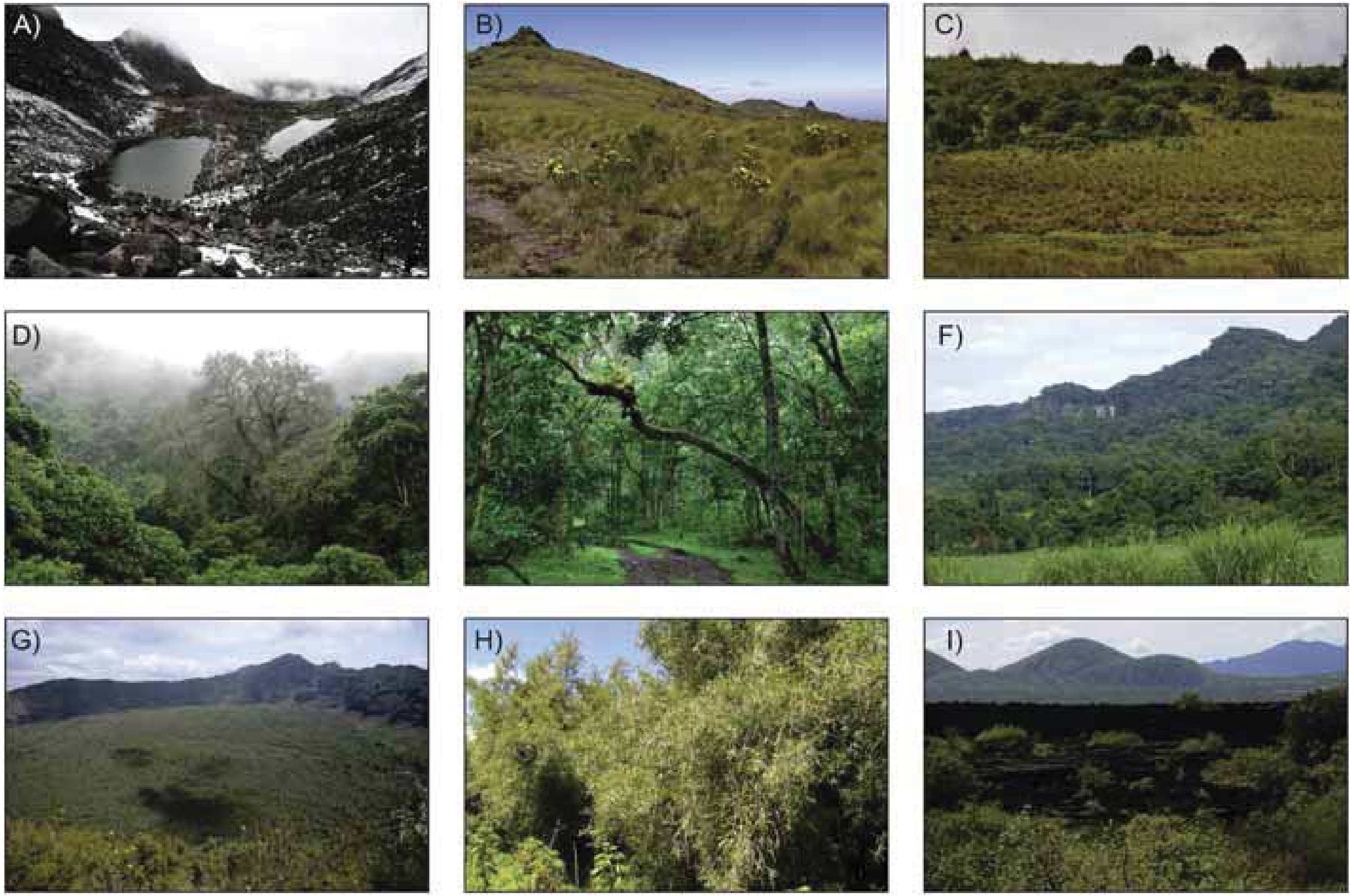


Figure 6

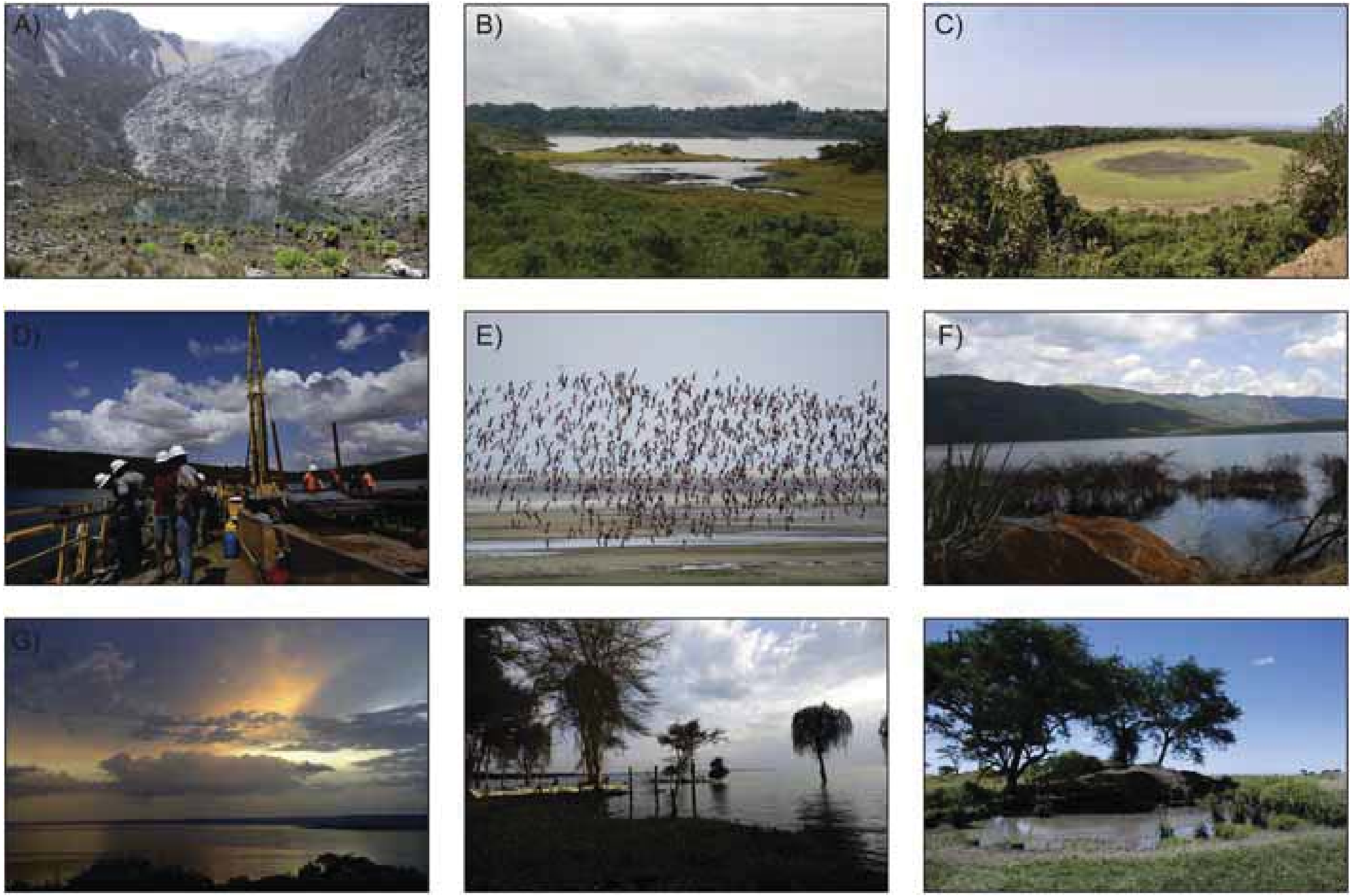


Figure 7

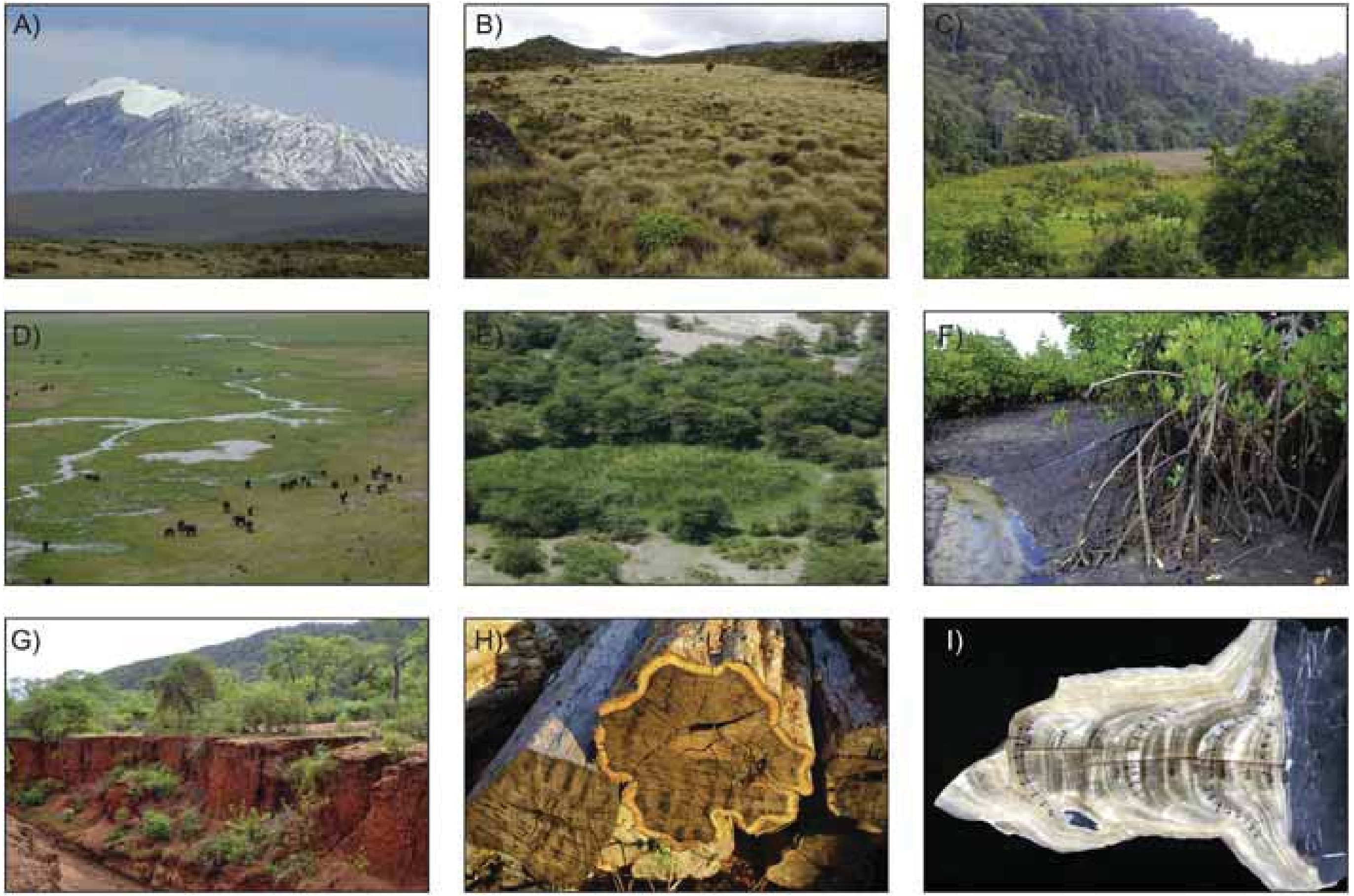
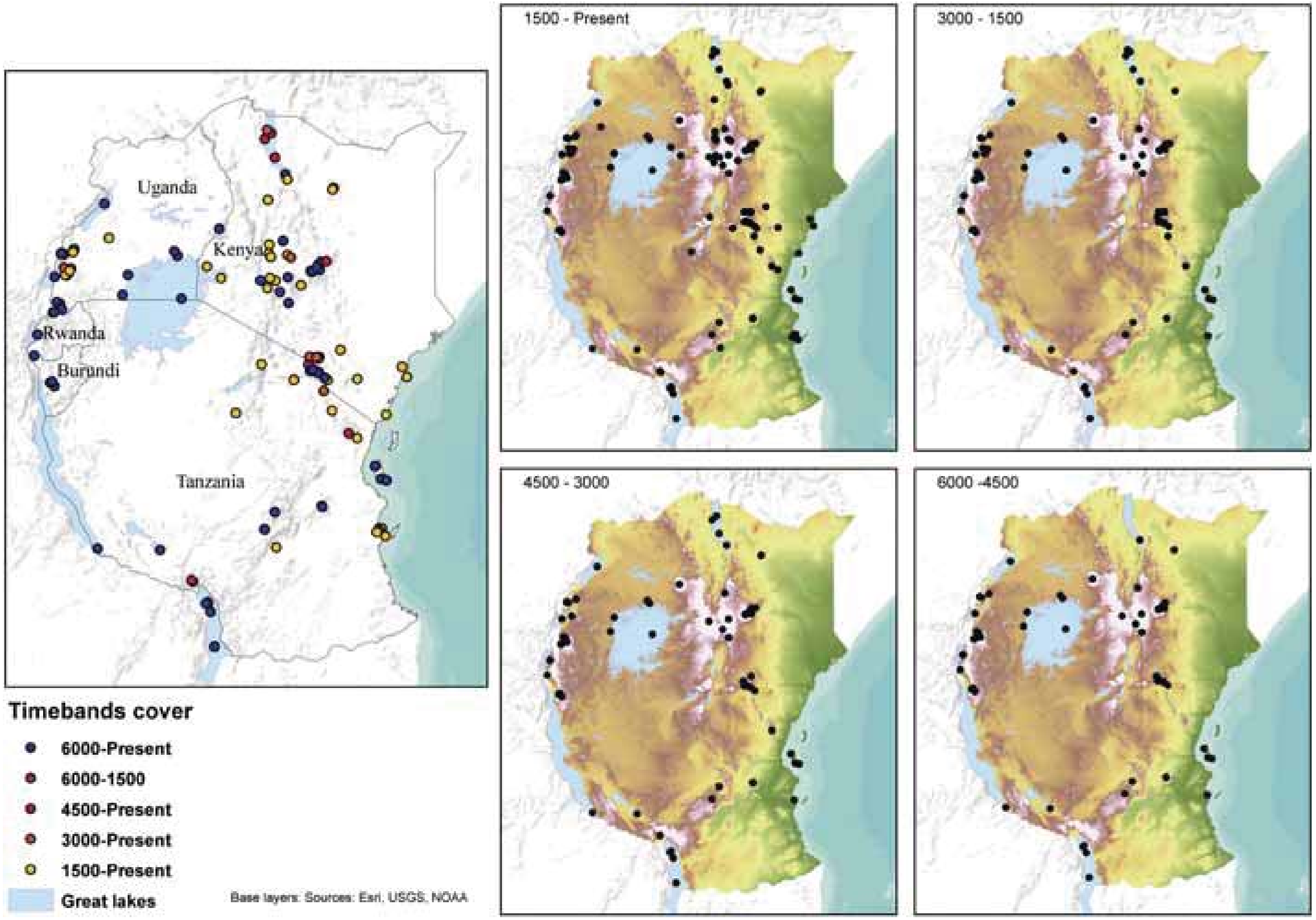


Figure 8



Base layers: Sources: Esri, USGS, NOAA

Figure 9

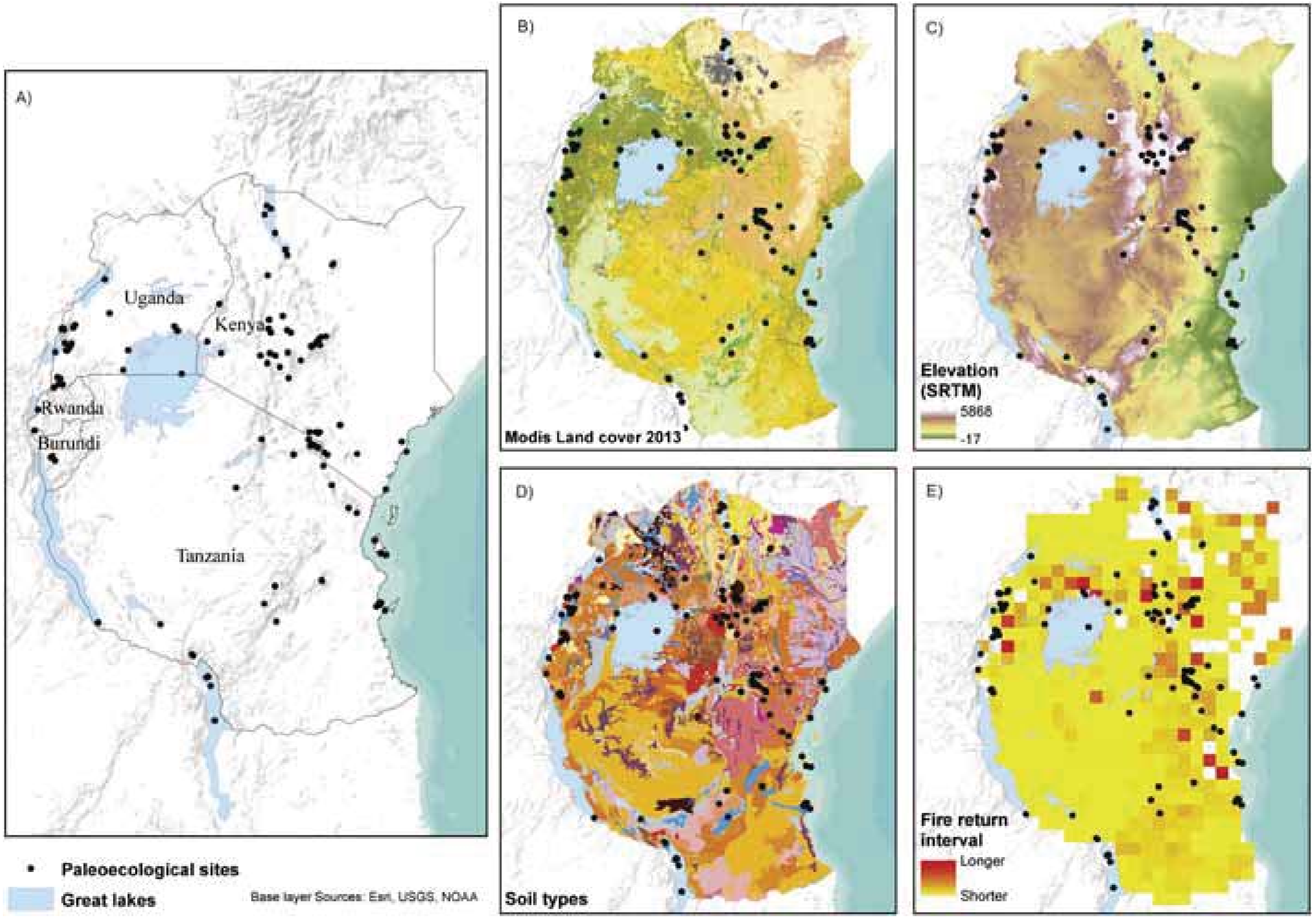

A)
Uganda
Kenya
Rwanda
Burundi
Tanzania
Paleoecological sites
Great lakes
Base layer Sources: Esri, USGS, NOAA
B)
Modis Land cover 2013
C)
Elevation (SRTM)
5868
-17
D)
Soil types
E)
Fire return interval
Longer
Shorter

Figure 10

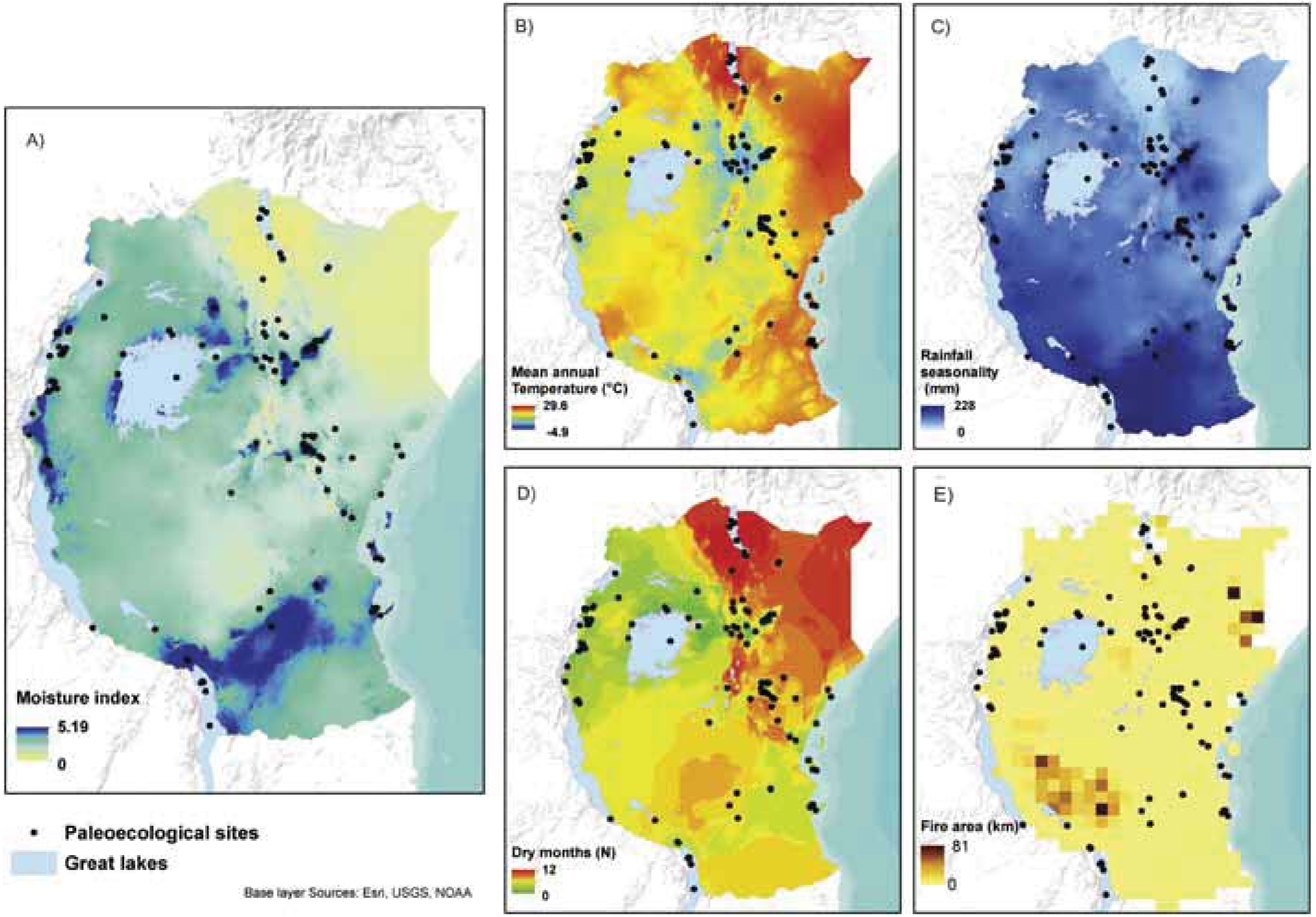

A)
Moisture index
5.19
0
• Paleoecological sites
Great lakes
Base layer Sources: Esri, USGS, NOAA
B)
Mean annual Temperature (°C)
29.6
-4.9
C)
Rainfall seasonality (mm)
228
0
D)
Dry months (N)
12
0
E)
Fire area (km²)
81
0

Figure 11

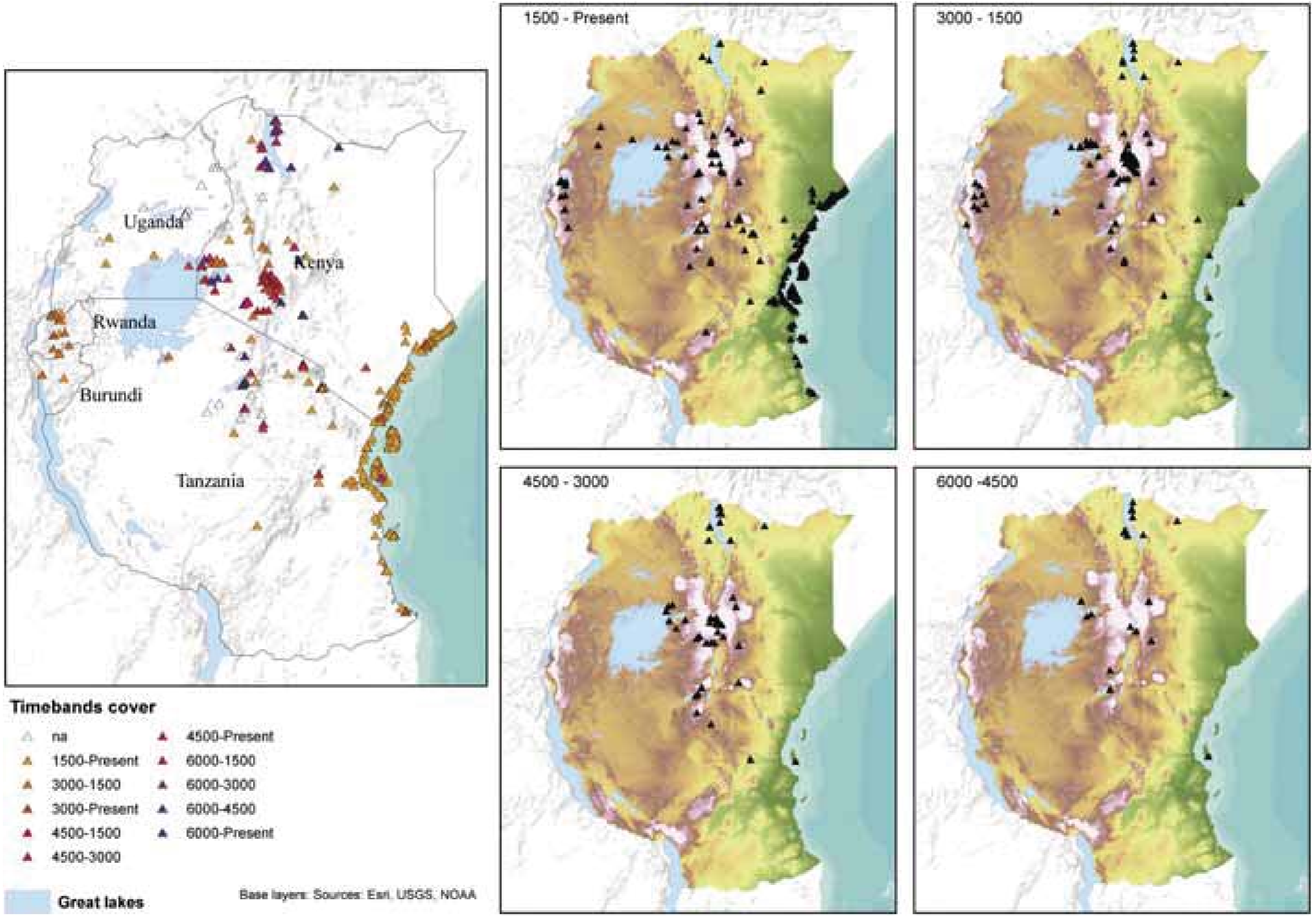

Uganda
Kenya
Rwanda
Burundi
Tanzania
Timebands cover
na
1500-Present
3000-1500
3000-Present
4500-1500
4500-3000
4500-Present
6000-1500
6000-3000
6000-4500
6000-Present
Great lakes
Base layers: Sources: Esri, USGS, NOAA
1500 - Present
3000 - 1500
4500 - 3000
6000 -4500

Figure 12

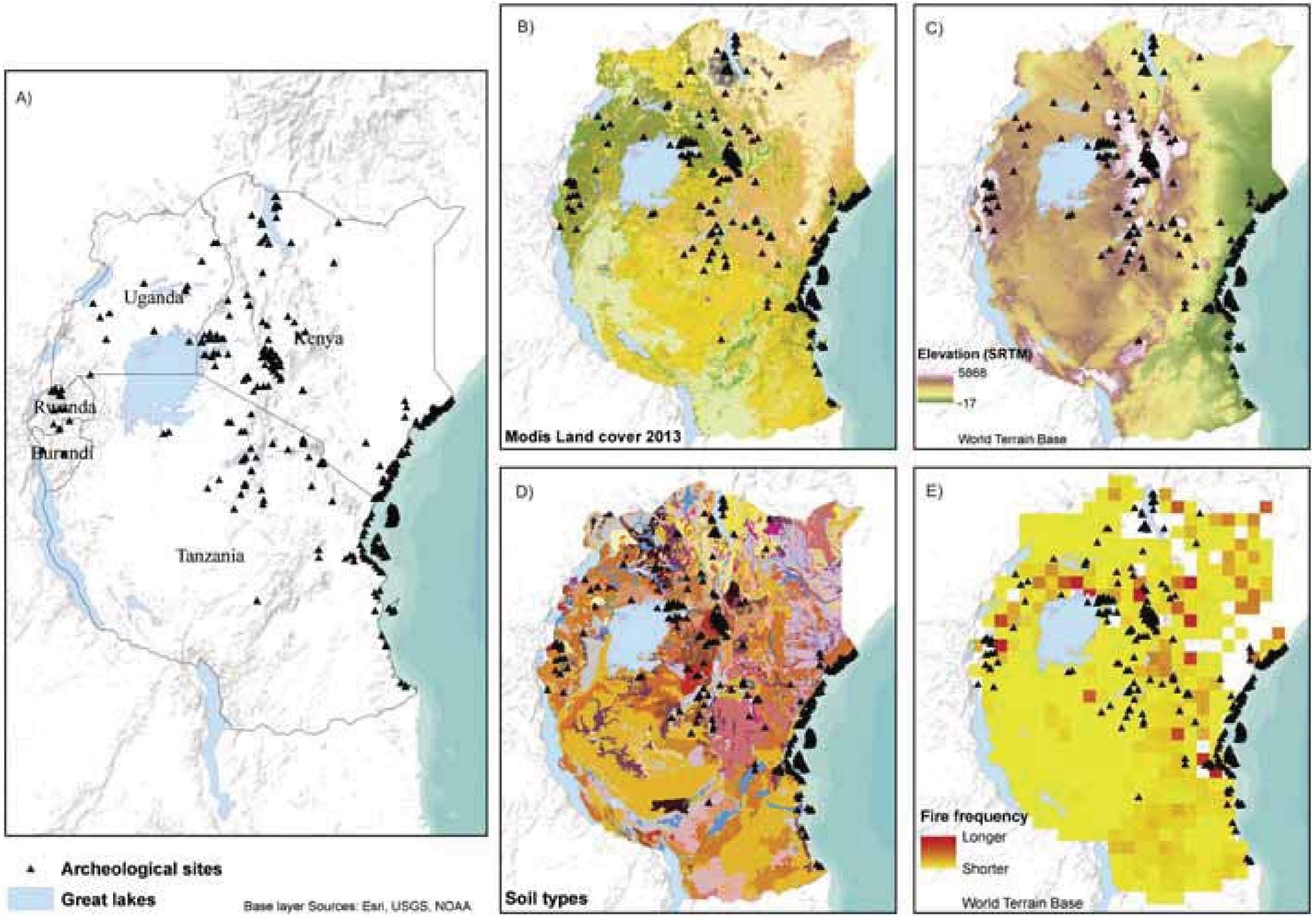

A)
Uganda
Kenya
Rwanda
Burundi
Tanzania
▲ Archeological sites
Great lakes
Base layer Sources: Esri, USGS, NOAA
B)
Modis Land cover 2013
C)
Elevation (SRTM)
5868
-17
World Terrain Base
D)
Soil types
E)
Fire frequency
Longer
Shorter
World Terrain Base

Figure 13

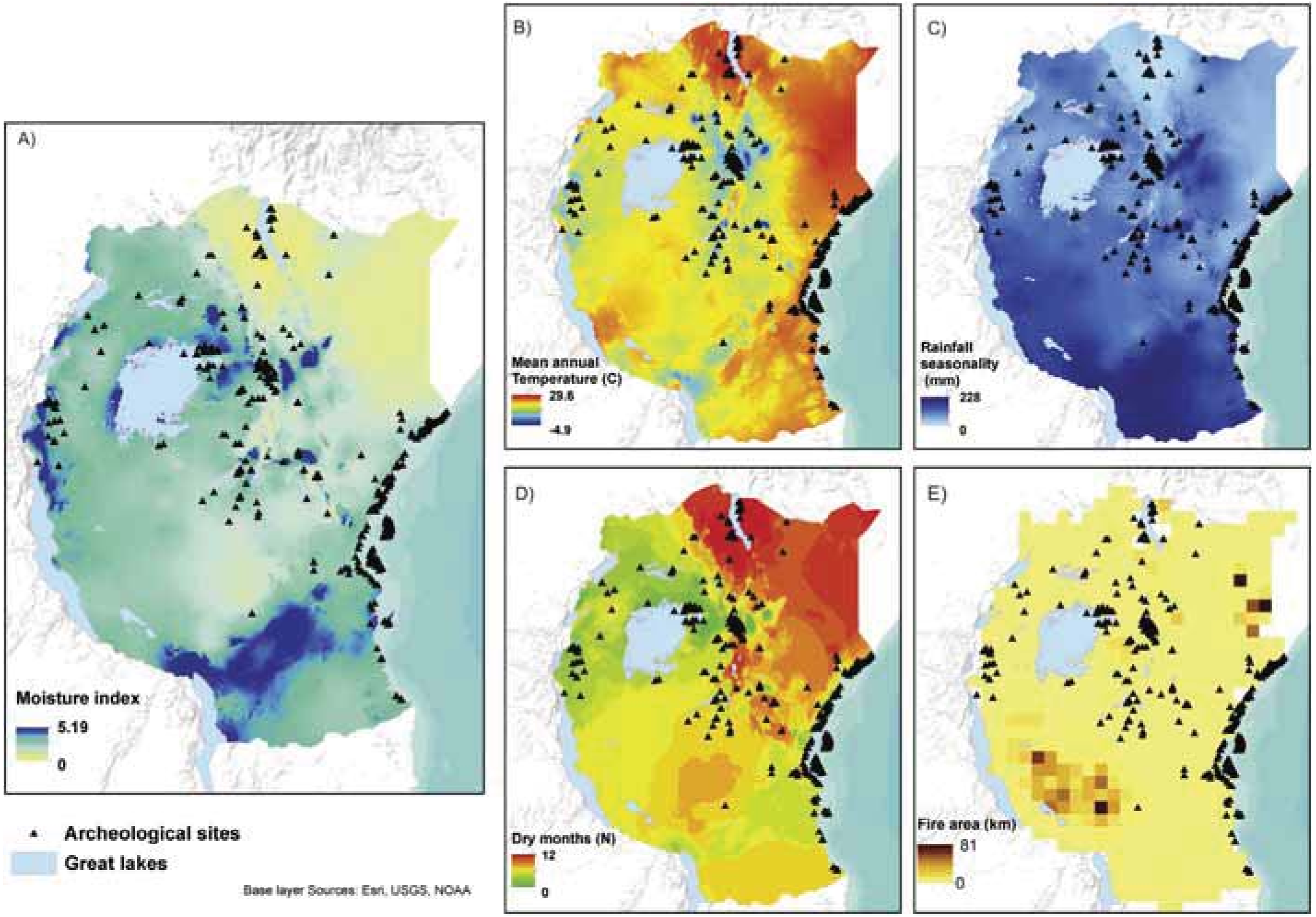

A)
Moisture index
5.19
0
Archeological sites
Great lakes
Base layer Sources: Esri, USGS, NOAA
B)
Mean annual Temperature (C)
29.6
-4.9
C)
Rainfall seasonality (mm)
228
0
D)
Dry months (N)
12
0
E)
Fire area (km)
81
0

Figure 14

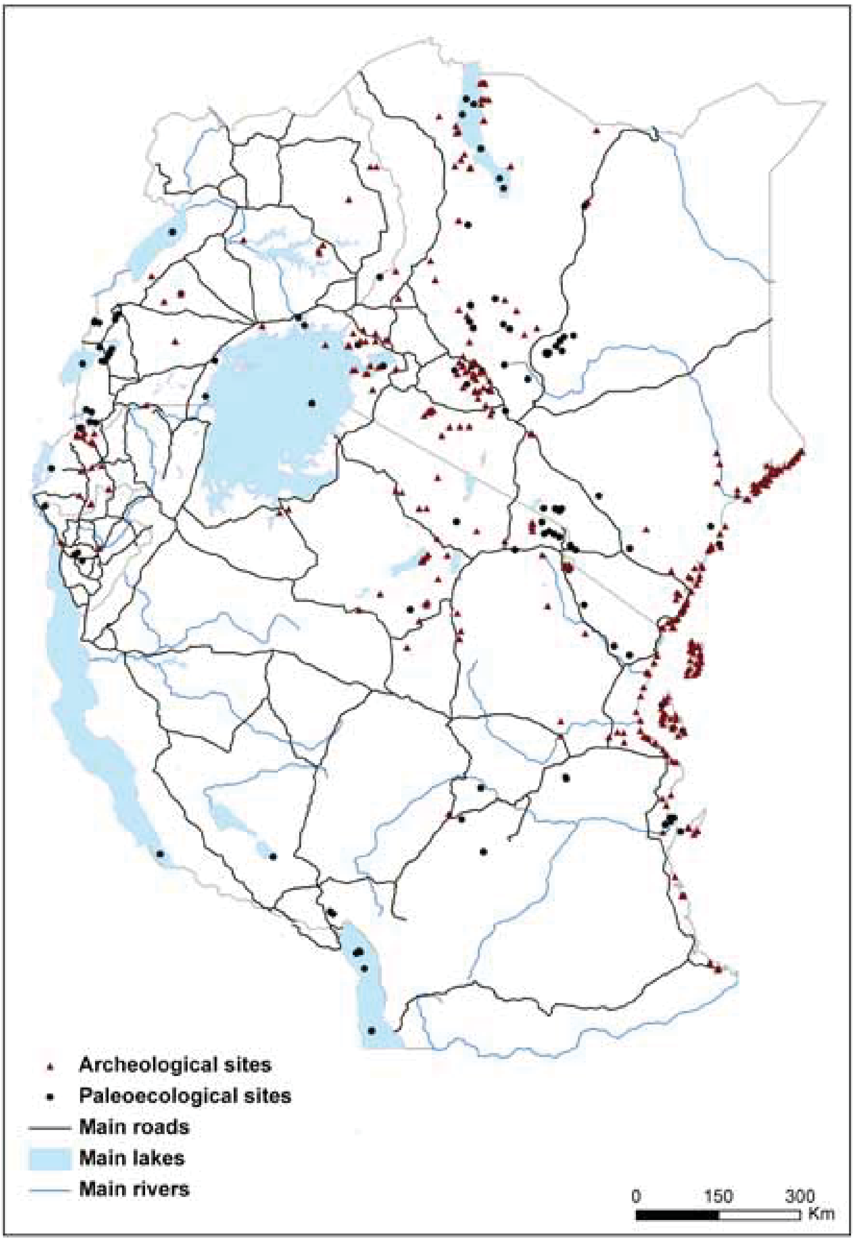

▲ Archeological sites
● Paleoecological sites
Main roads
Main lakes
Main rivers
0
150
300
Km

Figure 15

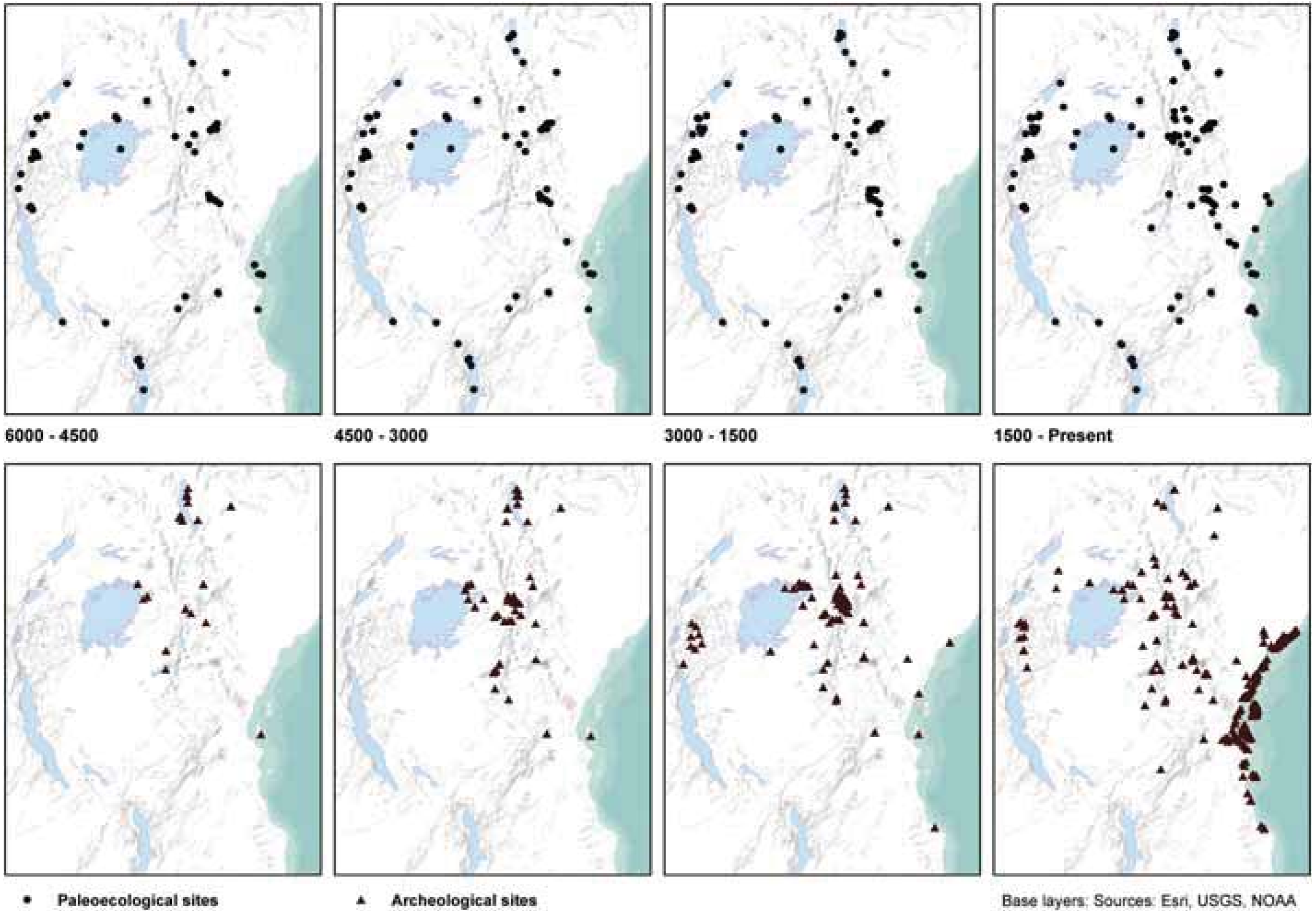

6000 - 4500
4500 - 3000
3000 - 1500
1500 - Present
● Paleoecological sites
▲ Archeological sites
Base layers: Sources: Esri, USGS, NOAA

Figure 16

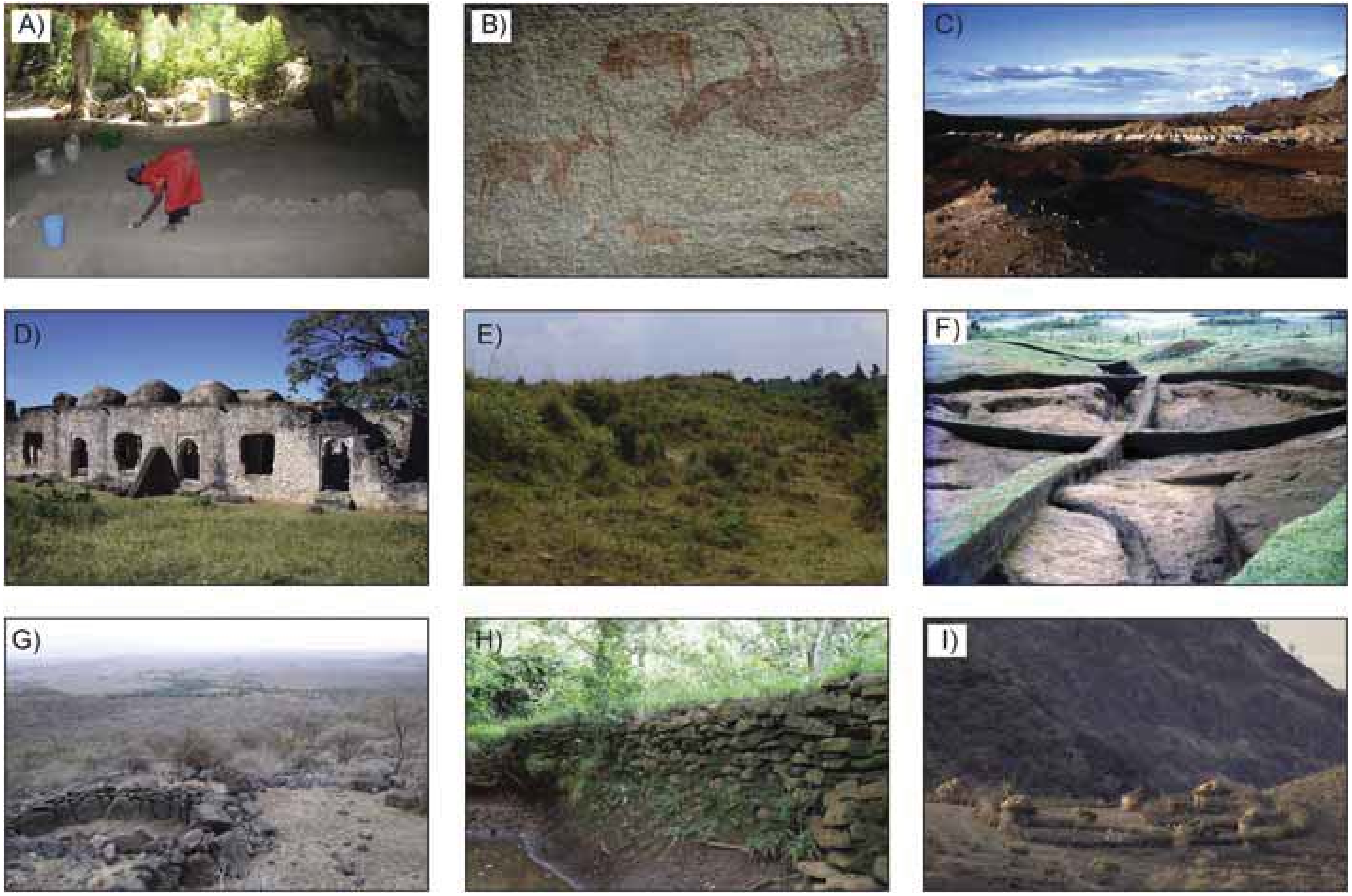


Figure 17

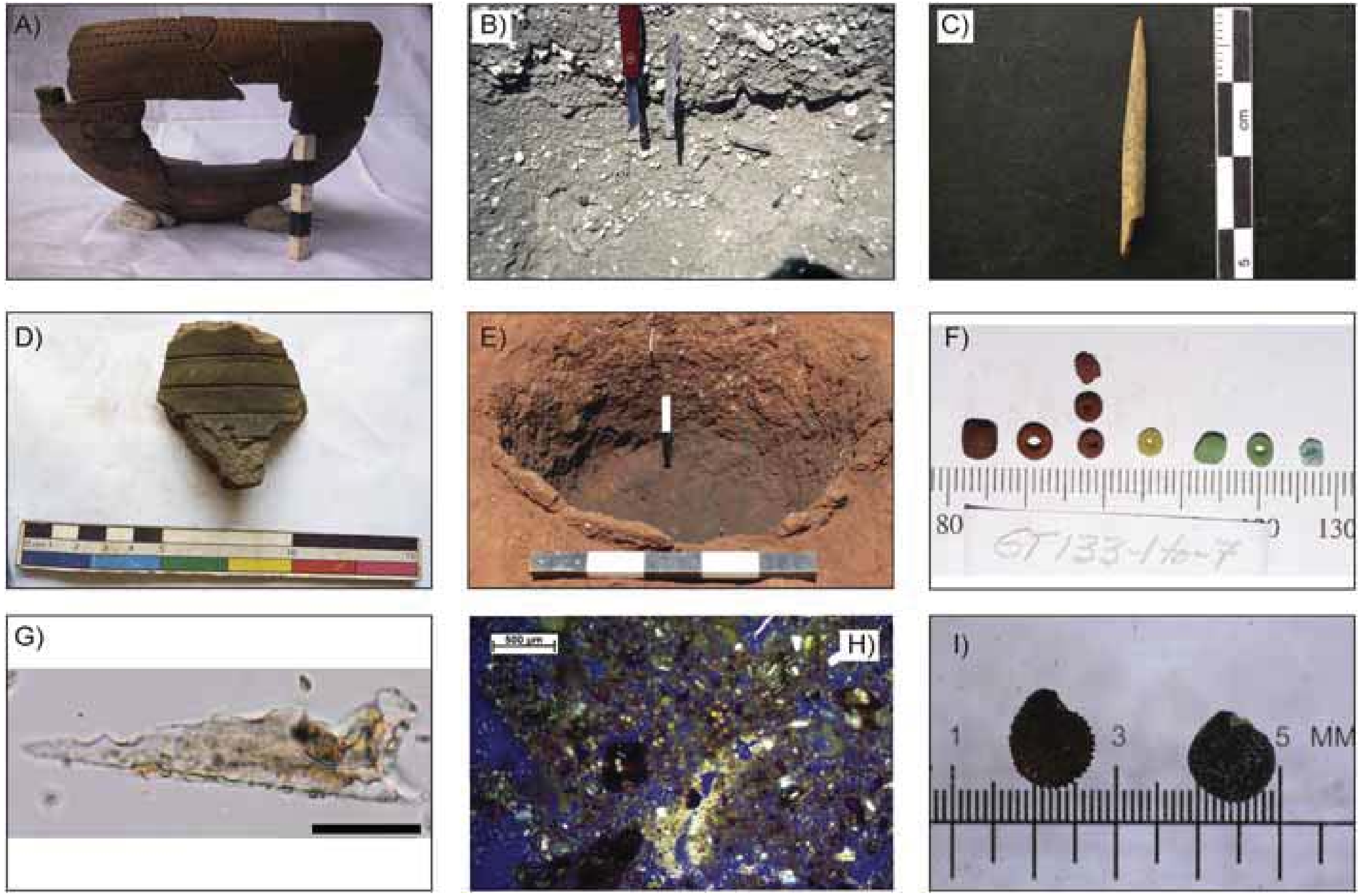


Figure 18

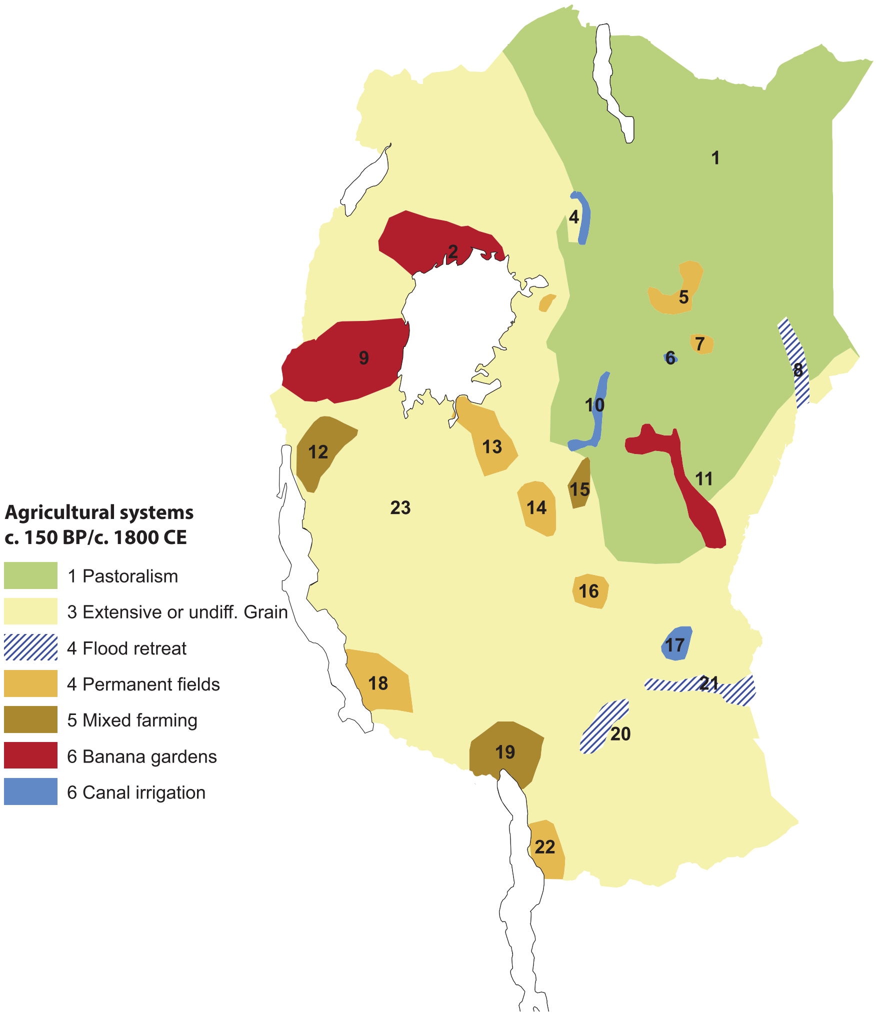

Agricultural systems
c. 150 BP/c. 1800 CE
1 Pastoralism
3 Extensive or undiff. Grain
4 Flood retreat
4 Permanent fields
5 Mixed farming
6 Banana gardens
6 Canal irrigation
1
2
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

Figure 19

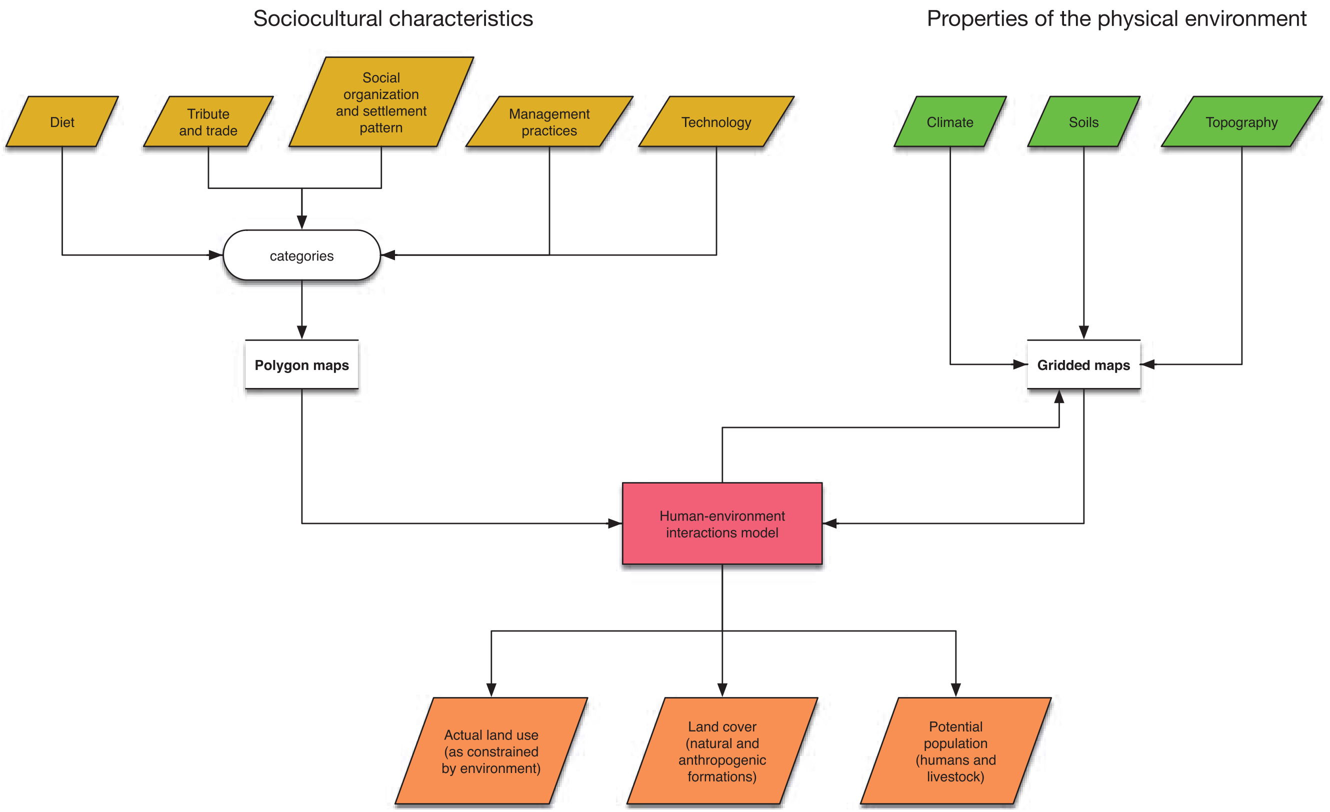

Sociocultural characteristics
Properties of the physical environment
Diet
Tribute and trade
Social organization and settlement pattern
Management practices
Technology
Climate
Soils
Topography
categories
Polygon maps
Gridded maps
Human-environment interactions model
Actual land use (as constrained by environment)
Land cover (natural and anthropogenic formations)
Potential population (humans and livestock)

Figure 20

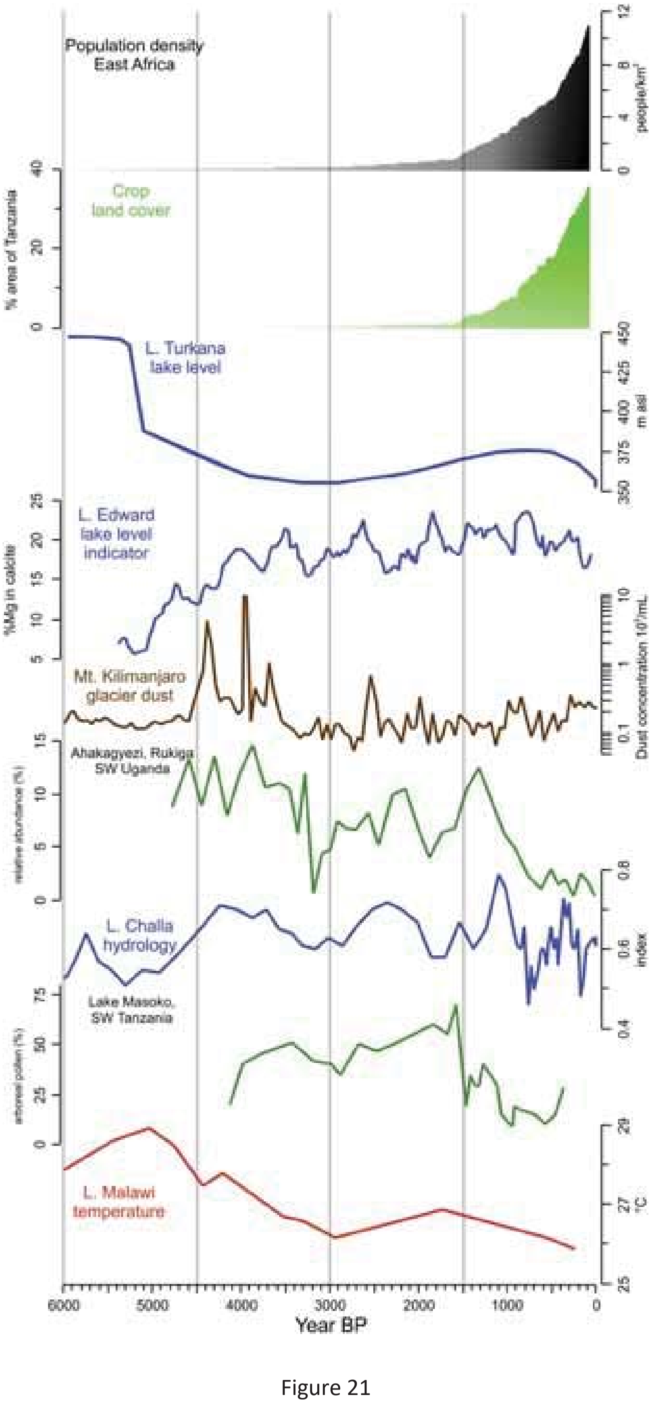

Population density
East Africa
people/km²
0
4
8
12
Crop
land cover
% area of Tanzania
0
20
40
L. Turkana
lake level
m asl
350
375
400
425
450
L. Edward
lake level
indicator
%Mg in calcite
5
10
15
20
25
Mt. Kilimanjaro
glacier dust
Dust concentration 10⁷/mL
0.1
1
10
Ahakagyezi, Rukiga
SW Uganda
relative abundance (%)
0
5
10
15
L. Challa
hydrology
index
0.4
0.6
0.8
Lake Masoko,
SW Tanzania
arboreal pollen (%)
0
25
50
75
L. Malawi
temperature
°C
25
27
29
6000
5000
4000
3000
2000
1000
0
Year BP

Figure 21

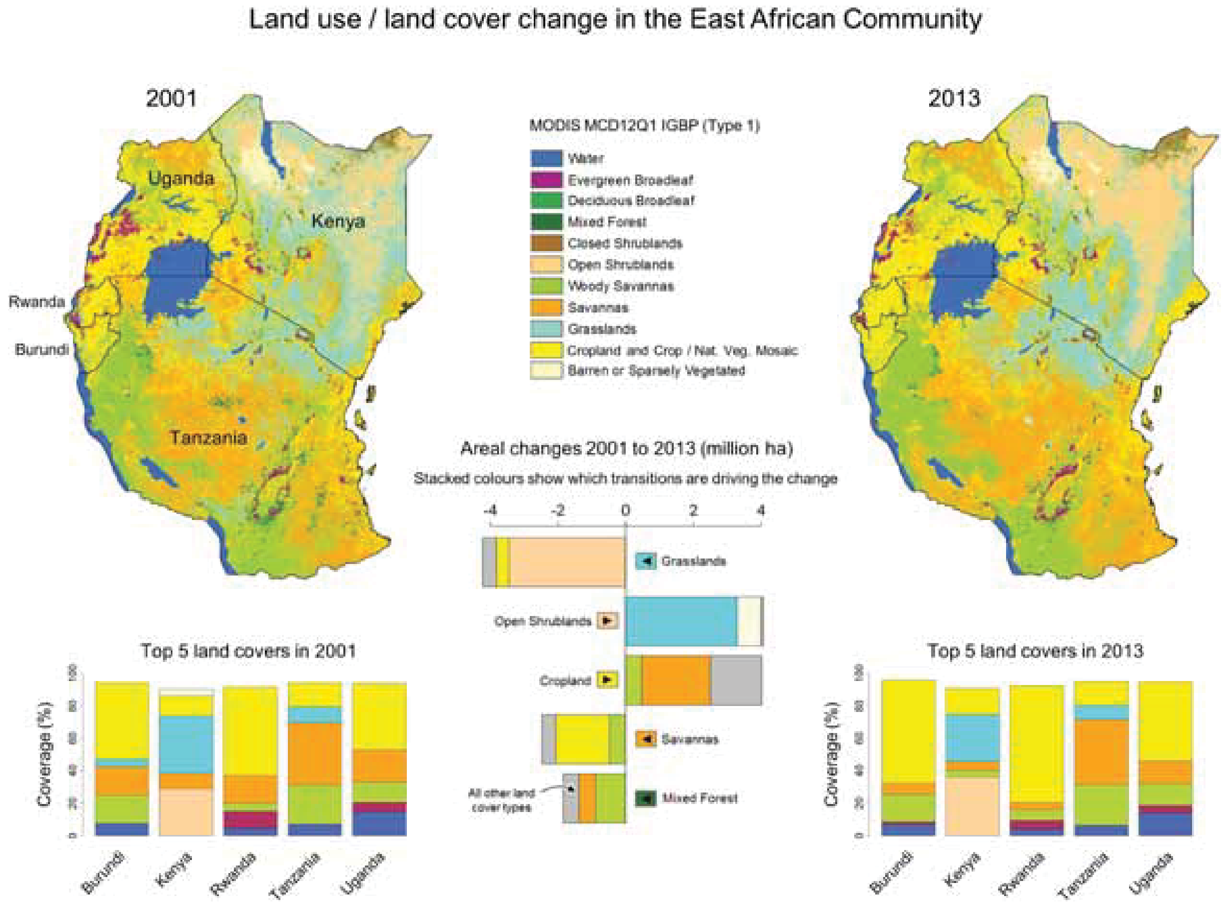

Land use / land cover change in the East African Community
2001
2013
Uganda
Kenya
Rwanda
Burundi
Tanzania
MODIS MCD12Q1 IGBP (Type 1)
Water
Evergreen Broadleaf
Deciduous Broadleaf
Mixed Forest
Closed Shrublands
Open Shrublands
Woody Savannas
Savannas
Grasslands
Cropland and Crop / Nat. Veg. Mosaic
Barren or Sparsely Vegetated
Areal changes 2001 to 2013 (million ha)
Stacked colours show which transitions are driving the change
-4
-2
0
2
4
Grasslands
Open Shrublands
Cropland
Savannas
Mixed Forest
All other land cover types
Top 5 land covers in 2001
Top 5 land covers in 2013
Coverage (%)
0
20
40
60
80
100
Burundi
Kenya
Rwanda
Tanzania
Uganda

Figure 22

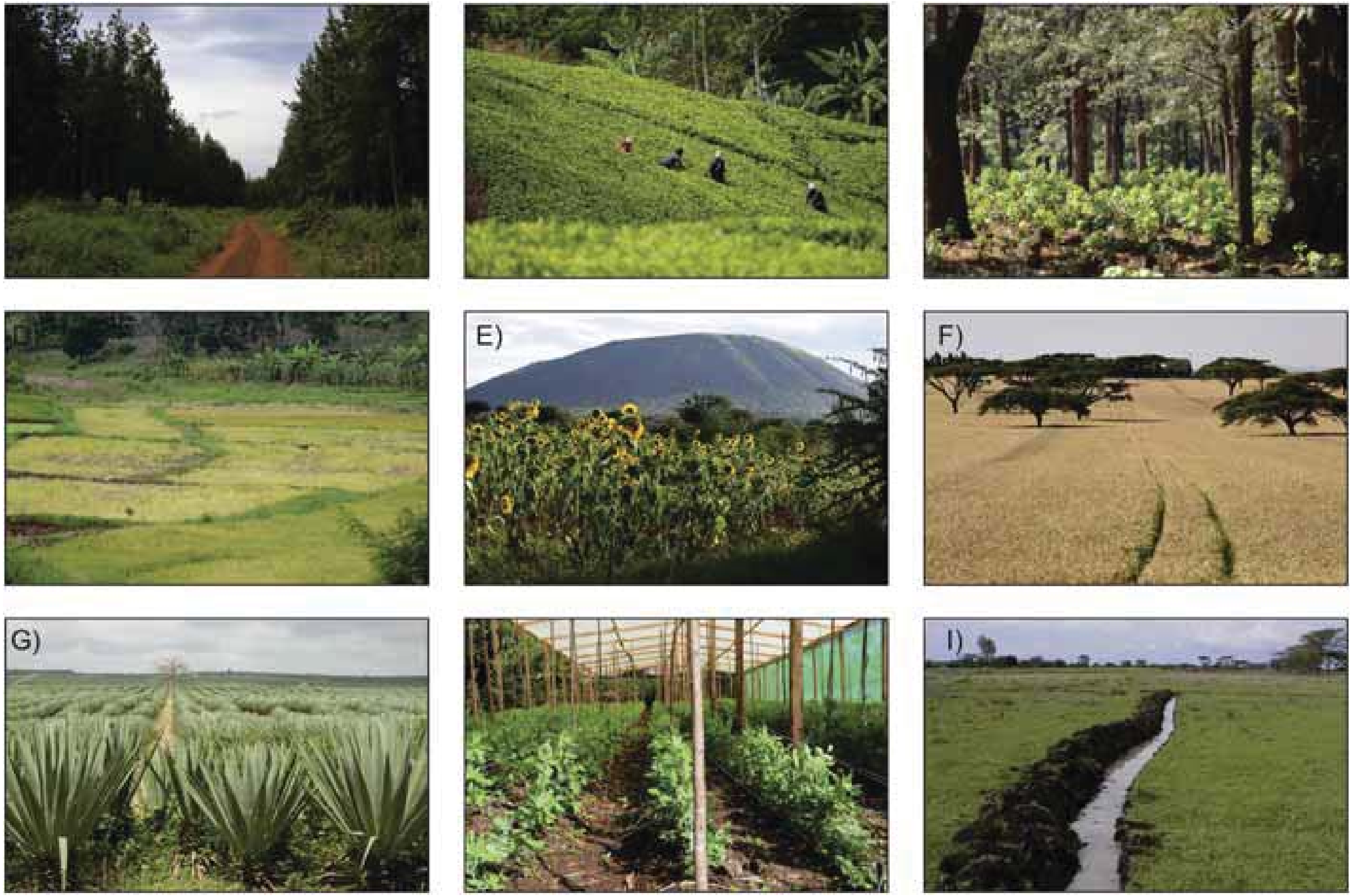


Figure 23

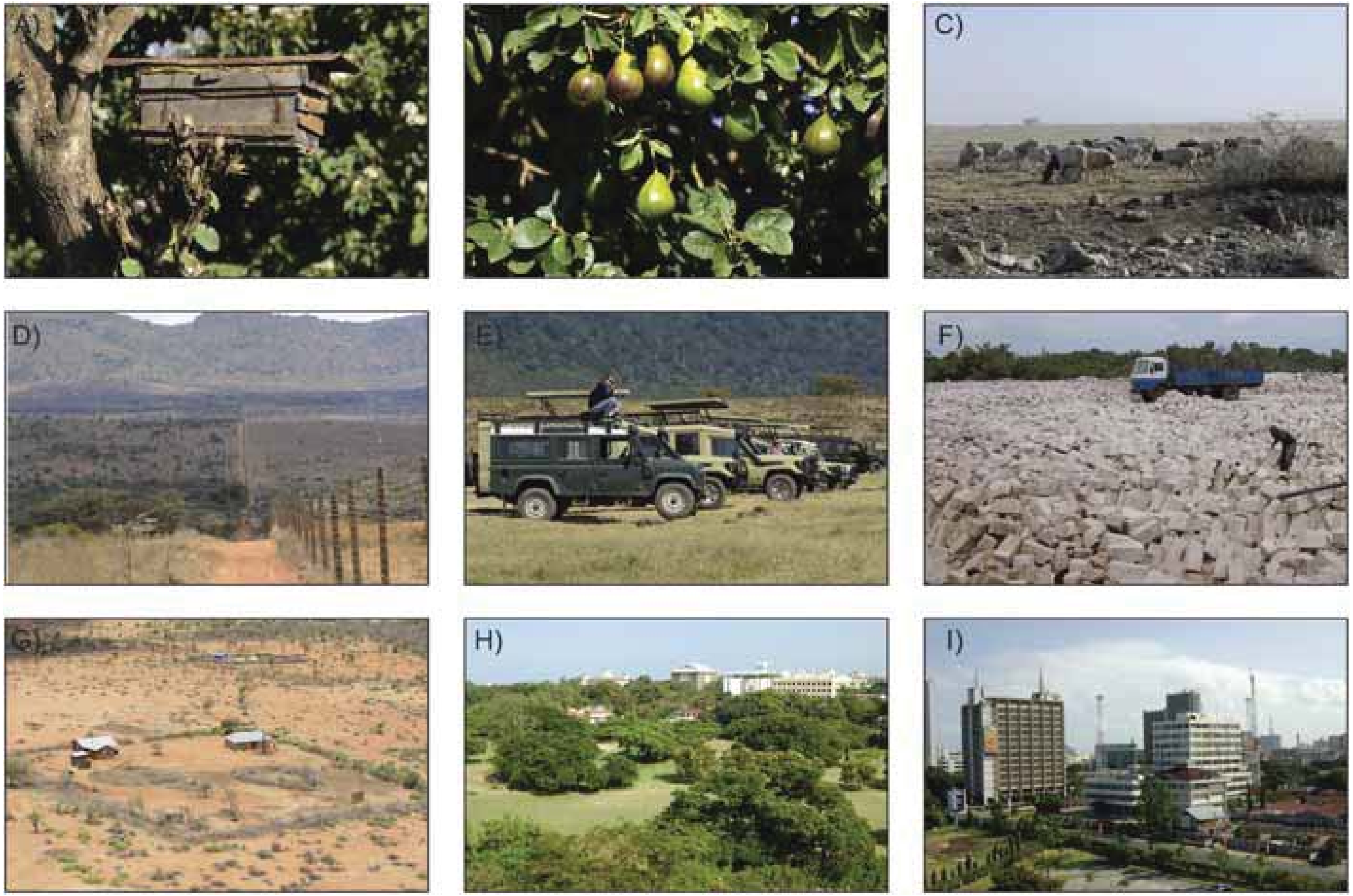


Figure 24

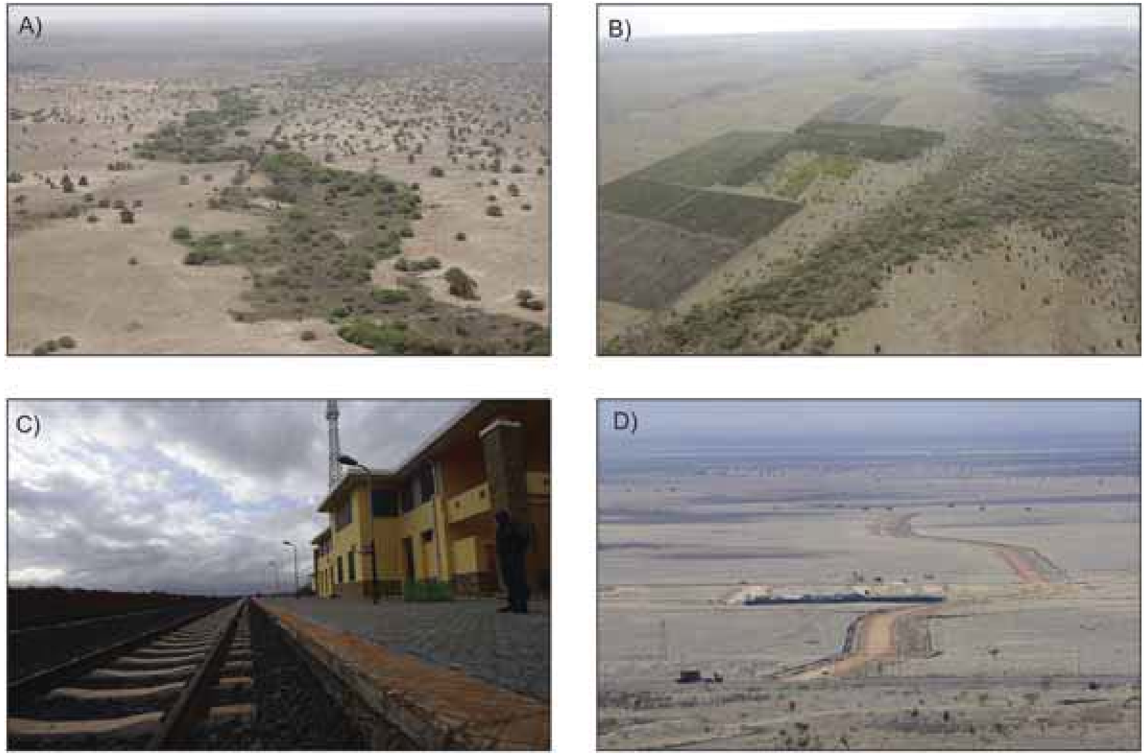


Figure 25