Turner and Schlecht *Pastoralism: Research, Policy and Practice* (2019) 9:13
https://doi.org/10.1186/s13570-019-0150-z

Pastoralism: Research, Policy and Practice

REVIEW Open Access

Livestock mobility in sub-Saharan Africa: A critical review

Matthew D. Turner[1*] and Eva Schlecht[2]

Abstract

Livestock mobility is a complex concept holding many different meanings for observers of pastoralism. The movement of African pastoralists with their livestock has historically been seen by outsiders as working against both environmental and development goals. Recently, there has been an embrace of the logics of livestock mobility while uncertainties persist of what it means and how it could be measured. In this void, various unexamined associations circulate tying livestock mobility to features of pastoral cultures, ecologies, and institutions. We review the empirical literature that has sought to measure and document livestock mobility, comparing two parameters of its components: grazing and travel mobility. We find strong similarities of daily grazing movements of herds around base locations (camps, villages, water points) but wide variation in the seasonal travel movement between base locations. This variation reflects the fact that mobility is not a cultural norm but responds to the nutrition needs of livestock. The magnitude of travel mobility parameters is the highest for those transhumance systems moving along latitudinal and elevation gradients, thus moving across variation that is more predictable than is commonly presumed in the pastoral literature. The implications of the observed spatialities of livestock mobility for pastoral institutions are discussed.

Keywords: Pastoralism, Herding, Transhumance, Grazing, Livestock nutrition, Non-equilibrium ecology

Introduction

Livestock mobility is a term that is increasingly used across a diverse set of forums including pastoral studies, rangeland ecology, social dimensions of climate change and conservation. In different parts of the world, commentators refer to mobility of livestock increasing or decreasing, expanding or contracting, and shifting or persisting with divergent impacts on landscapes, people, and the livestock themselves. A Web of Science search on the use of "livestock mobility", "herd mobility", "pastoral mobility", "livestock movement", or "herd movement" within title, keywords, or abstracts of peer-reviewed articles reveals that 35% of all uses of these terms have occurred from 2016 to 2018 with 75% of uses since 2008. Using Google Scholar, the average annual number of uses of "livestock mobility" over the last five years (2014–2018) is 58% greater than the annual average over the previous five (2009–2013). Livestock mobility and allied concepts are increasingly popular not only in the scholarly literature (as presented here) but in the broader literature on pastoralism and dryland development.

Despite its increased usage and possibly because of it, the term "mobility" remains vague with multiple meanings attached to it. These meanings extend beyond the livestock that are moving to the ecologies of vegetation they graze; the cultures, psychologies, and economies of the people husbanding them; and the human institutions that shape resource access to these livestock and their human managers. These meanings, left unexamined, have worked against effective efforts to understand, manage, and protect what one may see as the benefits of livestock mobility. Livestock mobility is necessarily a multidimensional concept—resisting reduced definitions and categorizations. In this paper, we review the published measurements of mobility in sub-Saharan Africa. In so doing, we will show the wide range of mobility patterns practised by those described as following a pastoral livelihood. This diversity, we will argue, results from herd managers varying their herds' mobility to improve

* Correspondence: mturner2@wisc.edu
[1]Department of Geography, University of Wisconsin-Madison, 160 Science Hall, Madison, WI 53706, USA
Full list of author information is available at the end of the article

or maintain the nutritional status of the livestock under their care, while maintaining necessary access to markets and avoiding crop damage and areas of insecurity with the herding labour at their disposal. In short, mobility is not a way of life but results from a succession of decisions shaped by the benefits and costs of mobility. Despite growing barriers and a changing set of incentives facing herders, their movement decisions are still strongly shaped by the health and nutritional status of their animals. We will argue that this focus sets them apart from major interests involved in conservation and development in pastoral regions. Without an explicit recognition of these differences and a refined vocabulary about livestock mobility, livestock productivity in extensive systems will stagnate and mobility, no matter how it is measured, will decline.

A brief history of views of livestock mobility

Livestock mobility can be seen as a cumulative measure of the movements of livestock within a given time period across open rangelands. Livestock mobility, so defined, can be associated with the mobility of all or just some of the people managing and depending on mobile livestock (Adriansen 2008). Those people, who depend economically on grazing livestock on common pastures, are often called pastoralists. Perceptions of livestock/human mobility as the prominent feature of pastoralists' livelihoods, culture, and economies have strongly shaped others' views of them. Just as importantly for this paper is that views of (agro) pastoralists shape in turn how outsiders have portrayed livestock mobility.

A brief summary of the long history of outsider portrayals of pastoralists is that their mobile livelihoods are seen to work against the interests of the state, progress/development, and a sustained environment (Kerven 1992; Niamir-Fuller 1999). The state's interest to control wealth within its borders while collecting taxes from and providing services to its citizens is, at the very least, complicated by the movements of people and livestock within and beyond the boundaries of the territorial state (Turner 2017). In fact, early accounts, despite evidence to the contrary, argued that pastoralism itself has worked historically against hierarchy and state formation (e.g. Burnham 1979).

Consistent with these views is the placement by early anthropologists of pastoralism and other mobile livelihoods (e.g. hunting/gathering) as primitive livelihoods along cultural evolutionary pathways leading to crop agriculture, economic surplus, and territorial forms of governance culminating in capitalism and the modern nation state (Kuper 2005). On more technical grounds, livestock mobility is seen to work against the spatial fixity of capital investments necessary for the intensification of livestock husbandry (Thornton 2010). Finally, and maybe most importantly, pastoralism as a livelihood and pastoralists as people have been seen to have interests (mobility) that work against private property institutions (McCarthy and Di Gregorio 2007). Livestock mobility as practised by pastoralists depends on common or open-access property regimes. Thus, pastoralists and livestock mobility are either seen as remnants of a primitive past soon to be replaced, or at the very least, the antithesis of economic development and progress.

Common and open-access property institutions, which are tied conceptually to the needs of livestock mobility, are also seen as leading to environmental tragedies due to the mismatch of individual incentives and the common good. While the idea of the "tragedy of the commons" is an old one and at least in modern times arguably first introduced into resource economics through a fishery analogy (Gordon 1954), pastoralist livestock are the narrative focus of the most well-known depiction of the tragedy (Hardin 1968; Picardi and Siefert 1976). These understandings, along with cattle complex views of pastoral logics (Herskovits 1926), led to persistent notions of the inherent tendency to overstock by African pastoralists (Sinclair and Fryxell 1985). This, coupled with longstanding ideas of mobile people lacking attachments to place and thus tending to not properly manage local resources, contributed to ideas that pastoralists are prone to misuse the environment (abuse and move on).

Given that pastoralism has been tied conceptually to livestock mobility, these understandings, most with some truth, have contributed to negative views of both within the domains of African conservation and development since the colonial era. While incidences of forced sedentarization of pastoralists are known, more widespread policy postures are best described as malign neglect. Governments have tended to not recognize pastoral customary authorities nor resource claims, and as a result, there has been, with the growth of rural populations, a long-term erosion of pastoral mobility and the institutions supporting it (Fernandez-Gimenez and LeFebre 2006; Niamir-Fuller 2000; Hobbs et al. 2008). Livestock mobility has proven particularly vulnerable to notions that it is a primitive cultural feature since its persistence under competing land-use pressures requires government actions to protect the public goods of pastures, water points, and movement corridors. Thus, we have witnessed pastoralists choosing to change livelihoods or reduce the mobility of livestock under their care as conditions change. Still, while it can be argued that we have witnessed a decline in the viability of pastoral livelihoods and an erosion of livestock mobility systems (Fernandez-Gimenez and LeFebre 2006; Niamir-Fuller 2000; Hobbs et al. 2008), more extensive livestock production systems have persisted with little growth in more "modern"

Western systems (except in some peri-urban areas and ranching systems in southern Africa). Such trajectories have not had a positive effect on the national economies of African countries dominated by dryland environments.

This history of malign neglect began to be increasingly questioned in the early 1990s. An accumulation of work in cultural, human, and rangeland ecology had highlighted both the productive rationales of pastoralism and problems with previous outside assessments of its low productivity and inherent environmental destructiveness (Hjort 1982; Dahl and Hjort 1976; Penning de Vries and Djitèye 1982; Wilson 1986; Sandford 1982; Olsson 1983; Mortimore 1989; Homewood and Rogers 1987; Starr 1987; Gilles 1988; Goldschmidt 1981; Ellis and Swift 1988; Boutrais 1992). The desertification narrative relied largely on the visual assessments of landscape change with little understanding of the magnitude and patterns of human land use. As a result, visual signs such as reduced vegetative cover were incorrectly treated as both signs of degradation and grazing. This early work has since been seriously undermined at least in the scholarly literature (Hiernaux 1996; Reynolds and Smith 2002; Swift 1996; Davis 2016; Tucker et al. 1991; Thomas 1993; Behnke and Mortimore 2017). In places such as the Sahel, this later work showed that much of the decline in vegetative cover accorded to livestock grazing was in fact due to spatio-temporal variation on rainfall. Moreover, much of the landscape change that was at least suggested through the use of the term 'desertification' (in contrast to desiccation) as being persistent has been proven to be ephemeral with dryland vegetation, particularly annual grasses and forbs, showing higher levels of resilience than was assumed (Hiernaux et al. 2009a, 2017; Dardel et al. 2014; Rasmussen et al. 2018; Hiernaux et al. 2009b).

Added to these studies questioning the evidence for widespread grazing-induced environmental change across African drylands was work questioning prior assumptions of over-stocking. Building particularly on the influential work of Ellis and Swift (1988), this literature showed that the population dynamics of domestic livestock are often independent of stocking rate and more shaped by inter-annual variation in rainfall. Thus, assumptions of equilibria between stocking rate and forage condition that underlie conventional rangeland management prescriptions for stocking rate adjustments were questioned in dryland environments with high coefficients of variation in annual rainfall. Under the new non-equilibrium rangeland ecology (Behnke et al. 1993; Scoones 1994), the dynamics of vegetation supporting domestic livestock populations is seen to be less influenced by grazing pressure and more shaped by abiotic factors (rainfall parameters) outside of the grazer-vegetation relationship. While adding additional evidence against widespread grazing-induced deterioration of African rangelands, non-equilibrium insights do not support arguments that pastoral livestock are environmentally benign—significant changes to the composition and productivity of grazed vegetation can occur before having a measurable effect on livestock numbers. Subsequent discourse since the mid-1990s suggests that this caveat has not been fully appreciated by some social scientists.

To what extent did the new range ecology interrogate existing perspectives about livestock mobility? The early seminal work compared temporal variabilities of rainfall and livestock population in a spatially aggregated fashion. Still, the new rangeland ecology was tied explicitly to African pastoralism. Arguments were developed that livestock populations are best maintained through flexible movements that track variable rainfall and that these movements would allow a larger sustainable livestock population (Scoones 1994). Thus, the embrace of the highly variable and unpredictable rainfall and forage conditions over time within non-equilibrium rangeland ecology was translated to also argue, given the presumed positive relationship between spatial variability of rainfall within a year and high temporal variability across years, that livestock mobility and pastoral livelihoods were key adaptations to the high spatio-temporal variability of forage in African drylands (Boone et al. 2008; Turner et al. 2016a). Moreover, building on the work focused on grazing patterns of wild East African ungulates (McNaughton 1979; McNaughton and Georgiadis 1986; Seagle and McNaughton 1992), it was argued that the within-season temporal pattern of grazing pressure experienced at any particular range site used by mobile grazing animals is that of heavy bouts of grazing separated by rest periods, which is assumed to be more sustainable, mimicking the patterns produced by rotational grazing systems (Savory and Butterfield 1999).

Thus, over a two-decade period, outsider perspectives on pastoralism and livestock mobility have shifted (not transformed), particularly among scientists, toward a view that these are consistent with the sustainable use if not development of African drylands. Still, rural residents, NGO personnel, protected area officials, and government functionaries may hold negative views about the ecology of pastoralism and livestock mobility; this is even more so in the realms of governance and economy with pastoral peoples' proclivity to move with their livestock seen as leading to social conflict and working against the interests of development. The persistent negative views in the political-economic sphere have been somewhat mollified by the expanded concern about the vulnerability of the tropical drylands of Africa to climate change. Climate change analysts have embraced

mobility of people and livestock and the maintenance of rural stores of wealth (livestock) as key parts of climate change adaptation and risk reduction (Swallow 1994). In contrast to crop fields, the ability of livestock to be moved to where rain falls has captured the imagination of climate change analysts. Moreover, there is a growing recognition of the important role of domestic livestock as wealth stores not only for pastoralists but for all rural people to reduce their vulnerability to the inter-annual variability of rainfall. Mobile wealth stores in the form of domestic livestock are not new to dryland regions of Africa and the world. What is new is the broader recognition of their importance, which until the last two decades, were often conveniently ignored due to the prevalent environmental concerns about domestic livestock.

Unexamined relationships

If we examine this history, we see a shifting set of concurrences presumed to connect ecology, mobility, livelihood, and institutions. Early environmental determinists such as Ellen Semple (1915) connected high spatio-temporal variability of African drylands to the need for mobility. This, coupled with an expanding herd, was seen as increasing the potential for political forms driven by predatory expansionism but with a limited ability to develop higher governance structures/hierarchies (Burnham 1979)—a kind of roving band. These connections are what supported the earlier but still persistent view of the concurrence of environmental variability, mobility, and primitiveness which contributes to the malign neglect of pastoral needs by governments and development actors. Are we now so enlightened to not fall into a different series of presumed concurrences? We may not be so lucky.

In fact, an underlying motivation for this paper is that there are sets of associations circulating today that while nominally supportive of pastoral livelihoods, could, if left unexamined, work to erode efforts to support and maintain pastoral mobility (Krätli and Schareika 2010). The set of concurrences are not fully articulated in any single written work. Instead, their articulation is only partial and implicitly stated. These coupled with statements, questions, and explanations made across a range of forums suggest incipient concurrences being formed. By articulating them here, we hope to initiate discussion and introspection.

A first concurrence is that made between livestock mobility and pastoralism. Livestock mobility is seen as a distinguishing feature of the pastoral livelihood and, as such, often is treated implicitly as an inherent and continuing characteristic of particular livestock-rearing societies. But do "pastoralists" see this feature as important to their identity as outside analysts do? If not, could our portrayals attach to pastoral societies a stronger adherence to livestock mobility than they actually hold? As will be developed below, the wide variation in mobility patterns of pastoral livestock across time and space suggests that mobility, as a set of practices, is not rigidly adhered to.

A second association ties pastoralism to non-equilibrium rangeland ecologies. A simple rule of thumb about the prevalence of non-equilibrium dynamics is the coefficient of variation (CV) of inter-annual rainfall being 33% or higher (Ellis and Swift 1988; Behnke et al. 1993). Under these conditions, it is thought that changes in rangeland production are more driven by variations of rainfall than by stocking rates (von Wehrden et al. 2012; Engler and von Wehrden 2018). Subsequent work has shown that the vast majority (72%) of the world's rangelands have CVs less than 33% (Sayre et al. 2017). Therefore, one needs to be careful about the overall facile link between pastoralism and non-equilibrium ecology when considering pastoralism's environmental effects. An example comes from a question-and-answer period witnessed by the first author following an international conference presentation describing an ecological assessment of a temperate alpine pastoral system that concluded that there were significant signs of environmental decline due to over-stocking. The presenter was strongly questioned by audience members who questioned the findings because the system, since it involved pastoral mobility, must be non-equilibrial.

A third and related concurrence is that of linking livestock mobility to high spatio-temporal variability of rainfall and the need for flexible movements. Flexible movements and forage tracking are seen as necessary responses to unpredictable environmental variability and thus cannot and should not be constrained. In the extreme, such portrayals preclude the building of tenure institutions that rely in part on predictable variability (seasonal or spatial). In short, this association ignores dimensions of environmental variability that are more predictable and calls into question territorial institutions designed to seek accommodation of livestock mobility with competing land uses (e.g. agriculture).

In the extreme, these associations together produce an imaginary of pastoralism (and livestock mobility) that is ironically similar to earlier misunderstandings: pastoralists are seen as rigidly adhering to a livelihood that is not tractable and therefore inconsistent with conventional Western institutions of management. We raise these questions to make the cautionary argument that we must critically examine our assumptions and what might be overly facile associations. If we do not, we may be working at cross-purposes to whatever policy or management goals we may hold. In addition, the vagueness of the term 'livestock mobility', while serving well as a

boundary object (Star and Griesemer 1989; Fujimura 1992), serves less well in building understandings of the diverse needs of and underlying motivations behind the movements of livestock herds. Such knowledge is very important. We start by seeking some clarification about how we might think about livestock mobility.

What is livestock mobility?

Today, the term 'livestock mobility' is most commonly used in the pastoralism literature—spanning the social and ecological sciences. It is a term that refers to many sets of practices whose descriptions are shaped by the spatial and temporal scales of observation. As a result of this complexity, livestock mobility most often remains undefined and its dominant use in the literature is to not characterize or compare different pastoral practices but instead to cite changes within a specified pastoral system—in short, livestock mobility is described as increasing or decreasing. But as will be further developed below—the geography of these movements matters—the distance and timing of livestock movements affect livestock nutrition, environmental effects, and the appropriate scale of the institutions needed to support and manage these movements.

In order to provide some sense of the parameters that could be used to describe livestock mobility, we will introduce a simple geographical model of African pastoralism. We recognize that it may not fit livestock trekking movements to markets nor some systems whose primary goal is meat production, but we argue that even these cases often do not violate the model we introduce. Most of all African livestock rearers manage their herds to produce meat and milk (especially for cattle). In extensive rangeland situations, unweaned calves must be separated from their mothers during a good portion of the day for herd managers to be able to effectively capture milk. This results in a point-centred pattern where livestock are reunited with calves at encampments or villages at the end of the grazing day.

This milk-oriented explanation does not explain point-centred patterns of grazing observed for pastoral livestock that are not milked, most commonly seen for small ruminants. Still, we should also note that even in situations where meat production is the main productive goal, this point-centred pattern exists with grazing movements around encampments or villages distinguishable from travel movements. In these cases, one can point to these sites as being socially accessible to a pastoral group (pastoral tenure) and with the combination of resources (water, forage, security) that are important for livestock production (e.g. Western and Dunne 1979; Scoones 1995). In most cases, the density of comparable sites does not allow daily movements from one site to another and so herds return to one site until it is necessary to make a longer directional move to another (a travel movement, as described below).

From these simple observations, we can distinguish between travel movements and daily grazing movements. The distinction is not necessarily one of distance, rate of movement, or whether any grazing occurs while walking. The distinction is that for grazing movements, the start and end points over a grazing period are the same (grazing orbits) while travel movements result in the net movement of livestock across a 24-h period (Adriansen and Nielsen 2002; Dongmo et al. 2012).

One can imagine that grazing and travel mobility could be measured in quite different ways. Table 1 presents a number of plausible parameters for measuring grazing and travel mobility. Possible grazing movement measures range from dispersal distances to distance travelled. It should be clear that different measurements may be of interest to different stakeholders interested in livestock mobility. For example, one can imagine that a herder would seek to maximize intake of quality feed by his herd at a given energy expenditure while avoiding various hazards (cropped fields). Thus for a herder, the fraction of the time spent on quality pastures is as important as the total distance covered. In contrast, for the range ecologist, the frequency of travel movements and the dispersal distance around bases may be of particular importance (Moritz et al. 2010; Tolsma et al. 1987; Turner 1998; Diawara et al. 2018; Rasmussen et al. 2018).

Grazing mobility

Over the last decade, there has been a revolution in terms of data acquisition about grazing movements (itineraries followed around a grazing orbit). While in the

Table 1 Plausible measures of grazing and travel mobility

Grazing mobility
Distance travelled per day
Maximal radius of movement from home base during the day
Time away from home base during the day
Frequency of movement while grazing
Frequency of watering (every *x* days) determining the orbit distance/duration
Travel mobility
Sum of travel movement distance across a year
Frequency of travel movements across the year
Maximal distance between base and travel movement destination
Weighted density of resting points visited during the year
Average distance travelled between adjoining resting points or water points

past, characterizations of daily grazing movements have indicated dispersal distances from a base, the increased availability of GPS technologies has expanded the type of parameters that can be captured. Still, studies are quite different in terms of the number of individual herds monitored, the seasonal periods of monitoring, and the monitoring rate of a single herd within the monitored period. Moreover, the ways in which mobility data are presented vary significantly from one publication to another. Table 2 presents a thorough but less than exhaustive list of studies in sub-Saharan Africa that have attempted to quantify grazing mobility. We are sure that there are studies we have missed with much data that have been collected remaining in the grey literature or unpublished.

As shown in Table 2, a major management difference affecting the length of dry-season grazing orbits was the location of the home base in relation to the source of water for the herd. Longer-distance daily grazing movements (> 20 km) are most often associated with movements made every other day from bases far away from a water point. Parameters are generally larger for cattle herds compared to herds of small ruminants. In many cases, mobility parameters vary more seasonally at one site than between sites with parameters larger during the dry season compared to the rainy season.

One thing to note is that despite the wide range of environments and management practices described in these studies, grazing mobility parameters are remarkably consistent, with most parameter ranges overlapping across different studies. The similar findings across studies point to the common constraints and needs of domestic livestock associated with spatial patterns of forage on offer, the decline in its quality over time as grazing (and selection) continues, and the time and energy expenditures of walking. These are the common factors affecting grazing around all types of bases, and travel movements to new bases are often made if the energy balance of animals suffers significantly at a particular base for more than two or three subsequent days (Fust and Schlecht 2018; Raizman et al. 2013; Feldt and Schlecht 2016).

Despite the importance of nutritional requirements as strongly shaping grazing mobility parameters, studies have found that grazing mobility patterns are different when managed by a herder through the grazing orbit compared to free grazing or what could be called, herd-and-release forms of management. A number of studies have found that herding increases the distance travelled while grazing and significantly improves forage on offer across the grazing orbit, although the effect varies by species and season (Schlecht et al. 2006a; Turner et al. 2005). Among herded livestock, some studies have found these parameters to be significantly affected by herder effort as shaped by labour availability and, to a lesser extent, by herd self-ownership (Turner and Hiernaux 2008), but these relationships have not been found in other studies (Coppolillo 2000).

Travel mobility

Travel mobility refers to the movement of livestock herds between two bases around which livestock graze. The description of travel mobility has been a major preoccupation among pastoral scholars given that for many, these travel movements distinguish pastoralism from more sedentary forms of livestock husbandry. Geographers in particular have depicted these movements as axes of seasonal movement or annual movement circuits depicted by broad arrows on maps (e.g. Barral 1974; Stenning 1960; Gallais 1967, 1975; Benoit 1979; Beauvilain 1977; Bassett 1986; Gomez 1979; Touré et al. 2012). These depictions are abstractions of how pastoralists most often describe these movements as a series of named points (encampments and water points), consistent with the geographical model described above (Marie et al. 1982; Turner et al. 2016b). These base points are likely to show some year-to-year continuity in cases of transhumance systems and much less so in more nomadic systems. The risk of abstraction is that it may reinforce notions that travel movements do not rely on key pastoral resources—physically identified on the ground. Instead, livestock movements are treated as infinitely flexible and ephemeral. Moreover, our knowledge about quantitative parameters that could describe travel mobility (Table 1) remains limited despite long-term attention to the topic.

Table 3 presents a less than exhaustive list of studies in sub-Saharan Africa that describe travel mobility of pastoralists. They are somewhat biased toward West African transhumance systems and to systems known for longer-distance seasonal movements since it is these that are more likely to be mapped or otherwise characterized. There are many pastoral studies where either no travel movements are mentioned or travel movements within a year are described as occurring within a 40-km radius (Coppolillo 2000; Butt 2010; McPeak 1999; Feldt and Schlecht 2016; Raizman et al. 2013). As mentioned above, the depictions of travel movements are dominated by works that present axes of common seasonal movements on maps based on interviews with pastoral communities. From such depictions, one can estimate the maximum distance between home and destination as has been done for the estimates presented in Table 3. A variant of this approach is to collect lists of the encampment points visited by herds during a typical year and, using this, to estimate travel mobility parameters. Unlike the case of grazing movements, the increased availability of GPS technology has not revolutionized the tracking of

Table 2 Parameters of grazing mobility previously reported in the literature. NR designates a characteristic or parameter that was not reported by the reference

Mode[1]	Species[2]	# herds[3]	# Itin[4]	Monitor period[5]	Average reported[6]	Grazing radius[7]	Dist. grazing (km/day)[8]	Hours grazing[9]	Country[10]	Ref[11]
Track	C	NR	NR	dry season	No	3.0–8.0	8–16	NR	Kenya	(Western and Finch 1986)
Track/GPS	C,CM,S,G	4	102	12 months	Seasonal	NR	CM 15–23; C 11–30; G/S 12–15	NR	Kenya	(Coppack et al. 1988)
Track	C	4	NR	12 months	Herd	NR	4.0–7.7	NR	Zimbabwe	(Scoones 1995)
Track/GPS	C	24	24	dry season	No	0.5–4.0	NR	NR	Tanzania	(Coppolillo 2000)
Interview	C,S,G	213	1566	19 months	Study site	NR	7.0–10.1	NR	Niger	(Turner et al. 2005)
GPS	C,S,G	24	237	12 months	Seasonal	NR	C 12.2–13.9; G 10.9–11.8; S 10.1–12.5	C 8.0–10.4; G 7.7–8.2; S 7.6–8.3	Niger	(Schlecht et al. 2006b)
GPS	C	7	102	12 months	Seasonal	2.8–4.6	8.0–10.8	11.0–11.4	Kenya	(Butt 2010)
GPS	C	21	21	March	No	2.2–7.6	9.7–20.5	10.2–11.75	Cameroon	(Moritz et al. 2010)
Track/GPS	C	25	125	24 months	Seasonal × site	NR	7–11	7.9–10	Cameroon	(Dongmo et al. 2012)
GPS	C	8	1525	17 months	Month × herd	NR	1.8–18.2	NR	Kenya	(Raizman et al. 2013)
Track	C,S,G	9	81	12 months	No	NR	C 7.5–17.4; G 4.5–10.5; S 7.3–18.8	NR	Burkina	(Zampaligré et al. 2013)
GPS	C	12	11	24 months	Seasonal	1.9–4.4	11–14	10.6–13.6	Madagascar	(Feldt and Schlecht 2016)
GPS	C	3	341	12 months	Study site	NR	9.2–15.9	NR	Ethiopia	(Wario et al. 2016)
GPS	C	4	214–218	214–218 days	Maximum for herd	6–9	NR	NR	Kenya	(Liao et al. 2017)
Interview/track	C	6	NR	12 months	No	3–4	NR	NR	Sudan	(Sulieman and Ahmed 2017)

[1]Mode of itinerary monitoring: *Track* physical tracked, *GPS* GPS recordings, *Interview* interviews of herders. [2]Livestock species: *C* cattle, *CM* camels, *S* sheep, *G* goats. [3]The number of herds monitored. [4]The number of grazing itineraries followed. [5]The period of time that itineraries were monitored. [6]The group variables for which averages are reported in parameter ranges (if minimum and maximum values of parameters are averages, otherwise no). [7]Range of grazing radii reported. [8]Range of distance (km) travelled per day while grazing. [9]The range of time spent grazing per day. [10]Country where monitoring occurred. [11]The reference reporting the parameters

Table 3 Parameters of travel mobility previously reported in the literature. NR designates a characteristic or parameter that was not reported by the reference

Form[1]	System[2]	# herd[3]	# routes/axes[4]	Max. radius (km)[5]	Displace (km)[6]	Annual dist. (km) [7]	Country[8]	Ref[9]
Map	LT/FL	NR	> 100	10–100	NR	NR	Senegal	(Bonnet-Dupeyron 1951)
Map	LT	NR	10	150–300	NR	NR	Niger	(Beauvilain 1977)
Map	LT	NR	6	40–120	NR	NR	Burkina Faso	(Benoit 1978)
Track	LT	1	1	NR	12–18	NR	Mali	(Diallo 1978)
Track	LT	1	1	160	NR	NR	Mali	(Traoré 1978)
Map	LT/FL	NR	> 100	5–200	NR	NR	Senegal	(Gomez 1979)
Track	ND	3	3	27–40	7–17	80–140	Ivory Coast	(Bassett 1986)
Map	LT	NR	8	100–200	NR	NR	Ivory Coast	(Bassett 1994)
Interview	LT	9	9	63–750	NR	183–1880	Niger	(Ziviler Friedensdienst et al. 2008)
Interview	FL	NR	NR	40–100	NR	NR	Cameroon	(Dongmo et al. 2012)
GPS	ND	10	10	0–12.5	NR	NR	Kenya	(Raizman et al. 2013)
Track	LT/FL	3	3	20–260	15–19	NR	Sudan	(Young et al. 2013)
GPS	VT	13	13	NR	10–45	NR	Madagascar	(Feldt and Schlecht 2016)
Interview	LT/FL		54	8–106	NR	NR	Senegal	(Turner et al. 2016a)
Interview	ND	91	91	0–50	NR	NR	Ethiopia	(Wario et al. 2016)
GPS	ND	20		5.8–12.5	NR	NR	Ethiopia	(Liao et al. 2017)
Interview/map	LT	6	8	66–290	NR	132–580	Sudan	(Sulieman and Ahmed 2017)
GPS	LT	6	6	53.3–172.7	3.2–4.1 (median)	633–763	Cameroon	(Motta et al. 2018)

[1]Form in which travel movements were monitored or reported (*Track* tracking of herds, *GPS* GPS recordings, *Interview* interviews of herders, *Map* movements designated on maps without information about how information was gathered). [2]The mobility system (*LT* latitudinal transhumance, *FT* floodplain/lowland transhumance, *VT* vertical transhumance, *ND* non-directional movements). [3]The number of herds monitored (# herds). [4]The number of routes or axes delineated (# routes/axes). [5]The maximum radius of annual travel movements. [6]Average displacement distance between encampments over the year. [7]The total travel distance covered across the year. [8]Country where monitoring occurred. [9]The reference reporting the parameters

travel movements. GPS or human tracking of herds across a yearly cycle has generally only been performed for a very small number of herds (Table 3).

The data presented in Table 3, despite its limitations, is revealing. First, larger travel mobility parameters are associated with the transhumance systems of West Africa along a N-S axis. In these systems, travel movements run parallel to the sharp bioclimatic gradient from the Sudano-Guinean zone in the south to the edge of the Sahara in the north. Rainy seasons are longer, but mature vegetation is of lower quality in the south (Penning de Vries and Djitèye 1982). Thus, herds may move south during the dry season to graze crop residues and then move further south, to catch the earlier rains. Herds move north during the rainy season to avoid cropped fields and to benefit from the sparser but more nutritious vegetation there. Work has shown that the timing of the phenological events (greening-up and senescence) that trigger travel movements across this latitudinal range is remarkably regular from year to year which runs counter, at this scale, to notions that livestock mobility is solely governed by unpredictable variation of weather parameters (Brottem et al. 2014). If we couple this finding with a consideration of the nature of the ecological gradients on which other sub-Saharan African transhumance systems rely, such as altitudinal gradients and dry-season movements to floodplains or depression areas (Beauvilain 1977; Moritz et al. 2013; Schmitz 1986; Gallais 1984; Dongmo et al. 2012; Homewood and Rogers 1991; Mortimore 1989; Western and Dunne 1979; Scoones 1989), it is clear that a portion of the bio-physical variation that drives travel mobility is predictable at wider scales (Young et al. 2013). The predictability of spatio-temporal variation in rangeland conditions varies across scales—longer-range travel movements are more likely to be responding to more predictable spatio-temporal variabilities in bio-physical conditions than shorter-range movements. The implications of this point will be discussed in the section on livestock mobility and institutions.

A second observation of the data presented in Table 3 is the wide variation of travel mobility parameters and that much of this variation can be witnessed within individual study areas (and within ethnic groups). This is consistent with arguments that the mobility choices made by herd managers are not shaped by a rigid adherence to a mobile livelihood but reflect an assessment of the benefits and costs of mobility. In short, livestock mobility is a means to an end.

Livestock mobility as a means toward an end

While outsiders might tend to focus on livestock mobility as the key identifying feature of pastoralism, either to romanticize or denigrate it, for pastoralists, it is their relationship to livestock rearing that is most important and not mobility per se (Adriansen 2008; Schareika et al. 2000). Pastoral and agro-pastoral identities may be tied to freedom of movement and to livestock. Still, there is little romanticization by pastoralists themselves of the "herding" lifestyle which involves long work hours, a restricted diet, and social isolation. Livestock movements are seen as necessary responses to livestock nutrition requirements, security risks, and market opportunities (Turner et al. 2014). With respect to livestock nutrition, the goal is to provide a mixed group of animals with forage of suitable quality (density and nutrient content) within an appropriate distance from water to maintain necessary watering frequency. A number of studies lend empirical evidence for the grazing management by herders distributing livestock well in relation to the available forage resource (Behnke 2018; Moritz et al. 2014; Turner et al. 2005). Arguably, livestock nutrition is the primary goal of both grazing and travel movement decisions (Schareika 2001), but in the case of travel movements, such decisions are complicated by incomplete information and the energy/time demands of movement. Incomplete information is due to the changing conditions that affect whether a location provides a good opportunity for grazing. These conditions are as much sociopolitical than bio-physical, since the number of herds at an encampment, livestock health risks, the presence/absence of a host, the presence/absence of bandits/government officials, the distribution of cropped fields, and conflicts among herders and with farmers can change more rapidly than water or forage quality.

In short, we are arguing that for most pastoralists, moving livestock is a means to an end with the primary end being to achieve a satisfactory level of nutrition of livestock. It is not an abstract lifestyle choice. Moving livestock from a home territory, where a herding family enjoys a denser network of social ties, always bears risk due to greater exposure of the family's wealth (livestock) on the move to loss, thieves, government officials, and crop damage payments. Moreover, a family with insufficient labour, or small numbers or weakened livestock, will be less likely to move their livestock. Livestock movement decisions thus follow cost-benefit logics. Moves are more likely to occur if the gains of moving livestock (improved forage, water, market or security conditions) are sufficient given the added risks to herds on the move. Weakened livestock in a herd may remain at the home base while others move. In situations of drought or at the end of the dry season, periods of time when the gains of moving to better forage conditions would be seen as high, the risks of moving weakened livestock are often too great and therefore one observes a reduction of mobility. This argument is not novel but bears repeating. It is supported by work outlining the changing mobility of pastoralists and agro-pastoralists

over time (Bonfiglioli 1988, 1990; Thébaud 1999; de Bruijn and van Djik 1995).

The mobility response to the expansion of cultivation pressure is illustrative of the importance of livestock nutrition in herders' decisions. As cultivation pressure increases, there are some that have argued that livestock husbandry will move to more sedentary forms to take advantage of the benefits of crop-livestock integration and intensification (McIntire et al. 1992; Powell et al. 1995; Boserup 1965; Bourn and Wint 1994). The empirical record for such a transition is mixed. The expansion of cultivation pressure actually often leads to an increase in travel mobility and seasonal movements away from one's home base (Turner et al. 2014; Lericollais and Faye 1994; Lhoste 1987; Bonfiglioli 1990; Bourn and Wint 1994; Turner and Hiernaux 2008) unless cash for feed supplements is available (Moritz 2012; Lericollais and Faye 1994). These observations reflect the difficult decisions made by herd managers faced with cultivation expansion. The increased presence of cultivation produces local forage scarcity (particularly in the rainy season) while increasing the risks of crop damage and social conflict in moving toward areas where pasture remains. The risky choice to move is one made in response to the nutritional needs of livestock.

Over the last two decades, there has been a growing recognition of the benefits of livestock mobility by a range of actors including range scientists, development practitioners, climate change specialists, conservationists, and government officials. As described earlier, these more positive views are new, after many decades of persistent negative portrayals of livestock mobility by non-pastoralists. Mobility is seen to reduce climate change vulnerabilities, distribute grazing pressure, and reduce risk—goals that are laudable but a bit abstracted from the realities of herders' practices and the challenges that herders face. What is most noteworthy is that livestock nutrition, a major consideration for travel movement decisions made by pastoralists, does not feature prominently if at all in the ends expressed by others. Livestock mobility, in its current vague usage, is thus a means to different ends.

Similar to the vagueness surrounding other terms, such as sustainable development (Lélé 1991), we find ourselves in increasing agreement about the rationality of livestock mobility but with little consensus on how to support it. Pastoral associations are formed, legislation is passed, and corridors are marked, all in support of livestock mobility without moving toward an understanding of the underlying goals and key material features and resources that drive and support mobility. Corridors are marked to move livestock safely and expeditiously through agricultural areas often with little consideration of the nutritional needs of livestock on the move—namely pastures and accessible water points at the encampment points that these corridors join. Such protections of livestock mobility can actually lead to significant nutritional costs to livestock resulting in pastoralists abandoning them and seeking alternatives (including reduced travel mobility), thus reinforcing notions that they are resistant to development and prone to wander as they please. Once again, despite the change in rhetoric and abstract support of livestock mobility, pastoralists continue to be viewed as unruly subjects of development.

Livestock mobility and animal nutrition

While issues of security, market access, herding labour, and disease risk play important roles in livestock movement decisions, the fundamental goal of such decisions is livestock nutrition. The movements of livestock to gain access to higher quality forage and water are the primary factor behind decisions to move. Improved livestock nutrition is associated with improved livestock condition and reproductive performance (age at first calving, calving rates, calf survival, etc.). Livestock nutrition results from tradeoffs among three variables: the quality of forage (density, quality) and water that is accessible, the time available to graze, and the energy expended to access grazing areas and water points. The movements to better grazing and watering resources may incur costs: greater energy expenditure and less time allocated to grazing. Except for areas of significant vertical gradients (highlands in East and Southern Africa), the energy costs of walking are relatively small compared to the daily forage energy consumption during most of the year, but these costs become more important as the quality of feed declines during the dry season. Reflecting this, livestock grazing and travel mobility often decline at the end of the dry season due to livestock weakness and fewer forage resources available to compensate for the energy expended while moving.

A closer look at the tradeoffs of livestock energy expenditures versus consumption potentials demonstrates why mobility may decline at the end of the dry season or during periods of drought-induced forage scarcity. The energy expended to move to other locations varies from 1.5 to 6 J/kg live weight/m (Lawrence and Pearson 1998; King 1983). If we take the example of an adult steer with a live weight of 350 kg covering a daily distance of about 4 km—a typical daily itinerary for transhumant cattle herds in the Adamawa region in Cameroon (Motta et al. 2018), the amount of feed dry matter (DM) needed to cover the energy cost of walking of 2.5 MJ/day would amount to 360 g DM/day in the early dry season assuming a feed quality of 7 MJ metabolizable energy (ME) per kg DM (Schlecht et al. 1999). If due to increasing feed scarcity the daily itinerary length increases to 12 km in

the late dry season (Butt 2010; Schlecht et al. 2006b), the amount of feed needed to cover the energy cost of walking would triple if feed quality remains constant. Yet, feed quality normally declines during the dry season, as a result of selection, trampling, and excretion of pasturing animals, and the energy content may thus decline to 6.5 MJ ME/kg DM or less (Schlecht et al. 1999), which further increases the demand of feed for covering the cost of walking. In these situations, it becomes thus increasingly difficult to meet the animals' additional energy requirements for maintenance (about 37 MJ ME/d in our example (McLennan et al. 2017), which is equivalent to 5.5 kg DM of late dry-season feed), let alone production (growth, milk), and therefore, live weight losses are regularly encountered at the end of the dry season (Fust and Schlecht 2018).

It is important to recognize as well that the movements of livestock herds, especially in the dry season, are as much about maintaining access to water as fodder. For each kilogramme of feed dry matter consumed, cattle need to ingest 3 to 5 l of water (Schlecht, unpublished data). While in the rainy season fresh grasses and forbs can largely supply this water given their high moisture content, the supply of drinking water is imperative when the forage is dry. Insufficient water intake will reduce livestock health and nutrition (and reduce the animals' ability to ingest and digest fibrous dry season feed).

Therefore, movement decisions are made through a consideration of the costs of energy expenditure incurred by livestock in grazing and travel movements against the benefits of improved access to water and forage. But even this is too simple since one must consider the lost grazing time incurred during periods of walking and waiting for water. The time remaining for feed intake at the destination shrinks as walking distances increase (Fust and Schlecht 2018). This may motivate herders to remain in remote grazing areas, ideally near distant watering points, and in this way lower the burden in terms of energy expenditures and time of long-distance walks (Raizman et al. 2013; Feldt and Schlecht 2016). Likewise, prolonged waiting times at water points will reduce the time available to graze. Water sources that require significant labour and time to draw water or where there are large numbers of herds waiting for water can reduce the effective time spent grazing during the day.

In these ways, the decisions to move are strongly shaped by the tradeoffs between forage/water access, energy/time expended by moving, and grazing time. The relative balance of the tradeoffs varies geographically, seasonally, and among livestock species. This helps explain the wide variation of travel mobility parameters reported among study sites, among different herds at particular study sites, and for individual herds across seasons (Table 3).

Institutions and livestock mobility

What are the institutional implications of the mobility needs and patterns of pastoral livestock? It is important to first review what a serious engagement with the complexities of livestock mobility has revealed:

1. Livestock mobility is a means toward an end with significant nutritional tradeoffs shaping mobility decisions.
2. Livestock mobility requires key physical resources. Pastoral toponymies are populated with names for encampment points, water points, and salt licks. The fact that these places have names supports the argument that while they may not be visited each year, pastoral groups return to them often over many years. Thus, depictions of travel mobility as being infinitely flexible, unmoored to particular sites on the landscape, are misleading.
3. The predictability of the spatio-temporal variation of rangeland conditions is strongly affected by scale. Longer-range travel movements (e.g. transhumance) respond to seasonal variabilities and spatial heterogeneities that display some predictable regularities. The spatial and seasonal differences between the floodplain and rainfed pastures, alpine and lowland pastures, and pastures across the latitudinal gradients in the tropics display more regularities than is commonly recognized by scholars of pastoralism.
4. Travel movements that are of shorter range (non-directional in Table 3) are responding to much less predictable variation in resource availabilities. The travel mobility parameters for these systems are generally smaller. The scale of unpredictable variation (e.g. linked to rainfall) is relatively fine-scaled with travel movements within a 40-km radius often sufficient to visit good pasture sites (Turner et al. 2016a).

The question then is what institutions, both in terms of scale and form, are appropriate to support livestock mobility? Pastoralism scholars have long argued that rigid rules of exclusion work against the flexibility required for livestock movements that need to be responsive to changing social and ecological conditions (Gilles 1988; Fernandez-Gimenez 2002; Niamir-Fuller 1999; Moritz et al. 2013; Turner 1999; Behnke 2018; Moritz et al. 2014). Some have emphasized the importance of few if any restrictions on free access to pastoral resources (Behnke 2018, Moritz et al. 2014), and others have emphasized the importance of porous social boundaries and the role of reciprocal social relations in gaining access to pastoral resources (Turner 1999). In all cases, pastoral tenure deviates strongly from the common property ideal of a clearly bounded resource managed by

a closed social group through a set of usufruct rules (Ostrom 1990).

Empirical and theoretical work has supported the argument that unrestricted grazing and travel mobility, as managed by herders, in fact leads to proper distributions of grazing pressure in relation to grazing resources (Behnke 2018; Moritz et al. 2014; Turner et al. 2005). Given what is seen as the unpredictable nature of forage and water availabilities over time and space, it could be argued that the ideal institutions managing pastoral movements and access to resources are in fact highly porous or open with few restrictions (Moritz et al. 2013; Behnke 2018; Herrera et al. 2014; Davies et al. 2016). This is a compelling argument—ecological dynamics working against the dominant exclusionary views of property—private or common (Fernandez-Gimenez 2002).

One important limitation of such arguments is that most pastoral systems must operate in shared spaces with competing land-use systems such as crop agriculture. The history of cropland encroachment across pastoral spaces is one that demonstrates that such open forms of pastoral tenure are quite vulnerable to exclusionary systems of control and zoning logics (Marty 1993; Turner 2011; Niamir-Fuller 1999). Agricultural encroachment represents more than the physical blocking of corridors and water points or the transformation of rangeland to cropland; it is a transition of de facto property regimes leading to the progressive erosion of more open or porous systems.

Some have argued for sets of institutions that would produce a mix of property forms across space and time to accommodate both crop agriculture and mobile forms of pastoralism (Turner 1999; Fernandez-Gimenez 2002). Such hybrid forms would combine components/features that are territorial, as per conventional views of common property, with more open processual forms. But finding analytical traction to identify and support such forms is challenged by common notions of rangeland dynamics and pastoral resource availabilities as unpredictable, stemming in part from the misleading amalgamation of assumptions about non-equilibrium ecology, pastoralism, and unpredictability. As our review of pastoral ecologies related to mobility has shown, there are identifiable key pastoral features that are revisited and a portion of the spatiotemporal variation in the pastoral resources, upon which many pastoral systems depend, is predictable. These spatial and temporal regularities can form the basis for conventions about the timing, direction, and magnitude of livestock movements within the regions where competing land uses are common. Thus, it is important to understand these regularities along with unpredictable features of a pastoral resource base to assess appropriate institutional forms.

Conclusions

Livestock mobility is a multidimensional concept that resists simple definitions and quantification. Shifting views of livestock mobility have been shaped less by empirical engagements with pastoral ecology and mobility and more by unexamined associations connecting ecology, mobility, livelihood, and institutions. Current scholarly views of livestock mobility reject earlier notions of it being contrary to modern development and instead point to it being an adaptation to high spatio-temporal variability and risks associated with unpredictable change, both tied to a pastoral or nomadic lifestyle. Pastoral land tenure in turn is seen as being incompatible to territorial forms that are overly rigid and constrain flexible response to unpredictable locations of water and fodder. These widespread characterizations are misleading and contribute to the lack of progress in pastoral development. We argue that it is important that we seek clarity about the spatio-temporal specificities and motivations behind mobile herding practices.

In this paper, we have reviewed previous work giving quantitative measures of the spatio-temporal characteristics of grazing and travel mobility in sub-Saharan Africa. This review shows the little variation in grazing mobility across studies with most radii of dispersion falling below 6 km (Table 2). This reflects the basic trade-offs of livestock movements and nutrition gains with dispersion around base locations and provides important insights in terms of spatiality of pasture needs and protections from competing land uses around encampment and water points in rangeland areas. Travel movements display much greater variability (Table 3). In fact, our review most likely underestimates inter-site variability since sedentary pastoral systems are not likely to be included in prior studies of livestock mobility. This questions the facile association of mobility with pastoralism. Travel mobility is a means toward the end of livestock nutrition with wide variations in different measurement parameters. Moreover, longer-distance travel mobility is most often across elevational and latitudinal spatial gradients along which there is high spatio-temporal variation but with predictable dimensions.

These findings raise important questions about the spatio-temporality of livestock mobility and pastoral institutions. Grazing mobilities are more constrained, and travel mobilities are more predictable than is invoked in the imaginaries of non-equilibrium systems and flexible movements. Only at intermediate spatial scales, falling between daily grazing radii and movements along elevational/floodplain/latitudinal gradients, should one expect to witness travel movements that are unpredictable in direction and distance. In short, pastoralists can only be seen as “chasing rain

clouds" within constrained geographies. We need to embrace not only the variabilities that pastoralists face but also the regularities. Understanding both provides one with much better understandings of mobility needs and the prospect of building and supporting flexible institutions that facilitate necessary movement but provide some territorial security against competing land uses. We hope that this review provides a first step toward greater attention being directed at the realities of livestock mobility: its regularities and variabilities, and institutional implications.

Acknowledgements
This paper has benefitted from discussions with Pierre Hiernaux and Kramer Gillin and two anonymous reviewers. Its remaining deficiencies are solely our own. The authors' collaboration was facilitated by a scholarship from the German Academic Award Service (DAAD) awarded to the primary author.

Authors' contributions
Both authors contributed to the conceptualization, secondary data collection and analysis, and writing. Both authors read and approved the final manuscript.

Funding
Work on this paper was facilitated by a DAAD Faculty Fellowship from the German Academic Exchange Service received by Turner.

Availability of data and materials
All data generated or analysed during this study are included in this published article.

Ethics approval and consent to participate
Not Applicable.

Consent for publication
Not Applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Geography, University of Wisconsin-Madison, 160 Science Hall, Madison, WI 53706, USA. [2]Animal Husbandry in the Tropics and Subtropics, University of Kassel and Georg-August-Universität Göttingen, Steinstrasse 19, 37213 Witzenhausen, Germany.

Received: 5 March 2019 Accepted: 26 July 2019
Published online: 26 August 2019

References

Adriansen, H.K. 2008. Understanding pastoral mobility: The case of Senegalese Fulani. *The Geographical Journal* 174 (3): 207–222.
Adriansen, H.K., and T.T. Nielsen. 2002. Going where the grass is greener: On the study of pastoral mobility in Ferlo, Senegal. *Human Ecology* 30 (2): 215–226.
Barral, H. 1974. Mobilité et cloisonnement chez les eleveurs du nord de la Haute-Volta: les zones dites 'd'endodromie pastorale'. *Cahiers ORSTOM, serie sciences humaines* 11 (2): 127–136.
Bassett, T.J. 1986. Fulani herd movements. *The Geographical Review* 76: 233–248.
Bassett, T.J. 1994. Hired herders and herd management in Fulani pastoralism (northern Côte d'Ivoire). *Cahiers d'Études Africaines* 34: 147–173.
Beauvilain, A. 1977. *Les Peuls du Dallol Bosso, Etudes Nigeriennes 42*. Niamey: Institut de Recherche en Sciences Humaines.
Behnke, R. 2018. Open access and the sovereign commons: A political ecology of pastoral land tenure. *Land Use Policy* 76: 708–718.
Behnke, R.H., and M. Mortimore, eds. 2017. *The end of desertification? Disputing environmental change in the drylands*. Heidelberg: Springer.
Behnke, R.H., I. Scoones, and C. Kerven, eds. 1993. *Range ecology at disequilibrium*. London: Overseas Development Institute.
Benoit, M. 1978. Pastoralisme et migration. Les Peul de Barani et Dokui (Haute-Volta). *Études rurales* 70: 9–49.
Benoit, M. 1979. *Le chemin des Peuls du Boobola: contribution à l'écologie du pastoralisme en Afrique des savanes*. Paris: O.R.S.T.O.M.
Bonfiglioli, A.M. 1990. Pastoralisme, agro-pastoralisme et retour: itinéraires sahéliens. *Cahiers des Sciences Humaines* 26 (1–2): 255–266.
Bonfiglioli, Angelo Maliki. 1988. *Dudal: Histoire de famille et histoire de troupeau chez un groupe de Wodaabe du Niger*. Cambridge: Cambridge University Press.
Bonnet-Dupeyron, M.F. 1951. *Carte de l'Élevage pour le Sénégal et la Mauritanie*. Paris: Office de la Recherche Scientifique Outre-Mer, Ministère de la France d'Outre Mer.
Boone, R.B., S.B. Burnsilver, and R.L. Kruska. 2008. Comparing landscape and infrastructual heterogeneity within and between ecosystems. In *Fragmentation in semi-arid and arid landscapes*, ed. K.A. Galvin, R.S. Reid, R.H. Behnke, and N.T. Hobbs, 341–367. Dordrecht: Springer.
Boserup, E. 1965. *The conditions of agricultural growth: The economics of agrarian change under population pressure*. London: Allen and Unwin.
Bourn, D., and W. Wint. 1994. *Livestock, land-use and agricultural intensification in sub-Saharan Africa*. London: Overseas Development Institute.
Boutrais, J. 1992. L'élevage en Afrique tropicale: une activité dégradante? *Afrique contemporaine* 161: 109–125.
Brottem, L., M.D. Turner, B. Butt, and A. Singh. 2014. Biophysical variability and pastoral rights to resources: West African transhumance revisited. *Human Ecology* 42 (3): 351–365. https://doi.org/10.1007/s10745-014-9640-1.
Burnham, P. 1979. Spatial mobility and political centralization in pastoral societies. In *L'equipe ecologie et anthropologie des societes pastorales*, 349–360. Cambridge: Cambridge University Press Pastoral Production and Society, ed.
Butt, B. 2010. Seasonal space-time dynamics of cattle behavior and mobility among Maasai pastoralists in semi-arid Kenya. *Journal of Arid Environments* 74 (3): 403–413.
Coppack, D.L., J.E. Ellis, and D.M. Swift. 1988. Seasonal patterns of activity, travel and water intake for livestock in South Turkana, Kenya. *Journal of Arid Environments* 14: 319–331.
Coppolillo, P.B. 2000. The landscape ecology of pastoral herding: Spatial analysis of land use and livestock production in East Africa. *Human Ecology* 28 (4): 527–560.
Dahl, G., and A. Hjort. 1976. *Having herds: Pastoral herd growth and household economy*. Stockholm: Department of Anthropology, Stockholm University.
Dardel, C., L. Kergoat, P. Hiernaux, E. Mougin, M. Grippa, and C.J. Tucker. 2014. Re-greening Sahel: 30 years of remote sensing data and field observations (Mali, Niger). *Remote Sensing of Environment* 140: 350–364.
Davies, J., P. Herrera, J. Ruiz-Mirazo, J. Mohamed-Katerere, I. Hannam, and E. Nuesiri. 2016. *Governance of tenure technical guide 6: Improving governance of pastoral lands*. Rome: FAO.
Davis, D.K. 2016. *The arid lands. History, power and knowledge*. Cambridge: MIT Press.
de Bruijn, M., and H. van Djik. 1995. *Arid ways: Cultural understandings of insecurity in Fulbe Society, Central Mali*. Amsterdam: Thela Publishers.
Diallo, A. 1978. *Transhumance: comportement, nutrition et productivité d'un troupeau zébus de Diafarabé*. Centre Pédagogique Supérieure. Bamako, Mali.
Diawara, M.O., P. Hiernaux, E. Mougin, M. Grippa, C. Delon, and H.S. Diakité. 2018. Effets de la pâture sur la dynamique de la végétation herbacée au Sahel (Gourma, Mali) : une approche par modélisation. *Cahiers Agricultures* 27: 15010.
Dongmo, A.-L., E. Vall, M.A. Diallo, P. Dugué, A. Njoya, and J. Lossouarn. 2012. Herding territories in Northern Cameroon and Western Burkina Faso: Spatial arrangements and herd management. *Pastoralism: Research, Policy, and Practice* 2 (26). https://doi.org/10.1186/2041-7136-2-26.
Ellis, J.E., and D.M. Swift. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management* 41: 450–459.
Engler, John-Oliver, and Henrik von Wehrden. 2018. Global assessment of the non-equilibrium theory of rangelands: Revisited and refined. *Land Use Policy* 70:479–484.
Feldt, T., and E. Schlecht. 2016. Analysis of GPS trajectories to assess spatio-temporal differences in grazing patterns and land use preferences of domestic livestock in southwestern Madagascar. *Pastoralism: Research, Policy and Practice* 6 (5). https://doi.org/10.1186/s13570-016-0052-2.
Fernandez-Gimenez, M.E. 2002. Spatial and social boundaries and the paradox of pastoral land tenure: A case study from post-socialist Mongolia. *Human Ecology* 30 (1): 49–78.

Fernandez-Gimenez, M.E., and S. LeFebre. 2006. Mobility in pastoral systems: Dynamic flux or downward trend? *International Journal of Sustainable Development and World Ecology* 13: 341–362.

Fujimura, J.H. 1992. Crafting science: Standardized packages, boundary objects, and "translation". In *Science as practice and culture*, ed. A. Pickering, 168–211. Chicago: University of Chicago Press.

Fust, P., and E. Schlecht. 2018. Integrating spatio-temporal variation in resource availability and herbivore movements into rangeland management: RaMDry - an agent-based model on livestock feeding ecology in a dynamic, heterogeneous, semi-arid environment. *Ecological Modelling* 369: 13–41.

Gallais, J. 1967. *Le Delta intérieur du Niger. 2 vols, Mémoires de l'Institut Fondamental d'Afrique Noire #79*. Dakar: IFAN.

Gallais, J. 1975. *Paysans et pasteurs du Gourma. La condition sahélienne*. Paris: CNRS.

Gallais, J. 1984. *Hommes du Sahel. Espaces-temps et pouvoirs. Le Delta intérieur du Niger, 1960–1980*. Paris: Flammarion.

Gilles, J.L. 1988. Slippery grazing rights: Using indigenous knowledge for pastoral development. In *Arid lands today and tomorrow*, ed. E.E. Whitehead, C.F. Hutchinson, B.N. Timmerman, and R.G. Varady, 1159–1166. Boulder: Westview Press.

Goldschmidt, W. 1981. The failure of pastoral economic development programs in Africa. In *The future of pastoral peoples*, ed. J.G. Galaty, D. Aronson, P.C. Salzman, and A. Chouinard, 101–126. Ottawa: International Development Research Centre.

Gomez, O.S. 1979. *Contribution à l'étude de la transhumance au Sénégal: ses conséquences sur l'exploitation du cheptel et sur le développment économique et social des populations pastorales*. Thèse de doctorat vétérinaire. Dakar, Senegal: EISMY

Gordon, H.S. 1954. The economic theory of a common-property resource: The fishery. *The Journal of Political Economy* 62: 124–142.

Hardin, G. 1968. The tragedy of the commons. *Science* 162 (3859): 1243–1248.

Herrera, P.M., J.M. Davies, and P.M. Baena. 2014. Principles of pastoralist governance and land management. In *The governance of rangelands: Collective action for sustainable pastoralism*, ed. P.M. Herrera, J.M. Davies, and P.M. Baena, 1–31. New York: Routledge.

Herskovits, M.J. 1926. The cattle complex in East Africa. *American Anthropologist* 28: 633–644.

Hiernaux, P. 1996. *The crisis of Sahelian pastoralism: Ecological or economic?* London: Overseas Development Administration.

Hiernaux, P., C. Dardel, L. Kergoat, and E. Mougin. 2017. Desertification, adaptation and resilience in the Sahel: Lessons from long term monitoring of agro-ecosystems. In *The end of desertification? Disputing environmental change in the drylands*, ed. R.H. Behnke and M. Mortimore, 147–178. Heidelberg: Springer.

Hiernaux, P., L. Diarra, V. Trichon, E. Mougin, N. Soumaguel, and F. Baup. 2009a. Woody plant population dynamics in response to climate changes from 1984 to 2006 in Sahel (Gourma, Mali). *Journal of Hydrology* 375: 103–113.

Hiernaux, P., E. Mougin, L. Diarra, N. Soumaguel, F. Lavenu, Y. Tracol, and M. Diawara. 2009b. Sahelian rangeland response to changes in rainfall over two decades in the Gourma region, Mali. *Journal of Hydrology* 375: 114–127.

Hjort, A. 1982. A critique of 'ecological' models of land use. *Nomadic Peoples* 10: 11–27.

Hobbs, N.T., K.A. Galvin, C.J. Stokes, J.M. Lackett, A.J. Ash, R.B. Boone, R.S. Reid, and P.K. Thornton. 2008. Fragmentation of rangelands: Implications for humans, animals, and landscapes. *Global Environmental Change* 18: 776–785.

Homewood, K., and W.A. Rogers. 1987. Pastoralism, conservation and the overgrazing controversy. In *Conservation in Africa*, ed. D. Anderson and R. Grove, 111–128. Cambridge: Cambridge University Press.

Homewood, K.M., and W.A. Rogers. 1991. *Maasailand ecology: Pastoralist development and wildlife conservation in Ngorongoro, Tanzania*. Cambridge: Cambridge University Press.

Kerven, C. 1992. *Customary commerce: A historical reassessment of pastoral livestock marketing in Africa*. London: Overseas Development Institute.

King, J.M. 1983. Energy and water use in pastoral systems. In *Livestock water needs in pastoral Africa in relation to climate and forage*, 48–72. Addis Ababa: International Livestock Centre for Africa.

Krätli, S., and N. Schareika. 2010. Living off uncertainty: The intelligent animal production of dryland pastoralists. *The European Journal of Development Research* 22: 605–622.

Kuper, A. 2005. *The reinvention of primitive society: Transformations of the myth*. London: Routledge.

Lawrence, P.R., and R.A. Pearson. 1998. *Feeding standards for cattle used for work*. Edinburgh: Centre for Tropical Veterinary Medicine, University of Edinburgh.

Lélé, S. 1991. Sustainable development: A critical review. *World Development* 19: 607–621.

Lericollais, André, and Adama Faye. 1994. Des troupeaux sans pâturages en pays Sereer au Sénégal. In *A la croisée des parcours: Pasteurs, éleveurs, cultivateurs*, ed. Chantal Blanc-Pamard and Jean Boutrais, 165–196. Paris: ORSTOM.

Lhoste, P. 1987. *L'Association agriculture-élevage. Evolution du système agropastoral au Sine-Saloum (Sénégal)*. Maisons-Alfort: Institut d'Elévage et de Médecine Vétérinaire des Pays Tropicaux.

Liao, C., P.E. Clark, S.D. DeGloria, and C.B. Barrett. 2017. Complexity in the spatial utilization of rangelands: Pastoral mobility in the Horn of Africa. *Applied Geography* 86: 208–219.

Marie, J., S. Cissé, S. Soumaré, I. Ag Youssouf, and M. Haywood. 1982. *Carte foncière pastorale du Delta Intérieur du Niger, République du Mali*. Bamako: CIPEA/ODEM.

Marty, A. 1993. La gestion des terroirs et les éleveurs: Un outil d'exclusion ou de négociation? *Revue Tiers Monde* 34 (134): 329–344.

McCarthy, N., and M. Di Gregorio. 2007. Climate variability and flexibility in resource access: The case of pastoral mobility in Northern Kenya. *Environment and Development Economics* 12: 403–421.

McIntire, J., D. Bourzat, and P. Pingali. 1992. *Crop-livestock interactions in sub-Saharan Africa*. Washington, D.C.: The World Bank.

McLennan, S.R., M.J. Bolam, J.F. Kidd, K.A. Chandra, and D.P. Poppi. 2017. Responses to various protein and energy supplements by steers fed low-quality tropical hay. 1. Comparison of response surfaces for young steers. *Animal Production Science* 57: 473–488.

McNaughton, S.J. 1979. Grassland-herbivore dynamics. In *Serengeti: Studies of ecosystem dynamics in a tropical savanna*, ed. A.R.E. Sinclair and M. Norton-Griffiths, 46–81. Chicago: University of Chicago Press.

McNaughton, S.J., and N.J. Georgiadis. 1986. Ecology of African grazing and browsing mammals. *Annual Review of Ecology and Systematics* 17: 39–65.

McPeak, J.G. 1999. *Herd growth on shared rangeland: Herd management and land-use decisions in Northern Kenya*. Ph.D. dissertation, Department of Agricultural Economics. Madison: University of Wisconsin.

Moritz, M. 2012. Pastoral intensification in West Africa: Implications for sustainability. *Journal of the Royal Anthropological Institute* 18 (2): 418–438.

Moritz, M., I.M. Hamilton, Y.J. Chen, and P. Scholte. 2014. Mobile pastoralists in the Logone floodplain distribute themselves in an ideal free distribution. *Current Anthropology* 55 (1): 115–122.

Moritz, M., P. Scholte, I.M. Hamilton, and S. Kari. 2013. Open access, open systems: Pastoral management of common-pool resources in the Chad Basin. *Human Ecology* 41: 351–365.

Moritz, M., E. Soma, P. Scholte, N. Xiao, L. Taylor, T. Juran, and S. Kari. 2010. An integrated approach to modeling grazing pressure in pastoral systems: The case of the Logone floodplain (Cameroon). *Human Ecology* 38: 775–789.

Mortimore, M. 1989. *Adapting to drought. Farmers, famines and desertification in West Africa*. Cambridge: Cambridge University Press.

Motta, P., T. Porphyre, S.M. Hamman, K.L. Morgan, V.N. Ngwa, V.N. Tanya, E. Raizman, I.G. Handel, and B.M. Bronsvoort. 2018. Cattle transhumance and agropastoral nomadic herding practices in Central Cameroon. *BMC Veterinary Research* 14 (1): 214.

Niamir-Fuller, M., ed. 1999. *Managing mobility in African rangelands*. London: Intermediate Technology Publications.

Niamir-Fuller, M. 2000. Managing mobility in African rangelands. In *Property rights, risk, and livestock development in Africa*, ed. N. McCarthy, B.M. Swallow, M. Kirk, and P. Hazell. Washington, D.C.: International Food Policy Research Institute.

Olsson, L. 1983. *Desertification or climate? Investigation regarding the relationship between land degradation and climate in the central Sudan, Lund Studies in Geography. Ser. A, Physical Geography #60*.

Ostrom, E. 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge: Cambridge University Press.

Penning de Vries, F.W.T., and M.A. Djitèye, eds. 1982. *La productivité des pâturages sahéliens*. Wageningen: Centre for Agricultural Publishing and Documentation.

Picardi, A.C., and W.W. Siefert. 1976. A tragedy of the commons in the Sahel. *Technology Review* May: 42–51.

Powell, J.M., S. Fernandez-Rivera, T.O. Williams, and C. Renard, eds. 1995. *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol. II: Technical papers*. Addis Ababa: International Livestock Centre for Africa.

Raizman, E.A., H. Barner Rasmussen, L.E. King, F.W. Ihwagi, and I. Douglas-Hamilton. 2013. Feasibility study on the spatial and temporal movement of Samburu's cattle and wildlife in Kenya using GPS radio-tracking, remote sensing and GIS. *Preventive Veterinary Medicine* 111: 76–80.

Rasmussen, Kjeld, Martin Brandt, Xiaoye Tong, Pierre Hiernaux, Abdoul Aziz Diouf, Mohamed Habibou Assouma, Compton J. Tucker, and Rasmus Fensholt. 2018. Does grazing cause land degradation? Evidence from the sandy Ferlo in Northern Senegal. *Land Degradation & Development* 29 (12): 4337–4347. https://doi.org/10.1002/ldr.3170.

Reynolds, J.F., and M.S. Smith, eds. 2002. *Global desertification. Do humans cause deserts?* Berlin: Dahlem University Press.

Sandford, S. 1982. Pastoral strategies and desertification: Opportunism and conservatism in dry lands. In *Desertification and development: Dryland ecology in social perspective*, ed. B. Spooner and H. Mann, 61–80. London: Academic Press.

Savory, A., and J. Butterfield. 1999. *Holistic management: A new framework for decision-making*. New York: Island Press.

Sayre, N., D. Davis, B. Bestelmeyer, and J. Williamson. 2017. Rangelands: Where anthromes meet their limits. *Land* 6 (31): 1–11.

Schareika, N. 2001. Environmental knowledge and pastoral migration among the Wodaabe of south-eastern Niger. *Nomadic Peoples* 5 (1): 65–88.

Schareika, N., F. Graef, M. Moser, and K. Becker. 2000. Pastoral migration as a method of goal-oriented and site-specific animal nutrition among the Wodaabe of south-eastern Niger. *Die Erde* 131: 311–329.

Schlecht, E., P. Hiernaux, I. Kadaouré, C. Hülsebusch, and F. Mahler. 2006a. A spatio-temporal analysis of forage availability, grazing and excretion behaviour of cattle, sheep and goats in Western Niger. *Agriculture, Ecosystems and Environment* 113: 226–242.

Schlecht, E., M. Sangaré, and K. Becker. 1999. Supplementation of Zebu cattle grazing Sahelian pastures. I. Diet selection and feed intake. *Journal of Agricultural Science, Cambridge* 133: 69–81.

Schlecht, Eva, Pierre Hiernaux, Ibrahima Kadaouré, Christian Hülsebusch, and Friedrich Mahler. 2006b. A spatio-temporal analysis of forage availability and grazing and excretion behaviour of herded and free grazing cattle, sheep and goats in Western Niger. *Agriculture, Ecosystems & Environment* 113 (1): 226–242. https://doi.org/10.1016/j.agee.2005.09.008.

Schmitz, Jean. 1986. L'État géomètre: les leydi des Peul du Fuuta Tooro (Sénégal) et du Maasina (Mali). *Cahiers d'Etudes Africaines* 26 (3): 349–394.

Scoones, I. 1989. *Patch use by cattle in dryland Zimbabwe: Farmer knowledge and ecological theory*. Pastoral Development Network Paper 28b. London: Overseas Development Institute.

Scoones, I., ed. 1994. *Living with uncertainty. New directions in pastoral development in Africa*. London: Intermediate Technology Publications Ltd..

Scoones, I. 1995. Exploiting heterogeneity: Habitat use by cattle in dryland Zimbabwe. *Journal of Arid Environments* 29: 221–237.

Seagle, S.W., and S.J. McNaughton. 1992. Spatial variation in forage nutrient concentrations and the distribution of Serengeti grazing ungulates. *Landscape Ecology* 7 (4): 229–241.

Semple, Ellen C. 1915. *Influences of geographic environment*. New York: Henry Holt.

Sinclair, A.R.E., and J.M. Fryxell. 1985. The Sahel of Africa: Ecology of a disaster. *Canadian Journal of Zoology* 63: 987–994.

Star, S.L., and J.R. Griesemer. 1989. Institutional ecology,"translation", and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrae Zoology,1907–39. *Social Studies of Science* 19: 387–420.

Starr, M. 1987. Risk, environmental variability and drought-induced impoverishment: The pastoral economy of central Niger. *Africa* 57 (1): 29–49.

Stenning, D.J. 1960. Transhumance, migratory drift, migration: Patterns of pastoral Fulani nomadism. In *Cultures and societies of Africa*, ed. S. Ottenburg and P. Ottenburg, 139–159. New York: Random House.

Sulieman, H.M., and A.G.M. Ahmed. 2017. Mapping the pastoral migratory patterns under land appropriation in East Sudan: The case of the Lahaween ethnic group. *The Geographical Journal* 183 (4): 386–399.

Swallow, B.M. 1994. The role of mobility within the risk management strategies of pastoralists and agro-pastoralists. *IIED Gatekeeper Series 47*. London: International Institute for Environment and Development.

Swift, Jeremy. 1996. Desertification: Narratives, winners, and losers. In *The lie of the land*, ed. M. Leach and R. Mearns, 73–90. London: International African Institute.

Thébaud, B. 1999. *Gestion de l'espace et crise pastorale au Sahel: Étude comparative du Niger oriental et du Yagha burkinabé*. Docteur de L'EHESS, Socio-économie du développment. Paris: Ecole des Hautes Études en Sciences Sociales.

Thomas, D.S.G. 1993. Sandstorm in a teacup? Understanding desertification. *Geographical Journal* 159: 318–331.

Thornton, Philip K. 2010. Livestock production: Recent trends, future prospects. *Philosophical Transactions: Biological Sciences* 365 (1554): 2853–2867.

Tolsma, D.J., W.H.O. Ernst, and R.A. Verwey. 1987. Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. *Journal of Applied Ecology* 24: 991–1000.

Touré, I., A. Ickowicz, A. Wane, I. Garba, and P. Gerber. 2012. *Atlas of trends in pastoral Systems in Sahel*. Montpellier: FAO / CIRAD.

Traoré, G. 1978. *Evolution de la disponibilité et de la qualité de fourrage au cours de la transhumance de Diafarabé*. Thèse. Bamako: Centre Pédagogique Supérieure.

Tucker, C.J., H.E. Dregne, and W.W. Newcomb. 1991. Expansion and contraction of the Sahara Desert. *Science* 253: 299–301.

Turner, M.D. 1998. Long-term effects of daily grazing orbits on nutrient availability in Sahelian West Africa: 2. Effects of a phosphorus gradient on spatial patterns of annual grassland production. *Journal of Biogeography* 25 (4): 683–694.

Turner, M.D. 1999. The role of social networks, indefinite boundaries and political bargaining in maintaining the ecological and economic resiliency of the transhumance systems of Sudano-Sahelian West Africa. In *Managing mobility in African rangelands: The legitimization of transhumance*, ed. Maryam Niamir-Fuller, 97–123. London: Intermediate Technology Publications.

Turner, M.D. 2011. The new pastoral development paradigm: Engaging the realities of property institutions and livestock mobility in dryland Africa. *Society & Natural Resources* 24 (5): 469–484.

Turner, M.D. 2017. Livestock mobility and the territorial state: South-Western Niger (1890-1920). *Africa* 87 (3): 578–606.

Turner, M.D., B. Butt, A. Singh, A.A. Ayantunde, and B. Gerard. 2016a. Variation in vegetative cover and livestock mobility needs in Sahelian West Africa. *Journal of Land Use Science* 11 (1): 76–95.

Turner, M.D., and P. Hiernaux. 2008. Changing access to labor, pastures, and knowledge: The extensification of grazing management in Sudano-Sahelian West Africa. *Human Ecology* 26 (1): 59–80.

Turner, M.D., P. Hiernaux, and E. Schlecht. 2005. The distribution of grazing pressure in relation to vegetation resources in semi-arid West Africa: The role of herding. *Ecosystems* 8 (6): 668–681.

Turner, M.D., J.G. McPeak, K. Gillin, E. Kitchell, and N. Kimambo. 2016b. Reconciling flexibility and tenure security for pastoral resources: The geography of transhumance networks in eastern Senegal. *Human Ecology* 44 (2): 199–215.

Turner, M.D., John McPeak, and A.A. Ayantunde. 2014. The role of livestock mobility in the livelihood strategies of rural peoples in semi-arid West Africa. *Human Ecology* 42 (2): 231–247. https://doi.org/10.1007/s10745-013-9636-2.

von Wehrden, Henrik, Jan Hanspach, Petra Kaczensky, Joern Fischer, and Karsten Wesche. 2012. Global assessment of the non-equilibrium concept in rangelands. *Ecological Applications* 22 (2): 393–399.

Wario, H.T., H.G. Roba, and B. Kaufmann. 2016. Responding to mobility constraints: Recent shifts in resource use practices and herding strategies in the Borana pastoral system, southern Ethiopia. *Journal of Arid Environments* 127: 222–234.

Western, D., and T. Dunne. 1979. Environmental aspects of settlement site decisions among pastoral Maasai. *Human Ecology* 7 (1): 75–98.

Western, D., and V. Finch. 1986. Cattle and pastoralism: Survival and production in arid lands. *Human Ecology* 14: 77–94.

Wilson, R.T. 1986. *Livestock production in Central Mali: Long-term studies on cattle and small ruminants in the agropastoral system*. ILCA Research Report No. 14. Addis Ababa: International Livestock Centre for Africa.

Young, H., H. Sulieman, R. Behnke, and Z. Cormack. 2013. *Pastoralism in practice: Monitoring livestock mobility in contemporary Sudan*. Nairobi: United Nations Environmental Program.

Zampaligré, N., L.H. Dossa, and E. Schlecht. 2013. Contribution of browse to ruminant nutrition across three agro-ecological zones of Burkina Faso. *Journal of Arid Environments* 95: 55–64.

Ziviler Friedensdienst, Deutsher Entwicklungsdienst, Fédération Nationale des Éleveurs du Niger, and Comité National du Code Rural du Niger. 2008. *L'élevage mobile dans les regions de Zinder et de Diffa, Niger. Petit atlas analytique et synthétique*. Niamey: Imprimerie Bebelle Arts.

Publisher's Note