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Historical Ecologies of Pastoralist Overgrazing in Kenya: Long-Term Perspectives on Cause and Effect

Oliver J. C. Boles[1,2,3] • Anna Shoemaker[4] • Colin J. Courtney Mustaphi[2,4,5] • Nik Petek[4] • Anneli Ekblom[4] • Paul J. Lane[4,6,7]

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Abstract
The spectre of 'overgrazing' looms large in historical and political narratives of ecological degradation in savannah ecosystems. While pastoral exploitation is a conspicuous driver of landscape variability and modification, assumptions that such change is inevitable or necessarily negative deserve to be continuously evaluated and challenged. With reference to three case studies from Kenya – the Laikipia Plateau, the Lake Baringo basin, and the Amboseli ecosystem – we argue that the impacts of pastoralism are contingent on the diachronic interactions of locally specific environmental, political, and cultural conditions. The impacts of the compression of rangelands and restrictions on herd mobility driven by misguided conservation and economic policies are emphasised over outdated notions of pastoralist inefficiency. We review the application of 'overgrazing' in interpretations of the archaeological record and assess its relevance for how we interpret past socio-environmental dynamics. Any discussion of overgrazing, or any form of human-environment interaction, must acknowledge spatio-temporal context and account for historical variability in landscape ontogenies.

Keywords Historical ecology · Compression effects · Rangeland management · Pastoralist mobility strategies · Eastern Africa · Kenya

Introduction

As Europeans pushed to colonize and cultivate lands in the intemperate tropics they became intensely interested in the relationships among deforestation, rainfall, soil erosion, and desertification (Grove 1996; Davis 2004). Eighteenth- and nineteenth-century observers linked the practices of indigenous communities with landscape degradation and loss of productivity. In North Africa, for instance, French settlers' belief that the Maghreb had once been 'the abundant granary of Rome' (Perier 1847: 29), stripped of its productivity over centuries of misuse by nomadic pastoralists, was used to justify policies of land appropriation and forced-sedentarization (Davis 2004). This vilification of herders was widespread across the continent throughout the colonial era, supported by academic theorising. The 'cattle complex' as constructed by Herskovits (1926), framed pastoralists as constantly and irrationally seeking to accumulate livestock with little regard for efficiency or sustainability (c f. Livingstone 1991) and was emblematic of attitudes in academic and political circles. Stock-keepers were perpetrators of the 'tragedy of the commons' (Hardin 1968) wherein commonly-held land would invariably be maximally exploited by individuals to the detriment of the collective good. These ideas were at the core of land management policy in colonial eastern Africa, and pastoralist inefficiency was viewed as anathema to productivity. For example, the Chief Agricultural Officer in colonial Kenya

✉ Oliver J. C. Boles
oboles@sas.upenn.edu

1 Department of Anthropology, University of Pennsylvania, Philadelphia, PA, USA

2 York Institute for Tropical Ecosystems, Environment Department, University of York, York, UK

3 Institute of Archaeology, University College London (UCL), London, UK

4 Department of Archaeology and Ancient History, Uppsala Universitet, Uppsala, Sweden

5 Geoecology, Department of Environmental Science, University of Basel, Basel, Switzerland

6 Department of Archaeology, University of Cambridge, Downing Street, Cambridge, UK

7 School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

during the 1950s considered the predominance of milk-based economies over meat-oriented production, deemed more efficient in terms of food provision per unit of forage, to be a demonstration of pastoralists' irrationality. He believed overstocking was an unavoidable consequence (Brown 1971).

Since the mid-1980s, more sophisticated understandings of the drivers of land degradation have emerged. These approaches apply new models of nonequilibrium ecosystem dynamics and awareness of the effects of long-term climatic variability, emphasising the incorporation of local knowledge into land use management and recognising the potential ecological benefits of pastoralist settlement and grazing regimes (Homewood 2008; Reid 2012). There is also growing recognition (e.g., Blake *et al.* 2018) that contrasting disciplinary perspectives, and information and implementation gaps between different stakeholders, can combine to limit the uptake of alternative approaches to land management by governments and pastoralists, resulting in the exacerbation of pressures leading to overgrazing. Notwithstanding these developments, established narratives of overgrazing still haunt recent discussions of current degradation and its drivers in Africa in both academic (e.g., Hein 2006) and public discourse (Shanahan 2016), and in many parts of the African continent continue to shape policy interventions (e.g., Gilbert 2013). These arguments have also resurfaced in broader studies concerning the antiquity of the Anthropocene (e.g., Zerboni and Nicoll 2018) and in interpretations of the drivers of palaeoenvironmental change (e.g., Wright 2017; for a counter argument see Brierley *et al.* 2018).

Overgrazing and attendant changes to land are certainly important issues that have significant consequences for rural livelihoods and the vulnerability of pastoralist communities to a variety of risks. However, understanding the connections between different agents and processes demands nuanced, evidence-based analyses rather than a priori generalisation. This is well illustrated by a series of recent studies of transformations in the nature of land holding and access in semi-arid areas of Kenya over recent decades, where privatization of former commons has not progressed in a simple linear fashion as often predicted by common theories of property evolution (Galaty 2016), and even in the context of privatized land pastoralists often seek to recreate social relations that are more characteristic of the commons (Archambault 2016). In a similar vein and with reference to some of these same areas, we argue in this paper that the impacts of livestock on African ecosystems are highly variable and contingent on particular political, social, and environmental context. To account for the diverse drivers of ecological change, analysis requires not only a longer temporal perspective, spanning decadal-to-millennial scales, but must be informed by multiple modes of enquiry. Here, we discuss the historical and ecological trajectories of pastoralism in three case studies in central areas of Kenya (Fig. 1). These three ecosystems – Laikipia, Baringo and Amboseli – have featured frequently in debates on conservation, sustainability, changing relationships between agriculturalists and herders, and the landscape-transformative potential of pastoralism for over seven decades. Each ecosystem has been subject to active intervention by governing authorities based on now-outdated paradigms in ecological theory. However, the removal of pastoralists from a landscape is not simply equivalent to the removal of livestock; centuries of anthropogenic fire regimes, for example, instituted by herders in order to influence rangeland productivity, have shaped savannahs as decisively as the nutrient re-distributive capacities of grazing animals. Landscape histories must therefore be understood with reference to the *longue durée* of human interaction. With this point in mind, we consider how the complex ontogenies of pastoral landscapes can be explored given the limitations of archaeological and palaeoenvironmental records in terms of their spatial and temporal resolution.

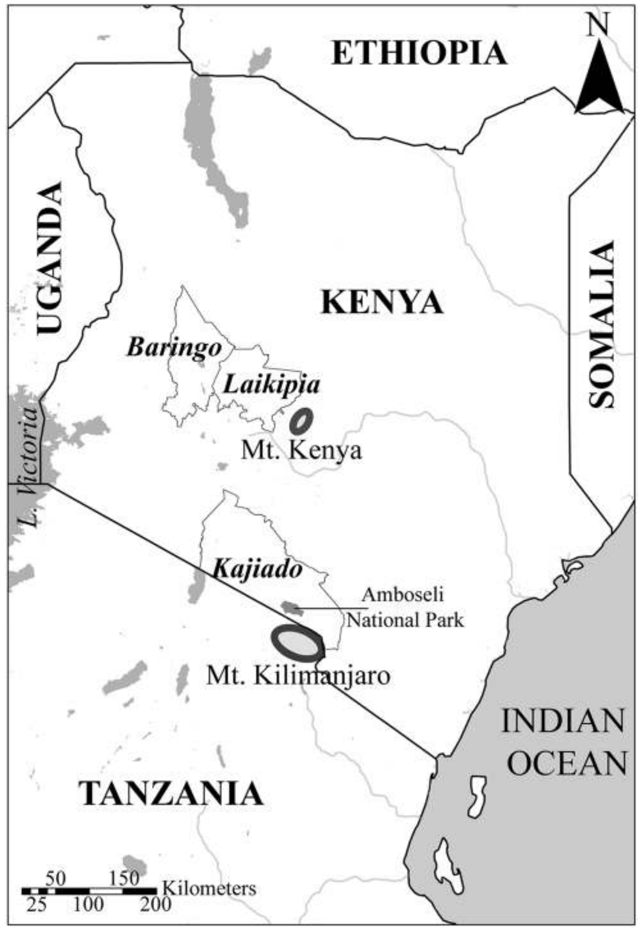

Fig. 1 Map of eastern Africa showing the three case study regions and other key locations

Case Study 1: Laikipia

The high-elevation rangelands of the Laikipia Plateau lie at the transition between the fertile, agricultural highlands of southern

Kenya and the drier plains of the north and have hosted pastoralist economies for several millennia. Dates from Ol Ngoroi rockshelter in the Lolldaiga Hills indicate that domesticates have been present in Laikipia since the fifth millennium BP, among the earliest such dates south of Ethiopia (Lane 2015). This presence continued throughout the Pastoral Neolithic and Pastoral Iron Age (Lane 2011; Boles and Lane 2016).

In the early twentieth century, following multi-year droughts and disease epidemics (e.g., rinderpest) that had decimated livestock numbers across eastern Africa (Waller 1988), the Laikipia region was designated the 'Northern Maasai Reserve' by the colonial administration. The proclamation of the reserve facilitated colonial appropriation of prime grazing and farming resources in the Central Rift Valley and the highlands around Nairobi. However, the reserve was withdrawn in 1911 following an agreement – now contested – between the British and certain Maasai leaders. Laikipia was apportioned for European holdings, and African pastoralists along with some one million sheep and 200,000 cattle were moved to the 'Southern Reserve' near the border with German East Africa (now Tanzania) (Hughes 2006). Delayed by the outbreak of the First World War, by the 1920s much of the region's productive land was appropriated through soldier settlement schemes. Nonetheless, vast empty areas remained and by the 1930s many potential farmers were declining to settle, citing the poor quality of the often-water-deprived soil. Issue was also taken with the size of the holdings available, which were normally in the region of 1000–5000 acres; a viable livestock farm was widely considered to require upwards of 15,000 acres. However, various processes whereby unoccupied land could be leased during periods of drought as well as a relaxed approach towards ranchers exceeding the limits of their licensed lands ensured that European control persisted throughout the colonial period (Vaughan 2005).

While the process of 'Africanisation' that followed Kenya's independence in 1963 led to the sale and division of certain ranches, over half remained under European ownership in the early-twenty-first century (Wambuguh 2007). Presently, many properties maintain some commercial livestock operations, often alongside interests in wildlife ecotourism, while others are now dedicated to conservation. Other land is designated for community ownership in the form of 'group ranches,' and many properties in the southern part of the plateau were subdivided around independence for small-scale farming by communities from the densely-populated former Kikuyu Tribal Reserve (Köhler 1987). The long-term prospects of these farms are unclear; however, of the 8.4% of the district already under cultivation only 1.7% is considered to have high agricultural potential (Huber and Opondo 1995).

Inequalities in land ownership in Laikipia are stark. Since the mid-1960s the population rose from around 60,000 to over half a million by the early twenty-first century, yet around 40% of the district is controlled by 48 wealthy individuals (Letai 2011). The number of cattle in Laikipia is thought to be in the region of 200,000 and sheep and goats nearly half a million (2011–2013 estimates, Ogutu *et al.* 2016). Importantly, though these numbers are similar to pre-twentieth century levels (Hughes 2006), there has been a significant contraction of rangelands since the expansion of agriculture in the verdant southern plateau. Furthermore, low stock-densities within the private conservancies mean that community ranches bear the greatest burden. The larger private ranches can generally afford to operate within their carrying capacities and, indeed, such surplus is vital to their success as wildlife reserves (e.g., Mizutani 1999). These relatively economically-secure enterprises can afford to be flexible with regard to their intensity of production (Sundaresan and Riginos 2010) – for example, cessation of milk production during drought (Mizutani 1999). The community ranches are mainly located in the drier northern part of the plateau (Letai 2011) and host livestock numbers that often exceed recommendations (Sundaresan and Riginos 2010).

Over two decades ago Livingstone (1991: 81) made the point that although the group ranches can be said to be 'overstocked' in terms of an observed year-on-year reduction in available herbage, average household livestock holdings are considerably below that required for subsistence, as documented among the Mukogodo Maasai in eastern Laikipia. While in some areas arrangements with landowners allow local pastoralists controlled-access to grazing and water within the private ranches, land invasion is an ongoing problem and Laikipia has garnered notoriety in the international media following the murders of several European ranchers, Kenyan rangers, and police reservists over recent years. These invasions can bring tens of thousands of cattle into the ranches with dramatic impacts on local ecologies and though usually associated with periods of drought (e.g., 2011–12 and 2016–17), their motivations cannot be divorced from political context (Iaccino 2017). Tensions arising from efforts to conserve and protect Laikipia's elephant populations, including debates over the need for, and contributions of, fencing (Bond 2015; Evans and Adams 2016), further complicate the situation. As noted by Galaty (2016: 717), in some parts of Laikipia over the last decade or so, and as a consequence of these frictions, 'land has gone through a transition, from being managed as private holdings - both large and small-scale - through a stage of 'open access' as owners have 'abandoned' them, to being relatively stable common holdings, governed by the pastoralists who have moved in and asserted rights.' The rules governing access to grazing land are also changing, with the significance of older practices based on traditions of reciprocity diminishing, and an increased emphasis on rights being acquired through membership of formal, territory-based institutions (such as group ranches or community conservancies). This has had a number of spatial and temporal consequences for mobility patterns that can further exacerbate lines of conflict between pastoralists and other land users in Laikipia (Pas Schrijver 2019).

At the same time as rangelands are divided, the population of Laikipia is increasingly sedentary. Besides the growing importance of agriculture in the southern part of the plateau, this can be linked to the influx of small-holder farmers from adjacent counties. Recent decades have also brought a trend towards sedentism on the part of formerly peripatetic herders, with many males abandoning herding in favour of employment on private ranches as professional stockmen and wildlife rangers (Yurco 2017). High rainfall associated with a strong El Niño-Southern Oscillation in 1997–1998 saw many pastoralists establish permanent settlements in the Mukogodo area of eastern Laikipia (Strum *et al.* 2015). Livestock are now perennially present where herders previously moved seasonally in accordance with grazing conditions (e.g., Huho *et al.* 2010). The ecological consequences of this are palpable: for example, the introduced invasive *Opuntia stricta* (prickly pear), a stress-tolerant species that thrives in degraded semi-arid environments, has spread throughout the ranches (Strum *et al.* 2015), reducing available pasture. Mechanical removal is time consuming and difficult, while biological controls, such as introduced beetles, have proven ineffective (Paterson *et al.* 2011). Notably, although *O. stricta* is also present in the adjacent Lolldaiga Hills Ranch – a privately-managed 200 km^2 ranch and wildlife conservancy – it is found in much lower densities. At Lolldaiga, grazing is managed according to a seasonal rotation between the hills in the southern part of the property and the plains in the north, such that no single pasture is subject to the perennial grazing that Strum *et al.* (2015) assert to be the principal degrading factor in Mukogodo (Fig. 2). Indeed, Taiti's (1992) claim that

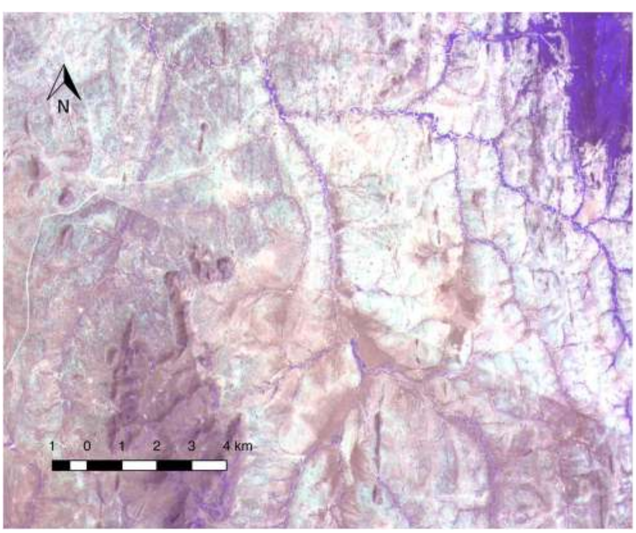

Fig. 2 ASTER L1B satellite image showing the boundary line between the privately-owned Lolldaiga Hills Ranch (bottom half of image) and the Mukogodo Group Ranch (top half). Note the paler colouring north of the fence depicting much-reduced grass cover

herding in Laikipia exerted no 'traumatic influence' prior to 1960 – at which point Kenyan national independence heralded a population boom and a reduction of pastoral mobility – is supported by the example of the Lolldaiga Hills Ranch, where stock numbers and management practices have seen little demonstrable intensification since the early twentieth century (Mizutani 1999).

Case Study 2: Baringo

The Lake Baringo basin lies immediately to the west of the Laikipia Plateau, extending over 6200 km^2 along the Rift Valley, and is characterised by bare soils, severe erosion, and invasive plants (Bessems *et al.* 2008; Becker *et al.* 2016). Though herding has been the dominant subsistence strategy for the past 3000 years, the intensity of pastoral occupation has fluctuated; this is apparent in the large number of sites associated with Pastoral Neolithic Turkwel ceramics (c. 200–1100 AD) coeval with a more arid period in the Lake Bogoria basin, and an almost complete lack of Pastoral Iron Age sites (c. 900–1700 AD) during the wetter Little Ice Age (c. 1250–1750) (Ashley *et al.* 2004; De Cort *et al.* 2013; Petek 2018). The form of agro-pastoralism practiced by the Ilchamus and Tugen people was established in the Baringo basin and surrounding areas in the late nineteenth century (Anderson 2002), and Pokot, Samburu, and Maasai pastoralists have been present in the region since at least the 1800s (Bollig 2016), at which point the climate was considerably drier.

Narratives of pastoral overgrazing in Baringo emerged during the severe droughts and locust infestations of the 1920s, when colonial officials began to question why the region, once famous as a granary due to its irrigated field systems, could not sustain its own population (Anderson 2002; Petek and Lane 2017). The notion that Baringo could be restored to a prior fertility was propagated in the following decades during deliberations about the expansion of the native reserve and developments such as the Perkerra Irrigation Scheme (Kramm 2015). Begun in 1952, this initiative was intended to feed the inhabitants of Baringo through grain cultivation and provide income through the export of cash crops, enticing people away from herding. However, the scheme incurred huge financial losses and was insufficiently productive to meet local needs (Kramm 2015).

Baringo is generally a dry region marked by a high inter-annual variability in rainfall, and early colonial maps describe vegetation in the lake basin as thornbush or shrub with rare grasses (Fig. 3). European explorers also remarked on barren lands and dust storms (Thomson 1885; von Höhnel 1892), indicating that the area might not have been as productive as reported in second-hand accounts written during the late 1800s. Some doubt existed during colonial times about the imagined past verdancy of the basin (Little 1992: 47;

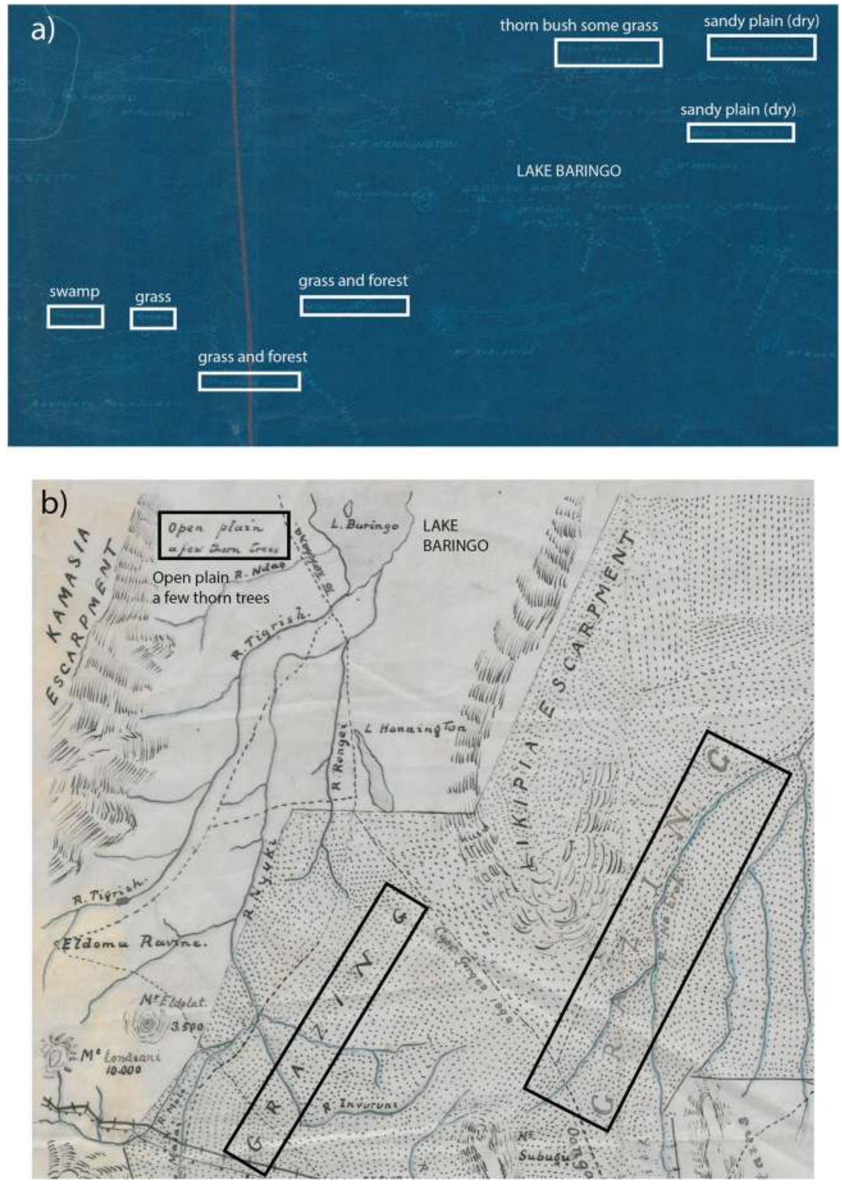

Fig. 3 Colonial maps with vegetation descriptions showing Lake Baringo and Laikipia. **a** map of the Expedition made by the East Africa Syndicate Ltd. from November 181,902 to March 41,903 (map# WOMAT-AFR-BEA-92 held by the British Library); **b** Map of Masailand (map# WOMAT-AFR-BEA-41 held by the British Library)

Anderson 2002: 231), and it remains to be established how natural and anthropogenic factors interplayed to form the pre-colonial woodland savanna. Soils in semi-arid regions regularly experience high erosion even without human influence (Dunne *et al.* 1978: 131), and in Baringo are especially prone to erosion by wind and water due to a silty, poorly-developed and powdery structure, high sodium levels that preclude water infiltration, and low organic matter content derived from scarce and rapidly decomposing vegetation (Republic of Kenya 1984; Kiage 2013). Sedimentary evidence shows increased terrestrial sediments being deposited into Lake Bogoria in recent decades linked to anthropogenic soil erosion in the watershed (de Cort *et al.* 2018).

The consequences of colonial intervention in Baringo included reduced social mobility between ethnic communities, discouragement of interethnic communication, as well as inhibited access to pastures controlled by other communities where access could previously be negotiated (Little 1992; Anderson 2002; Bollig and Österle 2013). Externally-imposed boundaries and decreased mobility made grass a contested resource. Access to it had to be controlled and pasture allocated for either wet or dry season grazing (Bollig and Österle 2013). With the establishment of group ranches, large numbers of livestock were present in varying densities within a fragmented landscape that experiences decadal-scale droughts and sporadic rains. Little movement was allowed beyond designated boundaries, resulting in enduring damage to some of the most intensively-grazed areas (Anderson 2002; Anderson and Bollig 2016). Fire setting, used by pastoralist communities to suppress woody plant growth and create or maintain pastures, was forbidden in Baringo under colonial rule and controlled burns eventually diminished (Vehrs and Heller 2017).

Wildlife too played an important role in keeping the landscape open, alongside domestic livestock and fire. Early European explorers and colonial officials describe large herds of buffalo, wildebeest, zebra, and other grazers and browsers, including elephant and rhinoceros (Thomson 1885; von Höhnel 1892; Dundas 1910). At the beginning of the twentieth century, Baringo was popular with sport hunters, which brought in considerable revenue at the expense of significant reductions in game animals (Powell-Cotton 1904; Chapman 1908). Limited resources also exacerbated human-wildlife conflict and large wild mammals in Baringo were nearly extirpated by the late 1940s (Little 1996). Defaunation contributed to the disappearance of grasses and the encroachment of the bushes and acacia trees that now dominate the landscape (Vehrs and Heller 2017). Pollen records from nearby Lake Bogoria show an ongoing decrease in grasses from c. 50% of the record in c. 1910 to 18% in the past decades and an expanding woodland component associated with acacias, Amaranthaceae and Asteraceae (van der Plas *et al.* in review). Remote sensing data show that the initially dispersed settlements of the early twentieth century also become more concentrated at specific centres around grass-rich swamps as pastures diminished, more land was put aside for farming, and people became more sedentary (Petek 2018). Although the population has continued to grow, livestock numbers have stagnated since the mid-twentieth century and many farms are not economically viable or able to support households (Little 1992; Anderson 2002) as a consequence of the continued application of colonial policies even after independence.

Case Study 3: Amboseli

The Amboseli ecosystem is centred on a 600 km^2 palaeolake basin in Kajiado County, south-eastern Kenya, with a further nearly 8500 km^2 of rangelands utilized seasonally by migratory wildlife. The area includes the Amboseli National Park and its spring-fed wetlands, charged by orographic precipitation onto nearby Mount Kilimanjaro. These perennial wetlands have persisted throughout the late Holocene (Githumbi *et al.* 2018a, b) and provide water and pasture to a diverse community of large mammals, including livestock (Western 1975). Archaeological research in Amboseli suggests that livestock herding has been practiced since the Pastoral Neolithic, with conclusive evidence dating to the Iron Age (Shoemaker 2018). Stock keeping remains a major livelihood component for many households in the region, often in combination with agriculture and ecotourism (BurnSilver 2009; Homewood *et al.* 2012).

State-led initiatives to manage water and land resources for wildlife have a long history in Amboseli, beginning at the onset of the colonial period (Lindsay 1989). Early policy interventions identified Maasai-owned cattle, sheep, and goats as drivers of overgrazing, environmental degradation and desertification (Lewis 2015). Justification for gazetting a National Reserve in 1948 and the creation of Amboseli National Park in 1974 lay in part in the perceived need to safeguard water, pasture, and wildlife in the basin from threats posed by pastoralism. An overarching trend in the Amboseli ecosystem throughout the twentieth century was the adjudication and commodification of communal rangelands into parcels of ever-diminishing size, transformations often driven by the notion that privatisation would reduce overstocking and increase investments in ranching and agricultural production systems (Rutten 1992). The fragmentation of rangelands has had deleterious effects on pastoralists and wildlife alike, however, as rangeland subdivision and increased sedentarization have encouraged the forced concentration of grazing pressure around diminishing resources (Western *et al.* 2009; Groom and Western 2013). The negative effects of sedentarisation and subdivision are evident in a comparative study between a subdivided and unsubdivided group ranch in Amboseli, which found that despite livestock densities being equal, pasture was diminished on the subdivided ranch and the capacity for grass to regenerate after drought was more limited (Groom and Western 2013).

Parallels can be drawn between overgrazing caused by insularized and sedentary livestock and that associated with elephant populations in Amboseli (Fig. 4). A study by Western *et al.* (2015) has found a doubling in grazing pressure in Amboseli National Park between 1982 and 2010, concomitant with a long-term fall in biomass yield per unit of rainfall. Estimates of livestock and most wild migratory grazing herbivore populations in eastern Kajiado between 1977 and 2011 indicate their numbers have been falling, whereas the number of elephants is calculated to have increased by 115% (Ogutu *et al.* 2014). Elephants in Amboseli have also become less mobile since the mid-twentieth century due to a regional contraction in habitat and the threat of poaching (Moss 2001; Croze and Lindsay 2011: 27–28). Such a localized population increase is consequential, as elephants have significant impacts on vegetation structure and woody plant coverage (Morrison *et al.* 2016). Over the last half-century woodland and bushland vegetation zones within the National Park have been in sharp decline, and along with this loss of habitat diversity has been a decrease in large mammal diversity (Altmann 1998; Western and Maitumo 2004). This loss in biodiversity is linked to elephants seeking refuge in the park (owing to intensifying human presence and a regional contraction in habitat), where they have extensively grazed on acacia woodlands (Western and Maitumo 2004). During the dry season elephants in Amboseli shift their diets from grass toward

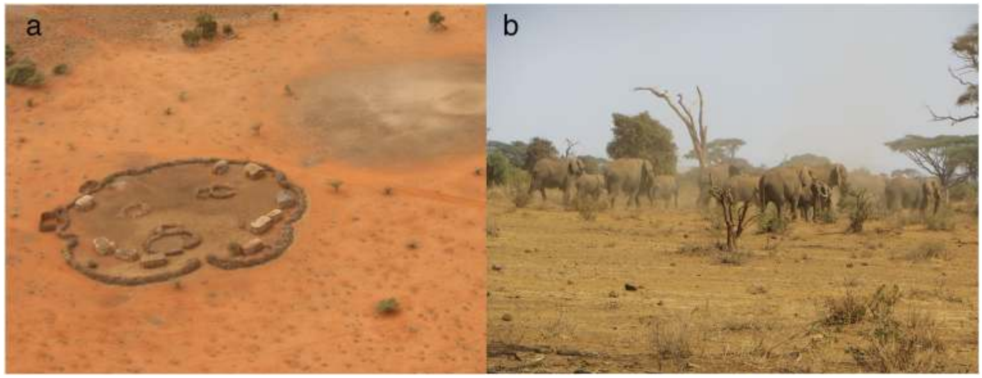

Fig. 4 **a** Maasai settlement in Amboseli. Note the adjacent dark patch which marks the site of a previous settlement (Photo P. Lane); **b** Elephants crossing into Amboseli National Park (Photo A. Shoemaker)

woody browse to enable them to better cope with the lack of pasture (Lindsay 2011: 68). In addition, the patchy distribution of water and woodlands in the arid and increasingly fragmented rangelands encourages elephants to cluster in high densities around vegetation and wetland refugia during periods of drought, depleting local forage resources (De Beer *et al.* 2006; Chamaillé-Jammes *et al.* 2008). As the mortality of trees has exceeded the recruitment of woody vegetation in the area, the landscape has become more open. The extent to which elephants are driving the contraction of woodlands in Amboseli remains contentious (see Spinage 2012), yet there is evidence in Amboseli indicating that as elephants are compressed into drought refugia, rangeland productivity declines (Western *et al.* 2015). In contrast, outside protected areas it is said that 'cattle create trees' (Reid 2012: 184). Here, the presence of humans to a large degree deters elephants from removing woody vegetation, and livestock grazing has been found to promote seedling growth by cropping the herbaceous layer and increasing space and access to light (Western and Maitumo 2004).

Discussion

The variety of approaches to land use policy and rangeland management employed in Laikipia, Baringo, and Amboseli, and the ecological consequences of these interventions with reference to overgrazing must be considered within the context of each area's colonial and post-colonial history, as we have shown here (Fig. 5). The disparity in resources between Laikipia's private and community ranches is reflected in the productivity and sustainability of their respective management strategies. Surplus resources within the private ranches ameliorate abiotic unpredictability in the form of climatic and environmental change, while overpopulated communal lands with restricted access to pastures are often inefficient and left vulnerable to drought and blight. In Baringo, landscape rehabilitation projects were based on a failure to comprehend the significant local hydroclimatic variability that makes the region suited to flexible and mobile stock-based production but not intensive agriculture. By limiting pastoralist mobility colonial authorities intended to prevent the degradation of potentially high-yield areas reserved for Europeans (Anderson 2002), yet these programmes alienated pastoralists from rangelands ill-suited to other forms of production. Amboseli has seen similar processes of rangeland fragmentation and a push from successive authorities towards sedentism, creating the conditions for overgrazing both on and off conservancies. It is also clear that degradation there may be partly attributed to mismanaged conservation strategies implemented in the early and mid-twentieth century. In all cases, landscape change, degradative or otherwise, is fundamentally a product of particular historical and socio-political conditions as opposed to being an inevitable outcome of pastoral production.

Maintaining 'Balance'

As well exemplified in Baringo, the mismanagement of eastern African rangelands stems from widespread misunderstandings of the dynamic variability of water and grazing resources, and a lack of awareness of the strategies pastoralists employ to navigate this variability. Non-equilibrium ecological theory highlights the environmental stochasticism seen in many semi-arid landscapes and cites variability as the principal driver of ecological persistence (Ellis and Swift 1988). In grazing systems with predictable rainfall and forage (so-called equilibrial systems), livestock populations are moderated by competition, and conservative stocking rates are encouraged so that pasture shortages during dry years do not bring drastic drought-induced mortality (Caughley 1979). However, in grazing systems where forage production is unpredictable and variable (non-equilibrium systems), competition over resources features minimally in regulating populations (Wiens 1977; Ellis and Swift 1988). It has been suggested that biotic factors like grazing have no lasting impact in systems where inter-annual rainfall varies by a coefficient of >30% (Stafford Smith 1996). Under such conditions, livestock populations are

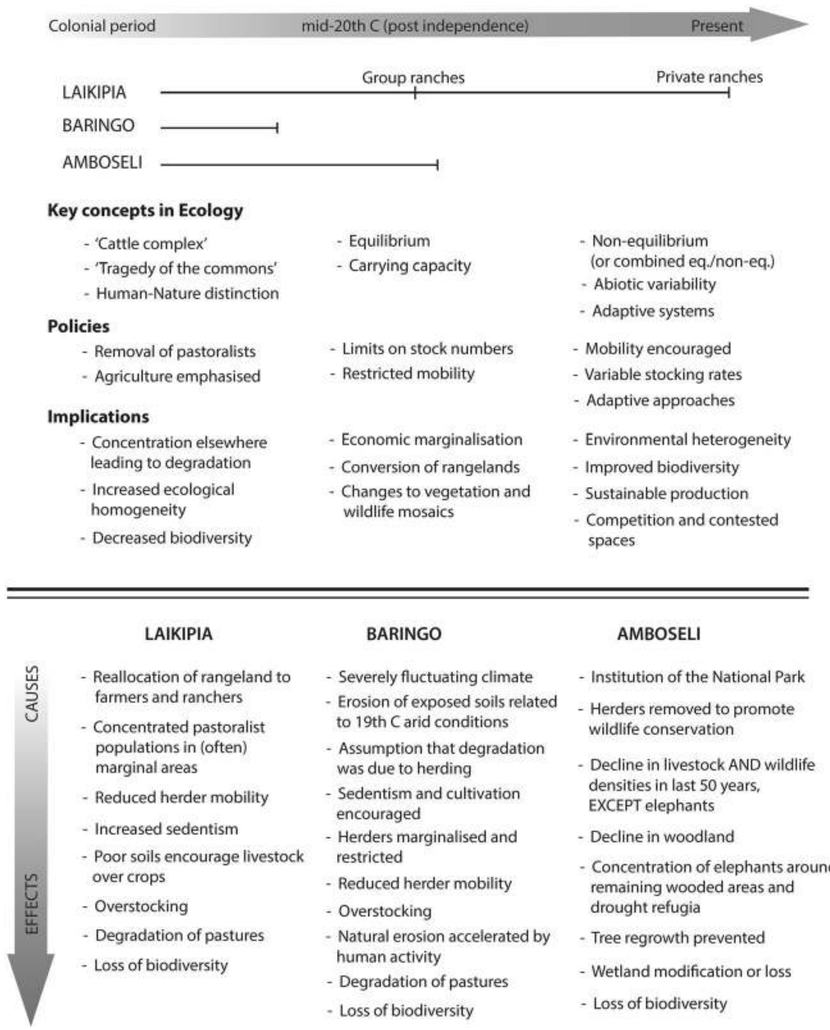

Fig. 5 Conceptual table summarising: a) theoretical developments in rangeland ecology and their relevance and application; b) the causal relationships between historical interventions and ecological modification and degradation in our case study areas

controlled by drought and disease, making overgrazing unlikely (Sullivan and Rohde 2002). Overall, there is growing acceptance that ecosystems can fluctuate between equilibrium and non-equilibrium dynamics (Briske *et al.* 2003; Vetter 2005).

Periodic deficits in forage are therefore unavoidable in semi-arid savannah ecosystems, and pastoralists have developed strategies to cope with such challenges. Mobility is embraced to maximize production in areas that have spatially and temporally uneven resource distributions (Western 1982; Shetler 2007). Livestock breeds favoured by pastoralists in highly seasonal and drought prone rangelands are able to adjust physiologically to food and water deprivation (Nkedianye *et al.* 2011). In anticipation of stock losses, large herd owners can also distribute their animals more widely to those with whom they have kin and non-kin alliances as a form of insurance or 'risk-pooling' (Aktipis *et al.* 2011). Pastoralists strategically manage their herds and model their livelihoods around ecosystems where losses are to be predicted. In this sense, large herds built up over good seasons are a way of storing surplus reserves to be used in poor seasons. During good times milk yields can be relied upon for sustenance, but under stressful conditions milk production falls and people consume their animals to reduce stocking rates and to meet dietary requirements, ultimately improving the health of the herd. After severe droughts, when continued offtake has reduced the rate of herd recovery, the rapid metabolic rate and milk response of cattle during realimentation is of importance, favouring dairy- rather than meat-based pastoral production strategies (Western and Finch 1986). Pastoralists in drought-prone parts of eastern Africa therefore maintain large herds that are managed for their ability to produce milk over meat and for their capacity to withstand periodic grazing deficits. Temporary participation in non-pastoralist economies and economic re-distributions also allow individuals who have taken large herd losses to re-enter herding following catastrophic losses (Shetler 2007). Pastoralists in Laikipia, Baringo, and Amboseli have all seen these strategies and their potential effectiveness severely curtailed: land divisions have restricted mobility and disrupted risk-pooling networks, and a lack of resources encourages overstocking in order to maximise milk production, with consequent negative impacts on herd and ecosystem health.

Ecologies of Herding

The notion that pastoralists are environmentally irresponsible and stand in opposition to rangeland conservation goals has been challenged for several decades (e.g., Ellis and Swift 1988; Warren 1995; Homewood 2008; Reid 2012). That livestock and wildlife are incompatible is contradicted by evidence that the presence of wildlife enhances cattle performance (survival, fecundity and weight-gain) and vice versa (Odadi *et al.* 2011). Similar arguments have been made based on studies of soil nutrient and seed redistribution linked to pastoralist activity. Cycles of daytime grazing and nightly corralling lead to concentrations of nutrients and seeds within temporary settlement sites that repel animals like elephants and which persist as 'glades' in savannah landscapes (e.g., Reid and Ellis 1995; Young *et al.* 1995; Veblen 2013; Fig. 6). The particular species that are represented within glades varies widely and appears dependent on highly specific local ecological conditions. While nutrient rich grasses are a common feature, species differ through space and time. Porensky and Veblen (2015), for example, observe high densities of *Cynodon plectostachyus* within glades in central Laikipia, yet this species was not recorded by Young *et al.*

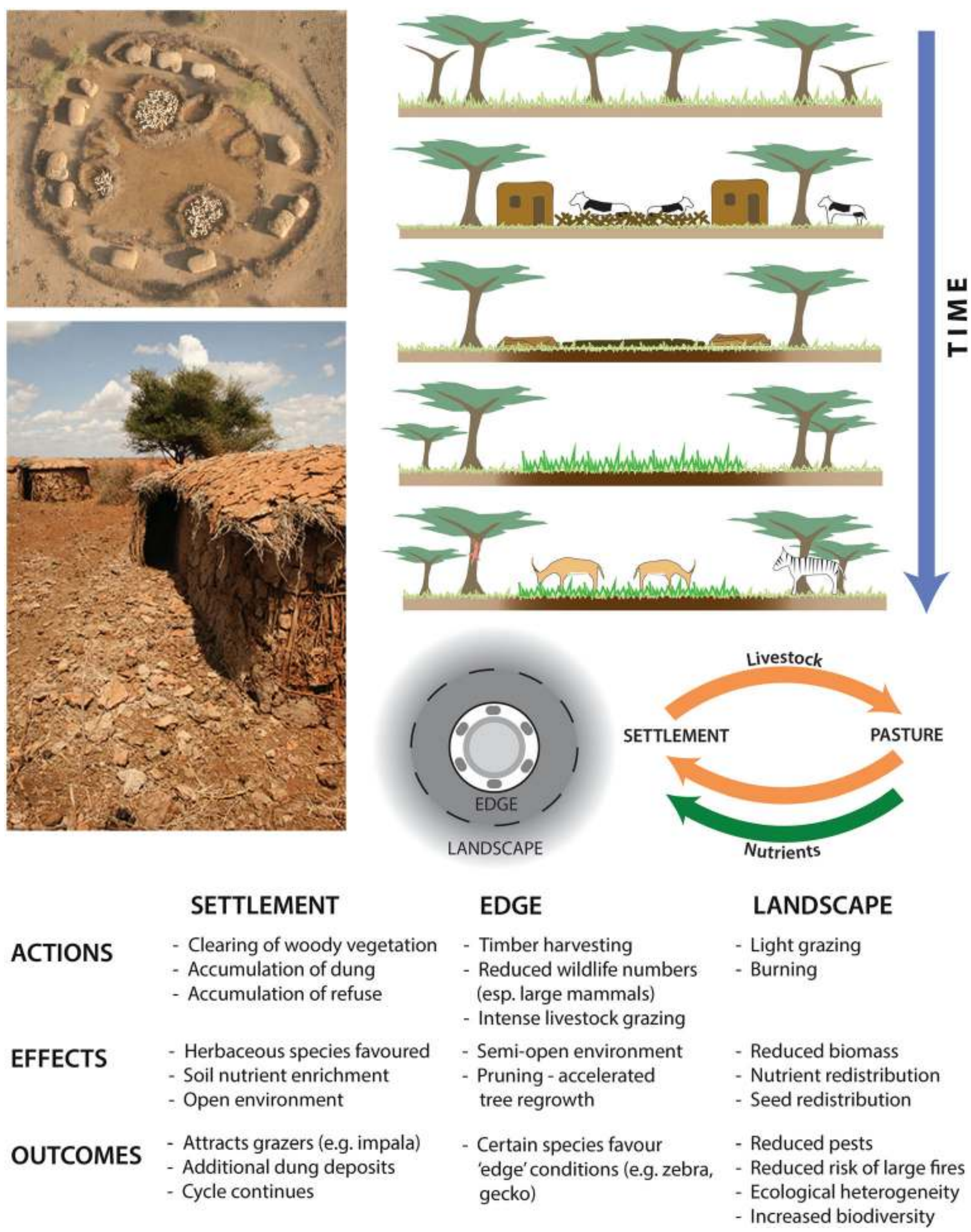

Fig. 6 The possible impacts and outcomes of pastoralist settlement activity in savannah landscapes in eastern Africa. Photographs (P. Lane) show aerial view of Maasai settlement and degrading houses within an abandoned settlement, both in Amboseli

(1995) when working in the same area; instead, *Digitaria milanjiana* was found to dominate. In Botswana, *Cenchrus ciliaris* is strongly associated with Iron Age pastoralist settlements (Denbow 1979), yet elsewhere in southern Africa, such locations host anomalous concentrations of woody taxa like *Vachellia* (*Acacia*) *tortilis* within a *Burkea africana*--dominated background (Blackmore *et al.* 1990). A similar pattern observed in northern Kenya is attributed to the transport and deposition of acacia seeds in the dung of browse-feeding livestock (Reid and Ellis 1995).

As distinct 'patches' within a wider savannah mosaic, glades encourage habitat heterogeneity with associated beneficial consequences for biodiversity (Young *et al.* 2018); rich grasses attract wild grazers (e.g., Augustine 2004), while edge effects ensure that their influence extends beyond the perimeter of former herder settlements (Young *et al.* 1995; Cadenasso *et al.* 2003). In addition, many pastoralists utilise controlled burning in order to promote grazing resources, with wider ecological implications. In woody savannah areas on the eastern edge of Amboseli, controlled seasonal burning by pastoralist communities reduces overall biomass and prevents hotter fires that damage trees (Kamau and Medley 2014). A co-benefit of anthropogenic burning is the reduction of disease vector-harbouring habitats through burning, reported across eastern Africa (Shetler 2007; Butz 2009; Kamau and Medley 2014). This has a similar effect to synthetic acaricides used to combat tick-borne infection of livestock and exercises a positive impact on biodiversity by reducing transmission to wild animal populations (Goodenough *et al.* 2017).

Most of the data generated and cited in support of these counter-arguments to narratives of declination are based on contemporary observation; questions remain over how best to access and integrate the longer-term dynamics of herder-rangeland interaction in present day ecological syntheses and rangeland management policy. Rangeland health is linked to more than simply rainfall and stocking densities, but rather is shaped by the cumulative (i.e., long-term) effects of how resource access and use is regulated (see also Lambin *et al.* 2001). Equally, socio-cultural processes must be considered alongside environmental drivers and legacies. It is further important to acknowledge that while this paper is highly focused on livestock rearing aspects of pastoral production systems, pastoral livelihoods have long incorporated diverse pursuits such as cultivation, iron-production, hunting and fishing, the impacts of which cannot be overlooked when investigating East African ecologies through time (Shoemaker 2018). The entanglement (sensu Lane 2016) of cultural, political, economic, and environmental dynamics is such that single-disciplinary approaches to issues like overgrazing are inadequate and prone to motivated reasoning.

Concepts of carrying capacity - the maximal population (e.g., of livestock) an ecosystem can support, beyond which productivity declines - and equilibrium have been instrumental in shaping management plans that would avoid overgrazing on a year-by-year basis. However, they are more challenging to understand from an archaeological or palaeoecological perspective. Conservation management generally focuses on the short-term, decadal-scale effects of pastoralism and human occupation, and can be limited to a single species (see Solbraa 2002). This level of specificity is not usually available to the palaeosciences. There is no clear method for identifying overgrazing in palaeoenvironmental proxy records, where generally only long-term consequences of certain actions are visible. At the Ngorongoro Crater Conservation Area, Tanzania, for example, pastures were observed to be overgrazed in terms of unsustainable livestock densities, yet without exhibiting conspicuous symptoms of long-term degradation (Homewood and Rodgers 1987) - i.e., the transformative changes that might be visible on the centennial and millennial scales that archaeologists and palaeoecologists generally work with.

Overgrazing and the Historical Record

In order to be identifiable in the historical record, the effects of overgrazing must constitute environmental or socio-cultural change at a scale sufficient to leave recognisable traces. Archaeologically, ecological degradation might lead to changes in hunting and herding patterns or a reduction of livestock densities, perhaps evident in zooarchaeological assemblages, or depopulation and significant change in settlement patterns. Geological and palaeoecological traces might include increased soil erosion (possibly resulting from bare grounds), reduced water infiltration into soils and increased runoff, damage to soil seed-banks, reduced grass cover and increased bush encroachment, expansion of niches and thus increased chances of species-invasiveness, reduction of coprophilic fungal spores, biogeochemical signals, and a general reduction of biomass and faunal and floral diversity. However, these must also be distinguished from the effects of non-anthropogenic drivers such as climate change.

In the historical sciences, overgrazing is more closely connected to degradation and ideas of thresholds or tipping points than in rangeland ecology or conservation (Mysterud 2006). Due to the nature of archaeological and palaeoecological data, overgrazing is more likely to be evaluated as a longer-term process with long lasting environmental and social effects leading to irreversible environmental change and degradation. Wright (2017), for example, argues that the emergence of pastoralism in the Sahara may have breached an ecological 'tipping point' that contributed to the abrupt termination of the African Humid Period (deMenocal *et al.* 2000). Wright's hypothesis explicitly avoids monocausal explanations for regime shifts, contending that an ecosystem already under stress and close to the 'precipice' of change might be triggered in response to new, external dynamics such as overgrazing (see Scheffer and Carpenter 2003). Various models trace steadily decreasing precipitation and increasingly xeric conditions following the Holocene Climate Optimum at c. 8200 BP, while contemporaneous pollen records point to swift transitions from grass- to shrub-dominated taxa seemingly coeval with archaeological evidence for the emergence and spread of stock-keeping. Indeed, a significant increase in the number of radiocarbon-dates from archaeological sites across the Sahara indicates rapid population expansion around the same time (Manning and Timpson 2014). Wright (2017: 9) attributes the vegetation change, albeit provisionally, to anthropogenic fire suppression and livestock grazing. An increase in albedo commensurate with such an ecological shift has been modelled to affect monsoon flow to the extent required for the observed drop in rainfall (Claussen and Gayler 1997).

Wright (2017) offers a persuasive synthesis of the climatic, ecological and demographic evidence for anthropogenic landscape change and its broader consequences, supported by more recent historical observations from New Zealand and North America where the introduction of domestic livestock by Europeans demonstrably impacted vegetation regimes. However, at a basic level, it is difficult to accept that the functional ecology of colonial European stock-keeping should be analogous to mid-Holocene herding in the Sahara. Moreover, given the scale of the region that was opening up - i.e., the breadth of the Sahara - pastoralist population densities and livestock counts were likely to have been relatively low during the early phases of domestication, even during the apparent demographic peak at c. 7500 BP (Manning and Timpson 2014). As is clear from our case studies, the degree of overgrazing required to exceed ecological regime transitions can often be linked to restrictions placed on pastoral mobility, itself akin to a self-policing mechanism that negates excessive exploitation of a single resource area (Krätli *et al.* 2013; see also Butt 2010). It seems unlikely that early Saharan herders were forcibly restricted in their movements. Indeed, the scholars on whose data Wright's hypothesis is based suggest a very different scenario: that the spread of pastoralism may in fact have increased vegetation biomass and prolonged the 'Green Sahara' (Brierley *et al.* 2018).

Studies like Wright's (2017) - whose findings we cannot entirely discount, even if they can be refuted - reinforce the importance of minimising generalisation and incautious analogy when exploring past human-environment relationships. Such research demands approaches that combine archaeological and palaeoenvironmental data framed by detailed understandings of ecology, ethnography, and history, and how they are entangled (Gillson and Marchant 2014; Marchant and Lane 2014). Though the principal generator of knowledge of the human past, archaeology is beholden to draw on lessons from other disciplines if its interpretations are to maintain accuracy and retain relevance. Likewise, palaeoenvironmental research should incorporate empirical data relating to land cover and land use (e.g., sedimentology, charcoal, fungal spores) in combination with spatial ethnography (e.g., Shetler 2007), historical mapping, and remote sensing. However, for integration to be successful, geochronological constraints and chronological and metrical uncertainties in all datasets need to be clearly presented and interpretive caveats clarified (e.g., Trachsel and Telford 2017).

In some cases, experimental work on the inclusion and exclusion of fire and herbivory (wild and domestic) can inform and be used to test historical research questions as well as modern land management or savannah rehabilitation (e.g., Riginos *et al.* 2012; Young *et al.* 2018). Anthropogenic glades and their associated ecological effects - such as localised soil enrichment (e.g., Muchiru *et al.* 2009) - have been shown to persist for centuries and are thus viable subjects for archaeological investigation (e.g., Boles and Lane 2016; Marshall *et al.* 2018). Such analyses might be refined through experimental work to differentiate between the specific drivers of local glade formations. Co-location of archaeological and palaeoenvironmental studies can also lead to stronger narratives of long-term human-environment interactions and each can support the limitations of the other (e.g., Taylor *et al.* 2005; Marchant *et al.* 2018).

Advances in GPS-tracking technology provide means to explore herding strategies and livestock grazing behaviour at high spatial and temporal resolutions (Coppolillo 2000; Butt 2010; Liao *et al.* 2018). Integrating empirical mapping data with knowledge of social, historical, and ecological contexts presents a more complex and variable picture of pastoralist livelihoods, one that brings into question models of past land use constructed using immutable typologies (e.g., mobile, semi-mobile, sedentary, or pastoral vs. agro-pastoral) and deterministic parameters like resource locations (Liao *et al.* 2018). Rather, production systems are shown to be influenced by dynamic relationships between diverse ecological and socio-cultural factors that vary through time. That such variation should be significant even at relatively short-term seasonal and intra-annual scales furthers the argument for the development and integration of historical data. Again, this complexity and dynamism highlights the need for subtler interpretations of herding strategies in the archaeological record using diverse datasets rather than reconstructions based on formulaic conceptual models.

Conclusions

Our case studies offer strong support to the argument that adaptive mobility is key to the ecological resilience of both pastoralist livelihoods and rangeland ecosystems. As tourism-led conservation and rapid urbanisation dominate land politics in eastern Africa, the pattern of pastoral-marginalisation that began with British colonialism (see Neumann 2002; Hughes 2006) has continued, with herders being denied access to historic rangelands, often with direct citation of overgrazing and misuse (Brockington 1999; Brockington and Homewood 2001). This has had severe consequences not only for the herders themselves (Msoffe *et al.* 2011) but also for the ecosystems from which they are excluded. Certainly, vegetation is extremely quick to change in the absence of cultural controls. In the Masol Plains northwest of Lake Baringo, for example, there was a 26% increase in bushland area and a 25% decrease in grassy areas over a period of 5 years between 1973 and 1978 when the Pokot abandoned the plains due to interethnic conflict (Conant 1982). In the case of state-supported evictions from wildlife reserves, lack of foresight in the planning process has sometimes deleteriously impacted the biodiversity of ecosystems that land-managers had sought to prioritise (e.g., Bhola *et al.* 2012; Veldhuis *et al.* 2019).

The scale of the ecological footprint of pastoralism is exemplified in a study undertaken in the Iremito region of Amboseli (Western and Dunne 1979). Nine new Maasai settlements were established within 157 km^2 between 1969 and 1970; assuming an impact radius of 225 m and allowing for a 68% resettlement rate - i.e., the re-use of previously occupied locations - over a century, it was predicted that almost 25% of the total area - nearly 40 km^2 - would be directly affected (Muchiru *et al.* 2009). Given the millennial timescales over which pastoralism has been present in African ecosystems, its potential consequences for shaping savannah ecologies is vast. However, pastoralism comes in many forms throughout its history and there is a pressing need to move beyond normative models of pastoralists' behaviour and impact if we are to understand their interactions with rangeland ecosystems. Heterogeneity is central to the functioning of these systems, which the curtailment of pastoralist and wildlife mobility, observed in our case studies, threatens to further homogenise and weaken.

The examples of Laikipia, Baringo, and Amboseli illustrate how damaging and unsustainable levels of grazing can frequently be attributed to external pressures such as conflict, restrictions on mobility, and the cascade effects of non-grazing resource exploitation. In Laikipia, the imposition of physical boundaries and the effective ghettoisation of small-scale herders in densely-stocked group ranches has seen those pastures suffer, while large landowners with fewer stock have seen biodiversity increases; similarly, in the early-to-mid-twentieth century restrictions were placed on herders in Baringo in order to limit their 'degradative' impact, only to increase pressures on an already relatively unproductive area; the contraction of rangelands in Amboseli and constriction of migratory wild animals to isolated zones and corridors has dramatically altered local ecologies, yet here again pastoralists have traditionally shouldered much of the blame. We do not expect that this degree of specificity can always be extracted from the historical archives that archaeologists and palaeoecologists work with, yet such alternative explanations force us to think beyond 'overgrazing' in our interpretations of past and present transformations of rangelands.

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Compliance with Ethical Standards

Conflict of Interest The authors declare they have no conflict of interest.

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