



**HAL**  
open science

## Why pastoralists grow tomatoes: Maasai livelihood dynamics in Amboseli, southern Kenya

Charlotte Hemingway, Hubert Cochet, François Mialhe, Yanni Gunnell

### ► To cite this version:

Charlotte Hemingway, Hubert Cochet, François Mialhe, Yanni Gunnell. Why pastoralists grow tomatoes: Maasai livelihood dynamics in Amboseli, southern Kenya. *Journal of Rural Studies*, 2022, 92, pp.253-268. 10.1016/j.jrurstud.2022.03.027 . hal-03652762

**HAL Id: hal-03652762**

**<https://hal.science/hal-03652762v1>**

Submitted on 30 Jun 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



**HAL**  
open science

## Why pastoralists grow tomatoes: Maasai livelihood dynamics in Amboseli, southern Kenya

Charlotte Hemingway, Hubert Cochet, François Mialhe, yanni Gunnell

### ► To cite this version:

Charlotte Hemingway, Hubert Cochet, François Mialhe, yanni Gunnell. Why pastoralists grow tomatoes: Maasai livelihood dynamics in Amboseli, southern Kenya. *Journal of Rural Studies*, Elsevier, 2022, 92, pp.253-268. 10.1016/j.jrurstud.2022.03.027 . hal-03652762

**HAL Id: hal-03652762**

**<https://hal.archives-ouvertes.fr/hal-03652762>**

Submitted on 30 Jun 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives | 4.0 International License

3

## 4 **Why pastoralists grow tomatoes: Maasai livelihood dynamics in Amboseli,** 5 **southern Kenya**

6

### 6 **Abstract**

7

8 This study documents the causes and processes behind the uptake of crop cultivation by a Maasai  
9 community of southern Kenya which, until recently, was still devoted to full-time mobile livestock  
10 keeping. Based on the methods of comparative agriculture and a detailed quantification of household  
11 income from livestock and cash crops, a classification of farm units ( $n = 38$ ) into nine production  
12 systems reveals that agro-pastoralism on the Mbirikani group ranch, which is situated between  
13 Amboseli and Chyulu Hills national parks, is now mainstream, and that crops can exceed 70% of  
14 household income. Microeconomic analysis also documents large disparities in household income,  
15 with irrigated tomato farms benefiting from access to a pipeline ranking highest in profitability.  
16 Overall, the pastoralist–peasant dichotomy ingrained in portrayals of East-African rural life has  
17 outlived its relevance, with the tomato currently being a key game changer. This growing appeal for  
18 agriculture, however, is threatening the wildlife conservation because the profitability of tomato  
19 cropping has begun to outcompete those employment alternatives. By promoting landscape  
20 fragmentation and water extraction, however, irrigated agriculture also undermines free movement  
21 of wild animals outside the parks, restricts access to the key resources they require, and exacerbates  
22 human–wildlife conflicts.

23

### 24 **Key words**

24

*comparative agriculture; pastoralism; cash crops; Maasai; Amboseli.*

25

## 25 **1. Introduction**

26

### 26 1.1. African pastoralism: trends and challenges in the 21st century

27

28 Pastoralism involves living with, but also from, uncertainty (Catley et al., 2016; Davies and Hatfield,  
29 2007; Krätli and Schareika, 2010; Scoones, 1995). This arises largely because climatic variability is a  
30 key characteristic of semi-arid rangeland ecosystems (Ellis and Galvin, 1994), which are typically too  
dry for reliable crop cultivation and thus primarily used for various forms of livestock production.  
Pastoralists have developed time-tested adaptations to variability in water, fodder, or disease through  
flexible strategies of land control, diverse tenure arrangements in mosaic landscapes (Swallow and

31 Bromley, 1995), and adaptable linkages between formal and informal markets. All of this is attained  
32 through dynamic social arrangements and varied collective social solidarities (Fratkin, 1997;  
33 Homewood and Rodgers, 1991; Krätli and Schareika, 2010; Lesorogol, 2008; Scoones, 2021). These  
34 socio-ecological systems have, however, been experiencing significant transformations as a result of  
35 expanding market economies, urbanisation, enclosure of common land, wildlife conservation policies,  
36 water infrastructure development, population growth, and sedentarisation (BurnSilver et al., 2008;  
37 Kimani and Pickard, 1998; Morris, 1988; Salzman, 1980; West et al., 2008). Such a dynamic context  
38 threatens pastoral ways of life and tends to increase socioeconomic inequalities (Fratkin, 2001, 1997;  
39 Nkedianye et al., 2019), exacerbated by the unequal access to resources such as water and pasture  
40 (Weesie and García, 2018; Bond, 2014). Climate change adds to these pressures, with some scenarios  
41 predicting even greater future variability in rangeland systems (Scoones, 2020).

42 With intensifying enclosure and commodification of land, and with greater commercialisation of  
43 livestock and agricultural produce, the livelihood strategies of pastoralists and farmers in Sub-Saharan  
44 Africa have begun to converge (e.g., Landais, 1994; Njeru, 1984; Scoones, 2000), even though some  
45 aspects of their cultural economies, identities, and associated narratives remain distinct. This new  
46 dynamic is blurring the conventional divide between settled, small-scale farmers and mobile livestock  
47 keepers; it also creates new winners and losers, with consequences on land use and local economies.  
48 Agricultural development and livestock intensification are thus two of the important drivers currently  
49 transforming livelihoods, landscapes and the resource base of rangeland ecosystems in East Africa,  
50 particularly through pressure on water and pasture. Key issues of relevance to research and  
51 policymaking in such contexts are to establish (i) what draws pastoralists to livestock intensification  
52 but also to agriculture, (ii) what kinds of novel production systems are being generated by these  
53 transformations, (iii) who benefits most from these new livelihood strategies, and (iv) what socio-  
54 ecological consequences these trends entail.

## 55 1.2. The pastoralism–agriculture nexus

56 This study focuses on a semi-arid rangeland in southern Kenya located between Amboseli National  
57 Park, Mt. Kilimanjaro, and the Chyulu Hills National Park, and populated by Maasai communities. The  
58 option of practising full-time pastoralism here is understood to have been made possible over the last  
59 2000 to 3000 years because of a bimodal rainfall regime, which allows for a longer birthing season  
60 than in comparatively drier parts of East Africa and thus secures year-round milk production (McCabe  
61 et al., 2010). Although the Maasai commonly specialise in pastoralism, depending on time and place  
62 they have nonetheless been known to also practice farming and hunting (Spear and Waller, 1993). The  
63 Maasai are divided into various categories defined by geographical, age, clan, sub-clan and gender  
64 criteria. The category relevant to territory is known as a section, and the Kisongo section is one among  
65 several devoted to full-time pastoralism (McCabe et al., 2010). It is also the largest, currently dominant  
66 between Lake Manyara in the west (Tanzania), the Pangani River in the east, and the Amboseli area in  
67 the north, where the Kisongo are also known as Loitokitok (Lewis, 2015; Ndagala, 1992).

68 Economic diversification of Maasai pastoral economies typically involves an intensification of livestock  
69 husbandry (e.g., cattle cross-breeding, adoption of veterinary drugs, raising of animals for niche  
70 markets: Morris, 1988; Bekure et al., 1991; Rutten, 1992) and/or an adoption of agriculture and other  
71 non-pastoral activities (Coast, 2002; Homewood, 2009; Little et al., 2008, 2001). Some Maasai  
72 pastoralists are thus becoming ‘agro-pastoralists’. An operational definition of agro-pastoral systems  
73 is that farmers engage in grazing-based livestock production as well as cropping activities (Aryal et al.,  
74 2018), with livestock predominantly fed on natural pasture (sometimes also crop residue) and crops  
75 grown mostly for cash or for direct household subsistence (Tolera and Abebe, 2007).

76 The number of Maasai who have entirely abandoned mobile livestock keeping and/or become full-  
77 time farmers is currently not well documented, but the stereotype of the one-dimensional Maasai  
78 herdsman as an obligate pastoralist is unravelling fast in this region. Pastoralist ‘dropouts’ have been  
79 anecdotally reported (Little et al., 2008), but patterns of diversification over time have been most of  
80 all context-specific. In northern Tanzania, the uptake of cropping occurred in two stages: household

81 horticulture to generate food supplements, followed by commercial agriculture (McCabe et al., 2010).  
82 Agriculture and livestock are thus not two separate, parallel activities. Among the Kisongo Maasai,  
83 documented causes of conversion to part-time agriculture include drought-related livestock losses  
84 (Western, 1997), loss of access to forage and water caused by the expansion of wildlife protection  
85 areas (Fratkin, 1997; West et al., 2008), and the recurrence of cattle-related diseases (McCabe et al.,  
86 2010). National governments and multilateral agencies such as the World Bank have acted as catalysts  
87 in these diversification patterns, for example by promoting infrastructure and land policies aimed at  
88 avoiding a 'Tragedy of the Commons'. In Kenya, these have typically involved sedentarisation,  
89 commercial ranching, and land privatisation through various land rights reforms (Fratkin, 1997). The  
90 disintegration of customary institutions is thus both a cause and a consequence of economic  
91 diversification among full-time pastoralists.

92 Individual decisions to diversify occur either by choice or by necessity. The impetus for choice is to  
93 reduce nutrition-related risks (with dietary improvements especially benefiting children: Galvin et al.,  
94 2015; McCabe et al., 2010; Stavi et al., 2021), but also reflects changes in social and cultural norms  
95 through co-existence and interaction with more recently settled, non-Maasai agricultural populations  
96 (McCabe et al., 2010). Whether or not poverty among pastoralists is a cause of livelihood  
97 diversification is less clear-cut: Little et al. (2001) have argued that only the wealthiest and poorest  
98 were driven to livelihood diversification, and Homewood et al. (2009) reported instead that all  
99 socioeconomic categories of pastoralists were concerned. There is little evidence that women benefit  
100 much from either livestock keeping or from agriculture (Hodgson, 1999), but it would appear overall  
101 that (i) human population growth, with the average reduction of cattle per capita that this entails; and  
102 (ii) Kenya's market economy, which exerts constraints but also generates opportunities, are the two  
103 key drivers currently pushing all socioeconomic categories of pastoralists towards diversification.

104 Livestock-related activities have sometimes gained from diversification. Revenue from agriculture, for  
105 example, can be reinvested in herd restocking or livestock healthcare, and can contribute to avoid

106 selling animals when cash is required for domestic expenditure or for bridging food deficit periods  
107 (Landais, 1994; Zaal, 2011). The expansion of agriculture on East-African rangelands, however, has  
108 been detrimental in other respects by reducing access to key resources for livestock and wildlife  
109 (forage, water), and by fragmenting the landscape and impeding the mass dispersal of herbivores and  
110 their predators (Fratkin, 1997; Hobbs et al. 2008; McCabe et al., 2010).

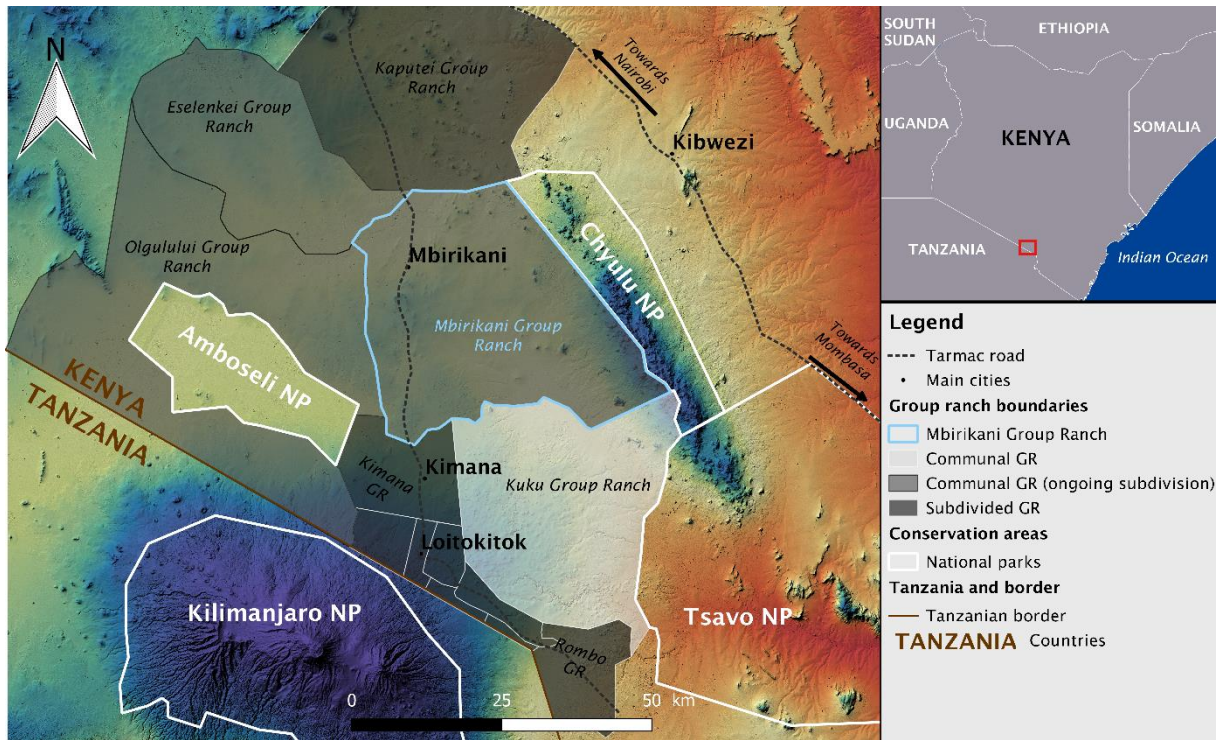
111 The pastoralist–peasant dichotomy having thus mostly outlived its relevance in many parts of the  
112 world (Scoones, 2020), here we go beyond idealised anthropological categories or simplistic models  
113 about rangeland management by recognising that mixed livelihood strategies exist among the Kisongo  
114 Maasai. This generates landscape dynamics where the coexistence of, and interaction between,  
115 agriculture and livestock call for being investigated at face value, with potential for conclusions being  
116 fed back into decision-making about the future of the pastoralism–agriculture–wildlife nexus in East  
117 Africa’s savanna ecosystems. Based on the methods of comparative agriculture, which in the present  
118 case include a microeconomic analysis of household income from a combination of livestock and crops  
119 (including tomatoes), we document the uptake of crop cultivation by a Maasai group-ranch  
120 community that, until recently, was still devoted to full-time livestock keeping. We reconstruct the  
121 20th century context leading up to this step change in Maasai livelihood strategies, and characterise  
122 the current diversity of production systems that has arisen from this new dynamic.

## 123 **2 Field setting**

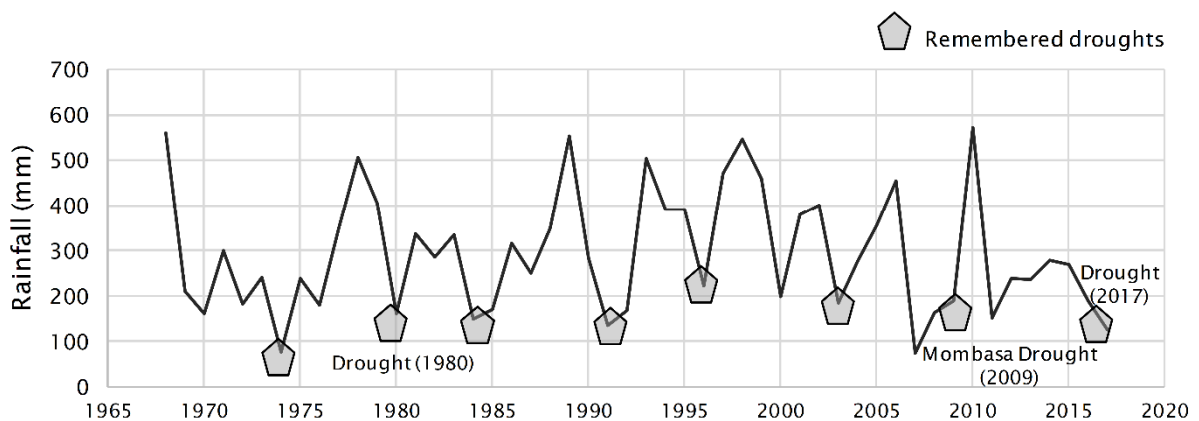
### 124 2.1. Physical landscape

125 The study area is a savanna extending east of the Great African Rift at an elevation of ~1200 m (Fig.  
126 1). The vegetation mosaics are chiefly controlled by climate, water availability, herbivory patterns, and  
127 soil types, and consist of woodland savanna dominated by *Commiphora*, *Balanites* and *Acacia spp.*  
128 (Western and Sindiyo, 1972), and grassland savanna dominated by C4 plants. The climate is semi-arid,  
129 with a bimodal rainfall regime. Aridity-related uncertainty is exacerbated by a recurrence of droughts

130 (Fig. 2) and by large interannual rainfall variation (Altmann et al., 2002). Droughts typically occur after  
 131 failure of the short rains (Ogotu et al., 2014), and years of drought are followed by above-normal  
 132 rainfall, such as in 1998 and 2018.



133  
 134 **Fig. 1.** Study area location map. Topography generated from the ALOS World 3D Digital Elevation  
 135 Model (ground resolution ~30 m)

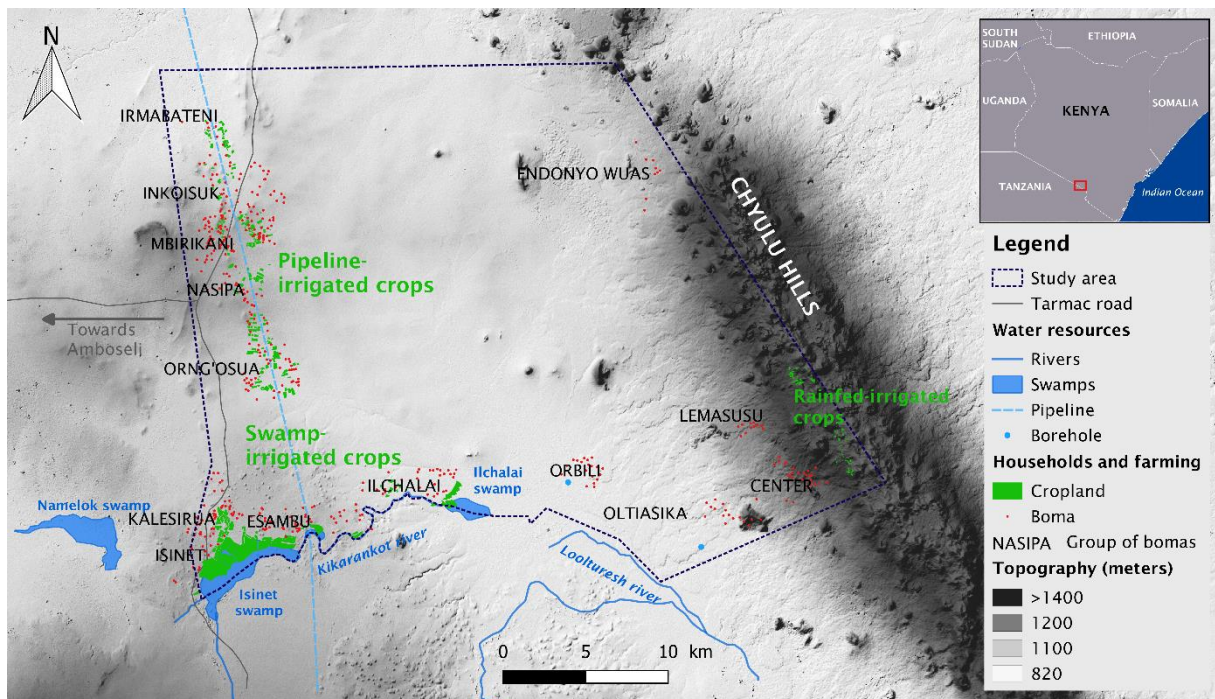


136  
 137 **Fig. 2.** Droughts in southern Kenya (1965–2017), including three of the most severe in 1980, 2009 and  
 138 2017 (source: Kenya Wildlife Service, 2017)



139 Water is available for wildlife from spring-fed perennial swamps (e.g., Isinet, Ilchalai, Fig. 1), from their  
 140 outflowing, low-discharge streams, and a from few lakes (Fig. 3). Accordingly, agriculture has also  
 141 concentrated around these small areas with direct access to water (Fig. 3), the rest of the group ranch  
 142 being only suitable for pastoralism. The springs are supplied by subterranean water flowing out of the  
 143 volcanic lava structures along the foothills of Mt. Kilimanjaro, thereby making this savanna  
 144 environment somewhat unique. The ecosystem functions as a major wildlife dispersal area for large  
 145 mammals (e.g., gnu, zebra, gazelles, elephants; Ojwang' et al., 2017; Okello and D'Amour, 2008), with  
 146 an alternating pattern of high dry-season concentrations around perennial swamps in Amboseli  
 147 National Park (392 km<sup>2</sup>, a game reserve in 1948 gazetted as a national park in 1974), and rainy-season  
 148 dispersal throughout the Greater Amboseli Ecosystem, which extends between Mt. Kilimanjaro and  
 149 the Amboseli and Chyulu national parks and hosts a number of Maasai group ranches and farming  
 150 settlements (Fig. 1).

151



152

153 **Fig. 3.** Location of *bomas* and water sources on Mbirikani group ranch. Topography generated from  
154 the ALOS World 3D DEM. *Boma* and land use mosaics obtained by photo-interpretation of high-  
155 resolution satellite imagery provided by Google Earth

## 156 2.2. Social and political context in historical perspective

157 The Kisongo Maasai are the oldest recorded occupants of the area (Boles et al., 2019), which was  
158 maintained as a pastoral 'homeland' (Maasailand) with vast game reserves by British rulers. Since  
159 Kenya's independence in 1963, however, the area has also become an agricultural frontier, attracting  
160 pioneer migrants among ethnic groups who are primarily farmers (e.g., Kikuyu) and who harness the  
161 water resources provided by the Kilimanjaro spring line and the swamps. From 78% in 1960, the  
162 Maasai population of Kajiado District had thus fallen to a proportion of 60% in 1984 (Fratkin, 1997).  
163 This is an ongoing process.

164 We focus here on Mbirikani group ranch (1258 km<sup>2</sup>), created in 1975 and today hosting 4636  
165 members. With support from USAID and the World Bank (Fratkin, 1997), group ranches were  
166 established in the Maasai rangelands by the government of Kenya following the Land Adjudication Act  
167 of 1968 (Kibugi, 2009; Veit, 2011). Ranching was deemed an improvement on traditional mobile  
168 livestock keeping because it would encourage optimal pasture management and more market-  
169 oriented output (Woodhouse, 2003). As such, it was a continuation, now enshrined in Kenyan law, of  
170 the colonial 'Konza' and 'Il Kisongo' grazing schemes set up after 1945 by the colonial African Land  
171 Development Organisation (Kibugi, 2009). Although these failed and were soon abandoned, grazing  
172 schemes of this kind were aimed at creating large ranches (up to 20,000 acres) for extended families  
173 as a means of replacing nomadic pastoralism with supposedly sound ranching techniques, of  
174 encouraging settled agriculture, and eventually of opening up land ownership to private companies  
175 and cooperatives (Kibugi, 2009).

176 Under the group ranch concept, a 'group' refers to individuals who are recognised as members. The  
177 ranches are governed by an elected committee and the land is held collectively under private title  
178 (Kibugi, 2009). The original design of the reform was to pursue the land privatisation process that had

179 begun during the colonial era (Peron, 1995). The group ranch settlement was initially accepted by the  
180 Maasai community as a means of preventing further agricultural encroachment from outsiders onto  
181 their ancestral rangelands, and was instrumental in acquiring exclusive legal ownership of the land —  
182 property deeds being the only document guaranteeing access to bank loans (with the land mortgaged  
183 as collateral) for funding boreholes or cattle dips (Fratkin, 1997), and for investing in forms of  
184 enterprise other than livestock keeping.

185 Many group ranches, however, were not self-sufficient because the land could not provide its  
186 members with sufficient access to water and forage (Peron, 1995). This accelerated a transfer of  
187 capital from cattle (the highest-ranking resource in Maasai culture) to land (Galaty, 1992). The  
188 neighbouring Kimana group ranch, for example (Fig. 1), has already achieved full land subdivision. Of  
189 the initial 51 incorporated group ranches of Kajiado County, no fewer than 46 have already been  
190 subdivided in this way. The Rombo, Olgulului, Mbirikani and Eselenkei ranches (Fig. 1) have been  
191 engaged in an on–off process of subdivision for nearly 20 years, with Kuku being the only ranch to not  
192 yet have begun a subdivision process. The belt formed by those four group ranches (Fig. 1) still  
193 represents in 2021 the last continuum of undivided rangeland between the Tanzanian border and  
194 Nairobi (BurnSilver and Mwangi, 2007; Galaty, 1999; Ntiati, 2002).

195 From the 1950s, the colonial authorities also developed water harnessing infrastructure (Swynnerton,  
196 1954). Isinet swamp, for example (Fig. 3), was reclaimed for irrigated agriculture, which also took off  
197 around Loitokitok and Kimana (Githumbi et al., 2018; Rutten, 1992). A pipeline was laid down in 1954–  
198 1956, parallel to the north–south all-weather road. In 1982, decisions were taken during an informal  
199 meeting to restrict human settlement to a corridor along the pipeline and thus to avoid residential  
200 scatter across the rangeland (Peacock, 1987). That pipeline captures the high-discharge (17 L/s)  
201 underground spring of Nolturesh in the foothills of Mt. Kilimanjaro, situated on Loitokitok group ranch.  
202 The pipeline was completed in 1992, conveying water to the urban areas of Kajiado, Machakos and  
203 Athi River (Rutten, 2005). Water tanks along the pipeline are dedicated to supplying neighbouring  
204 communities, but numerous illegal connections also provide free and unregulated access for

205 households and businesses. The farmed landscape at Mbirikani is thus overall controlled by  
206 opportunities of access to water, and currently forms three clusters: one on deep silt- and clay-rich  
207 red soils irrigated by pipeline water; another on clay-rich, shrink-swell black soils (Vertisols) irrigated  
208 by stream- and springwater; and a third, rainfed outlier located on young volcanic soils in the Chyulu  
209 Hills, where annual rainfall totals are higher (locally up to ~1000 mm) than in the lower-lying  
210 rangelands of the ranch (Fig. 3). Protected areas devoted to wildlife conservation in and around  
211 Mbirikani include Chyulu Hills National Park (Fig. 1), Kimana Sanctuary (adjacent to Isineti swamp),  
212 and Endonyo Wuas (Fig. 3). Agriculture is forbidden in these areas, and access to livestock is regulated.  
213 Development policies in Kenya's group ranches today largely focus on the promotion of improved  
214 livestock systems based on more productive breeds and on enhancing milk and meat output, thereby  
215 maximising feed and fodder inputs, reducing the use of pasture, and supporting market integration  
216 into a commodity chain (Kuria et al., 2015). Maasai pastoralists are commonly receptive to some of  
217 these modern incentives. For example, while maintaining herd mobility as a key feature, they use  
218 veterinarian products and acquire improved cattle breeds.

### 219 2.3 Maasai pastoralism

220 Pastoralism in the area today is based on the small East African shorthorn Zebu, Red Maasai Sheep,  
221 and Small East African Goat (Scarpa et al., 2003). Livestock is kept in a corral called a *boma*, which can  
222 also be broadly defined as the homestead (corral and house) (see Suppl. Fig. 1). Female livestock  
223 comprise the majority of the herd because the Maasai pastoral system prioritises dairy production  
224 over meat. Male calves will thus typically compose 20% of a Maasai herd but the number rapidly  
225 declines after they have reached finishing weight. Only a few mature bulls and steers are kept  
226 thereafter (King et al., 1984). Zebu cattle subsist on short grasses and forbs and have limited milk  
227 yields, but their tolerance to heat and aridity and to forage deficiencies is outstanding. They are  
228 nonetheless obligate drinkers and require ~60 L/day (Blackie, 1977). Mixed-breed and mixed-species  
229 herds overall allow pastoralists to harness a greater range of natural resources, access a greater  
230 diversity of habitats, and thus better withstand different types of shock (Scoones and Graham, 1994).

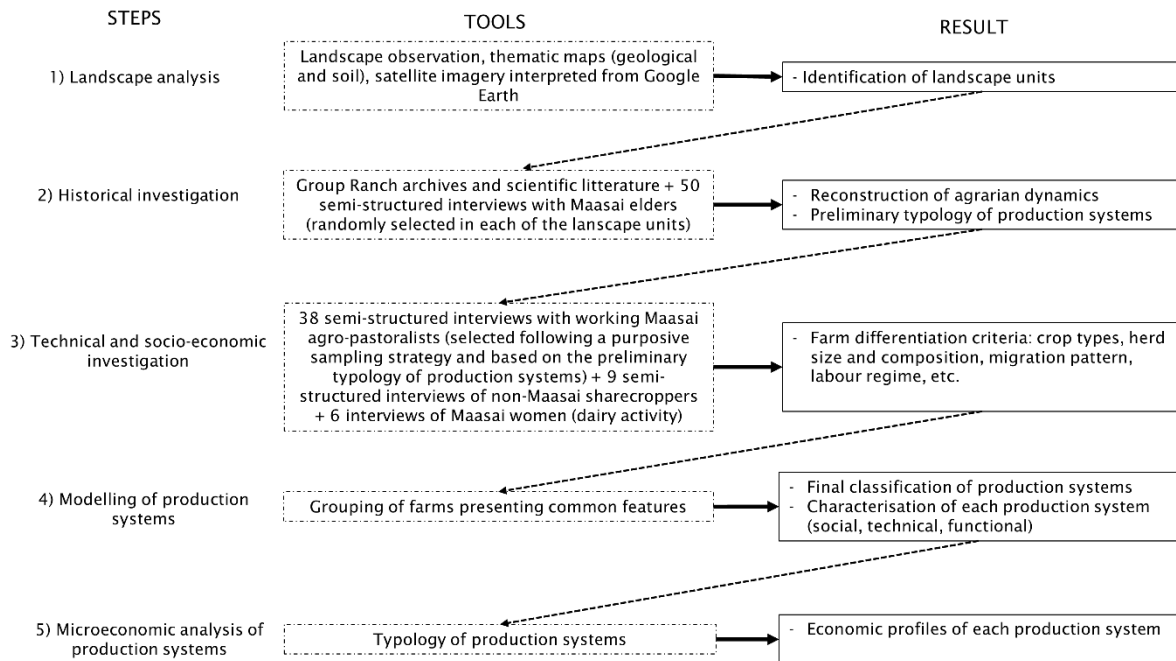
231 Livestock is living capital (Ridder et al., 1986). It provides goods consumed by the household, liquidities  
232 from sales, or gifts (a currency in social capital). The overarching economic rationale of the system  
233 consists in maximising milk production and herd size in order to cushion the impacts of periodic  
234 mortality hazards caused by drought and disease (Bierschenk and Forster, 1991). The herd is thus  
235 managed as a savings bank account 'on legs'. Livestock accumulation is itself also a drought-adaptation  
236 strategy aimed at maintaining stock after losses in order to bounce back. One of the worst droughts  
237 in living memory occurred in 1961 (the 'Year of powdered milk'), during which food was delivered by  
238 helicopter for 18 months. Other droughts with severe effects for pastoralists occurred in 1980, 2009  
239 and 2017 (Fig. 2). These events played a decisive role in the choices made thereafter by some  
240 pastoralists to diversify, in particular by practicing agriculture (Western, 1997).

### 241 **3 Materials and methods**

#### 242 3.1 Comparative agriculture: a methodological framework

243 The methodology is based on comparative agriculture, a standardised framework of mixed methods  
244 (e.g., semi-structured interviews, participant observation) aimed at characterising and comparing  
245 farm-level production systems situated in different social, cultural and environmental settings around  
246 the world (see Suppl. Material, sections 2 to 7). Investigations aim to understand farm trajectories and  
247 farm differentiation within small territories, each defined by specific socioeconomic and agro-  
248 ecological conditions (Cochet, 2015). Comparative agriculture is particularly useful for characterising  
249 agrarian diversity on a regional scale through farm profiling and classification (Lacoste et al., 2018),  
250 and for gaining a dynamic understanding of the socio-economic processes playing out in the rural  
251 economy. Comparative agriculture focuses on access to essential factors of production such as land,  
252 labour, and capital in order to understand the system's historical trajectory and structural diversity  
253 (Aubron et al., 2015). Its four core concepts are the agrarian system, production system, cropping  
254 system and livestock farming system. An agrarian system is an assemblage of several production  
255 systems in a particular region. Production systems encompass farms that share similar production

256 factors and economic orientation (Aubron et al., 2016; Cochet, 2012). A production system consists of  
 257 one or several cropping systems (plot level) and livestock farming systems (herd level). This nested  
 258 approach is synthesised in Figure 4 and detailed in the Supplementary Material.  
 259



260

261 **Fig. 4.** Steps of agrarian diagnosis in comparative agriculture

262

263 **3.2 Data collection and field surveys**

264 Field observations, informal discussions, and semi-structured interviews were conducted between  
 265 March and August 2018. Observation work focused on daily agronomic practices within or outside the  
 266 *boma* (e.g., at livestock markets, and on pastures in order to observe grazing strategies in relation to  
 267 soils and vegetation). Interviews focused on historical and economic aspects of livestock and crop  
 268 farming. They were guided by prior reviews of topical literature, and by observations and discussions  
 269 with key informants (e.g., veterinary officers and other staff working at the Departement of  
 270 Agriculture and Livestock). Interpreters were recruited among young Maasai men and women, and  
 271 interviews mostly conducted in Maa.

### 272 3.3 Documentation of landscape units and historical transformations (steps 1 and 2)

273 Given that biophysical constraints determine a spectrum of potential agronomic activities, step 1 (Fig.  
274 4) consisted in defining broad landscape units based on criteria such as water availability, topography,  
275 vegetation, soil, and land use. This was achieved using Google Earth, and complemented by direct field  
276 observations.

277 The aim of step 2 (Fig. 4) was to document an event chronology of the production systems in the area  
278 before and since the group ranch reform. Reconstructing these trajectories required piecing together  
279 information about livestock and farming practices from scientific and grey literature, and from  
280 narratives by Maasai elders. Fifty elders known to have reared livestock in Mbirikani were randomly  
281 selected among the landscape units identified during step 1. These included Endonyo Wuas, Lemasusu  
282 and Center (Chyulu foothills landscape unit); Orbili and Oltiasika (plains); Ilchalai, Esambu, Isinet and  
283 Kaliserua (swamp area); and Irmabateni, Inkoisuk, Mbirikani, Nasipa and Orng'osua for the pipeline  
284 corridor (see Fig. 3). A preliminary typology of production systems was established based on the  
285 information collected at this stage.

### 286 3.4 Modelling agricultural diversity (steps 3 and 4)

287 In comparative agriculture, 'modelling' consists in profiling different production systems by grouping  
288 farms that share similar characteristics in terms of historical trajectory, farm size, herd size and  
289 composition, land-use affinities, farming equipment, livestock migration pattern, origin of labour, etc.  
290 This facilitates comparisons, ranking, and the assessment of complex situations (Lacoste et al., 2018).  
291 In step 3 (Fig. 4), thirty-eight working Maasai agro-pastoralists were selected using a purposive  
292 sampling strategy based on the preliminary typology established after step 2. The technical and  
293 socioeconomic aspects of their activities were documented. As Maasai men were usually ill-informed  
294 about the details of milking and cropping, which are conducted by Maasai women and non-Maasai  
295 sharecroppers, respectively, six interviews with Maasai women, and a further nine with sharecroppers  
296 working for Maasai landowners, were also carried out. The final classification of production systems

297 is generated in Step 4. It is a simplified representation of reality (a model) based on a finite number of  
298 observed individuals (Couty and Winter, 1983; Delarue and Cochet, 2013).

299

### 300 3.5 Microeconomic analysis of the production systems (step 5)

301 Final step 5 (Fig. 4) focused on the estimation of household income. The balance-sheet approach to  
302 this task presents components of uncertainty because Maasai pastoralism (i) is not fully market-  
303 oriented, (ii) does not involve scrupulous book-keeping, and (iii) involves nested cycles of herd  
304 building, destocking and restocking over many years. A precise appreciation of household economies  
305 in agro-pastoral systems would thus ideally require taking account of social as well as financial capital  
306 afforded by livestock (Alary et al., 2011). Given further that animal-related produce is very rarely  
307 estimated in the same way as crop-related produce (Alary et al., 2011), an additional challenge thus  
308 arises in the estimation of household income when considering livestock and cropping activities  
309 together. Behnke (1985) has nonetheless shown that the benefits of subsistence production in African  
310 pastoral economies are often underestimated, whereas commercial assets, instead, are commonly  
311 overestimated.

312 Household income, i.e., what remains in a household's budget for consumption, investment or  
313 capitalisation over a defined period, was estimated for each of the production systems arising from  
314 the classification obtained in step 4. Microeconomic variables entering the calculation of household  
315 income are (i) gross product, (ii) intermediary costs, and (iii) external labour costs (Cochet, 2015).  
316 Those variables can be tailored to context (Cochet and Devienne, 2006) instead of being pre-ordained  
317 before the interviews (Lacoste et al., 2018). The values were calculated using data collected during  
318 step 3 and product prices obtained at the livestock market. Due to fluctuations in market prices, the  
319 calculated values provided in this study are valid for the year 2018.



320 3.5.1. Gross product (GP)

321 GP is the annual wealth produced at farm level from cropping- and livestock-related activities (Eq. 1).

322 The production values were calibrated on local market prices, thereby providing a price that farmers  
323 would have to pay for the product if they had not produced it.

324 
$$GP = GP_{\text{crops}} + GP_{\text{livestock}} \quad (\text{Eq. 1})$$

325  $GP_{\text{crops}}$  is a function of crop yield (kg/acre) (Eq. 2). As food prices vary throughout the year, we chose  
326 for each cropping season the average price (KES/kg) at peak sales time (KES: Kenyan shilling):

327 
$$GP_{\text{crops}} = \sum_i Yield_{\text{crop } i} * Sale\ price_{\text{crop } i} \quad (\text{Eq. 2})$$

328  $GP_{\text{livestock}}$  accounting cannot just rely on estimations of the animals sold or gifted because this approach  
329 (better suited to meat-oriented livestocking) only considers residual stock as a result of offtake and  
330 purchase rate.  $GP_{\text{livestock}}$  was thus estimated by adding the average annual growth of herd value to the  
331 value of the milk produced for human consumption (Eq. 3, in KES/CEqU<sup>1</sup>).

332 
$$GP_{\text{livestock}} = GP_{\text{milk consumed}} + GP_{\text{mean annual growth of herd value}} \quad (\text{Eq. 3})$$

333  $GP_{\text{milk}}$  equals a woman's milk harvest multiplied by the number of women in the household. There are  
334 no outlets (e.g., dairy cooperatives) for selling milk locally. Household size thus sets a ceiling on  
335 production needs. Maasai women use a calabash (*empokori*) to collect milk. One *empokori* has an  
336 average capacity of 4 L. During the rainy season, daily milk harvest is typically 16 L/woman. In the dry  
337 season, most of the cattle have been driven to pasture, and daily harvest from the remaining cows at  
338 the *boma* decreases to 4 L/woman. Small stock are milked year round but the milk harvest is only 0.6  
339 L/woman/day (i.e., two 30 cl cups) (see Suppl. Material for further details on the Maasai dairy

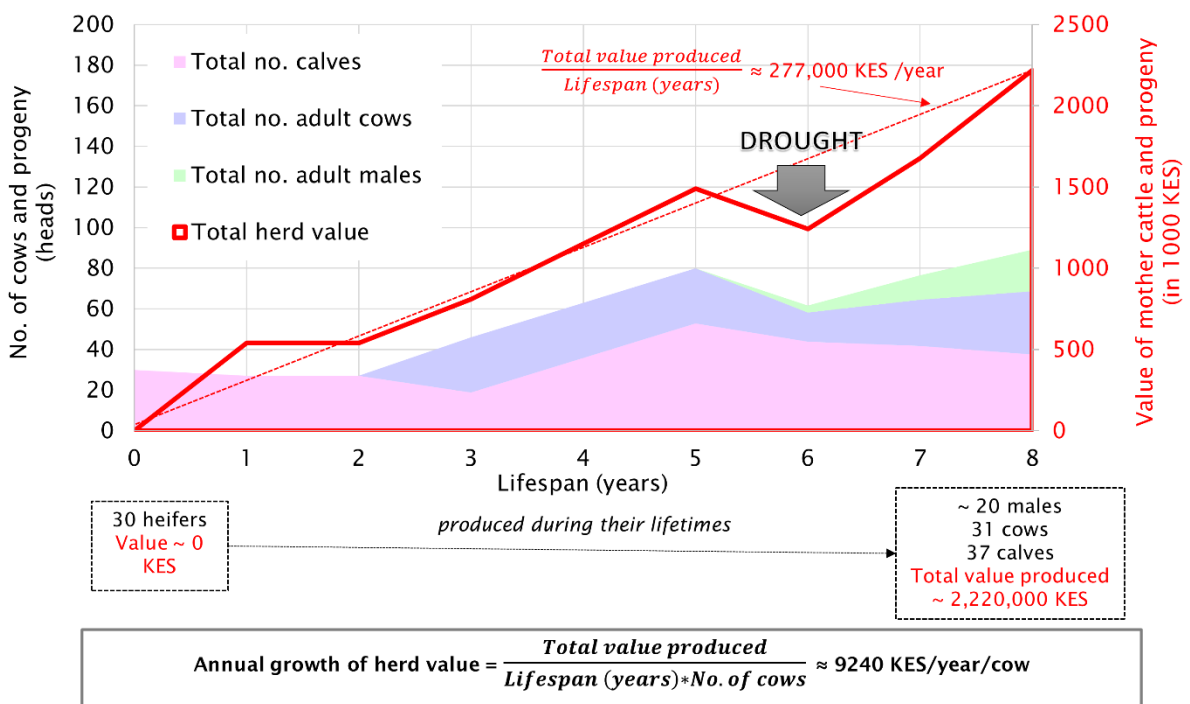
---

<sup>1</sup> Given that the livestock subsystems are multi-species, we combined bovine gross product and shoat (sheep + goat) gross product by reference to a standardised female unit, typically an Animal Equivalent Unit. Given that females are responsible for the growth of the herd (the living capital), we opted for a Cow Equivalent Unit (CEqU) because cows are iconic to the social identity of the Maasai and provide the staples of their economy.

340 economy). The estimation of  $GP_{\text{mean annual growth of herd value}}$  requires several steps and involves an annual  
 341 estimate of a cow's progeny aggregated over the duration of the cow's life (Fig. 5).

342 The estimated number of offspring per cow is then divided by average cow lifespan to obtain unit  
 343 mean annual herd growth per female cow. In line with the literature and confirmed by interviewees,  
 344 age at first calving is three. Heifers will thus contribute to increase herd size when their mothers are  
 345 six years old. Male calves are also valued but do not contribute to herd growth. The average annual  
 346 growth of herd value, 9240 KES/year/cow is calculated using a model assuming a drought impacting  
 347 herd demographics once every 6 years and using 2018 prices (held constant) (see Suppl. Material,  
 348 Section 3, for details about the herd growth model). Similar calculations were made for small stock.

349



350

351 **Fig. 5.** Herd-value growth model. See Supplementary Material for further details.

### 352 3.5.2. Intermediary costs

353 Intermediary costs (IC) are goods and services used as inputs in the production process; they also  
 354 encompass the depreciation of assets (Table 1). IC are deducted from the gross product to estimate  
 355 the value added (VA, Eq. 4). VA at the scale of the cropping system (in KES/acre) and at the scale of

356 the livestock farming system (in KES/CEqU) correspond to the total wealth created respectively for  
 357 one acre of cropping system and one CEqU of a livestock farming system. The combined VA at the  
 358 scale of the production system thus corresponds to the total wealth produced by the work force (e.g.,  
 359 family labour and external labour). Given that land on Mbirikani group ranch has not yet undergone  
 360 subdivision and is still communally owned (grazing is not limited by a ceiling in available pasture  
 361 surface area); and given further that any production system is characterised by a range of herd sizes  
 362 but by a fixed cropland acreage, expressing economic indicators for each farm unit per acre would be  
 363 unsuitable. The value added of the farm unit is thus standardised to animal units, and thus expressed  
 364 in KES/CEqU.

365  $VA = GP - IC$  (Eq. 4)

366 **Table 1.** List of intermediary costs and costs linked to depreciation of fixed capital

	<b>Intermediary costs</b>	<b>Annual depreciation of fixed capital (wear and tear)</b>
<b>Livestock system</b>	Watering of livestock	Truck (for livestock watering)
	Veterinary costs	Maintenance of <i>boma</i> fence
<b>Cropping system</b>	Fertilisers, Seeds	None (tractors used for ploughing belong to the labourers who are paid for this task)
	Water for pipeline irrigation (connection to pipeline)	
	Ploughing (outsourced to labourers)	

367

368 *3.5.3. External labour*

369 The need for external labour is greater than before because school attendance in Kenya curtails the  
 370 family workforce. Livestock left to wander unattended entails a higher vulnerability to predators and  
 371 diminishes observance of grazing rules. The wages for external labour were deducted from the VA for  
 372 calculating household income (HI, Eq. 5). Where relevant, land rent and/or food for sharecroppers  
 373 were also deducted.

374  $HI = VA - Wages - Land\ rent$  (Eq. 5)

375 Two categories of external labour, one engaged in herd management and the other in crop harvesting,  
376 were considered. The household income of each production system was compared against a survival  
377 threshold, which was calculated while taking account of expenses for food (2000 KES and 1000  
378 KES/month, respectively for an adult and for a child) and school fees (~4000 KES/quarter/child) for a  
379 standard household (most frequently encountered pattern: one husband, two wives, eight children).  
380 The minimum monthly earnings one adult requires for him-/herself and their children, i.e., the survival  
381 threshold, is approximately 88,000 KES/year/person. By comparison, the official overall rural and  
382 urban poverty lines in 2015 were 39,024 KES/year/person and 71,940 KES/year/person, respectively  
383 (KNBS, 2018).

#### 384 **4. Results**

##### 385 4.1 Differentiation processes among the production systems over time

386 Table 2 is a chronology of locally important historical events harvested from the history-focused  
387 interviews. Trends show that changes in access to natural resources essential to pastoralism were the  
388 main drivers of production system transformation, and that these were specifically spurred by wildlife  
389 conservation policies (Unks et al., 2021). The creation of Amboseli National Park in 1974 is primarily  
390 what deprived herders of key access to water and pasture during the dry season. Migratory routes  
391 were adjusted under this new, overarching constraint, but difficulties in accessing water entailed a  
392 cascade of other quantitative and qualitative adaptations, such as a reduction in herd sizes and a  
393 gradual increase in the number of shoats (which are better adapted to water scarcity and feeding on  
394 woody perennials). The eviction of farmers from the Chyulu Hills in 1983, and again in 2018 (Table 2),  
395 has continued to drive the wedge deeper between pastoralists on the one hand, and conservationists  
396 and wildlife on the other.

397 Infrastructures aimed at improving access to water multiplied after World War II. They played a central  
398 role in establishing permanent *bomas* near these new water access points and thus on fixing

399 transhumance routes. The pipeline had a particularly important effect on patterns of population  
400 settlement within Mbirikani group ranch (Fig. 3).

401 **Table 2.** Chronology of events at Mbirikani since 1880, with impacts on production systems

Date, time period	Events and their consequences
1880–1890	Period known as <i>emutai</i> (i.e., ‘complete destruction’; Waller, 1988) during which some Maasai turned to hunting (for ivory and rhinoceros horns), gathering (e.g., khat), or to agriculture in Loitokitok. Women were forced to marry men from the Arusha Maasai section to gain livestock through dowries. Political alliances with the British rulers occurred, with some Maasai joining the army and obtaining in exchange livestock looted from other Kenyan tribes.
1920s, 1930s	Monetisation of the local economy: using pots of different sizes filled with coins, the British introduced the notion of ‘monetary value’ applied to cattle. These new markets benefited men but excluded women, who remained confined to the barter economy (milk, hides). Expansion of livestock markets (Loitokitok and Ilasit) by colonial administrators: tax system to benefit from services. Tax system per cattle head (~10–20 KES for ten cows); price of one cow: ~100 KES.
1926	British administrators enforced veterinary rules (movement restrictions, quarantine, vaccination) officially dedicated to control epidemics but also to control pastoralists, which were accused of owning too much livestock and causing soil erosion.
1930s	The subsistence barter economy of the Maasai shifts to a more integrated market economy under British measures, such as attempting to substitute Maasai cattle currency with the Kenyan Shilling, developing cattle market infrastructures, and implementing a cattle taxation policy.
1946	Establishment of the 10-year development plan by the ALDEV (African Land Development Board) to “rehabilitated pastoral areas and building permanent water points” (Kategile and Mubi, 1993).
1950	Establishment of the “Kenya Meat Commission” by the British to develop a meat market for the benefit of pastoralists and consumers. Opening of a livestock slaughterhouse in Athi River (town).
1950s	ALDEV Development plan: borehole sinking and draining of Isinet swamp to allow cattle inside the swamp without risk of getting bogged down.
1954	Construction of the Noolturesh pipeline. Five water reservoirs ( <i>mbirika</i> , in Maa – hence the Mbirikani group ranch name) are built along the pipeline. Access to these storage facilities modified grazing patterns and organisation (Peacock, 1987).
1960s	Post-Independence (1963) creation of group ranches; were mostly welcomed in the aftermath of the deadly drought of 1961.
1974	Creation of the Amboseli National Park. Dry season pasture was thereafter restricted to Isinet and Ilchalai swamps.
1974–1975	First permanent settlement of families along the Kikarankot River to develop cropping activities (at Esambu, Ilchalai, Orbili, and Oltiasika; Fig. 3).
1978	First settlements in the Chyulu Hills because the plains were already occupied.
1980s	Series of droughts in the early 1980s: pastoralists owning fewer than ~30 cows per adult per household <sup>1</sup> diversified and expanded into subsistence farming (maize and beans) on the Amboseli plains. Most employed non-Maasai (Kikuyu, Kamba, Chagga ethnic groups) workers as sharecroppers. Wealthier pastoralists recovered from the crisis by using trucks for water supply.
1983	Creation of Chyulu Hills National Park and first eviction of farmers from the hills.
1985	Settlement of families at Endonyo Wuas (Fig. 3): these families own large herds that cannot rely on pastures in the plain alone. They require two <i>bomas</i> (one near the pipeline and one in Endonyo Wuas, in the Chyulu foothills) and practice rotational grazing. Settlement was also aimed at avoiding that these areas became conservation land.
1989	Grazing management plan developed by group ranch leaders to coordinate livestock movements and avoid early presence of pastoralist in dry pasture and/or installation of <i>bomas</i> within grazing lands. The plan enforced staggered moves from the pipeline eastward and in straight lines to the Chyulu Hills (see Fig. 6). Allocation (through allotment letters) to group ranch members of two acres of farmland in the swamps.
1990s	Beginning of tomato cultivation, spurred by high market prices in comparison with maize, and by growing access to fertiliser (its use doubled between 1992 and 2007; Ariga and Jayne, 2011).
2000s	Introduction of new breeds: cross-bred Borana (cow), Dorper (sheep), Galla (goat). Group ranch leaders encourage schooling (e.g., through scholarships and ‘herders programme’ aimed at employing hired herdsmen instead of moran or children). This ushered in a wage-based herding economy, thus modifying traditional division of labour.

2009 'Mombasa drought', where ~75% of herders lost more than 50% of their cattle.  
2017 Drought: ~50% of herders again lost more than 50% of their cattle.  
2018 Ministerial executive order forbids farming in the Chyulu Hills. Farmers are evicted.

---

Note. <sup>1</sup> According to Peron (1995, p. 56), the low milk yields of East African Zebu cows imply that Maasai families required large herds to survive: one adult Maasai required approximately 2 to 3 cows for his own consumption needs in the rainy season, 10 to 15 in the dry season, and more than 30 in times of drought.

402

403 Pastoralism was also strongly impacted by successive droughts:

404 • The 1961 drought precipitated collective adhesion to the group ranch as a land tenure  
405 arrangement.

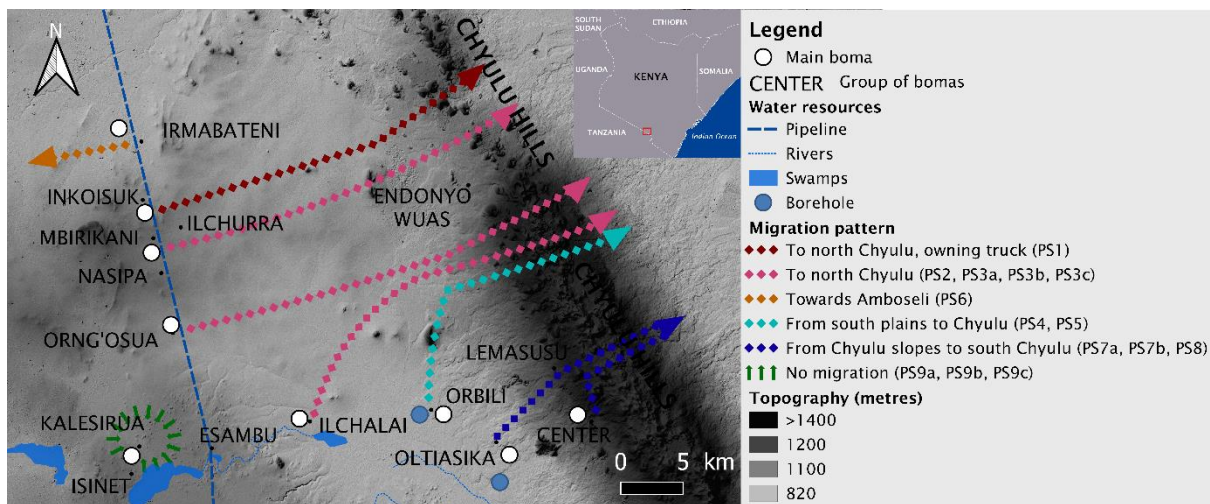
406 • The successive droughts of the early 1980s further led to the allotment of two acres of swamp  
407 land per male ranch member. This process, however, was not a legally valid group ranch land  
408 subdivision because the issued allotment letters were not recognised by the Kenyan state.  
409 Cropping and water-access potential of these lands nonetheless vary from one plot to another.  
410 The informal nature of the operation thus benefited some households more than others.

411 • The 2009 drought entailed major livestock losses, compounded by a frenzied rush to rumoured  
412 greener pastures around Mombasa. This event accelerated the urge to convert from livestock to  
413 crops. The 2009 drought entailed a 65% decline of livestock (Gichohi et al., 2014). Numbers of  
414 smaller livestock, particularly goats, also increased after the 2009 drought because of their  
415 resistance to water stress.

416 • A great drought occurred in 2017 and also had a strong impact on herd sizes, but at a time in the  
417 regional chronology when livestock mobility had already become much less prevalent than in  
418 1961. The largest breeders called on fodder and food supplements more than ever before, thus  
419 revealing strong inequalities in economic resilience to drought hazards within the community.

420 The interviews also revealed that conversion to agriculture among the Mbirikani Maasai first occurred  
421 in the mid-1970s, initially among poorer livestock owners. Spurred by necessity, the smallest livestock  
422 owners were thus first to adopt subsistence agriculture under sharecropping agreements with other  
423 ethnic groups (Table 2). Other categories followed suit thereafter. Possession of a larger herd is clearly

424 a major economic buffer against drought hazards and an insurance policy against milk shortages. A  
 425 critical illustration of this is that larger breeders were able to invest in water transport trucks after the  
 426 1980s droughts by decapitalising their stock (i.e., selling cows). This operation provided access to  
 427 pastures devoid of natural water reserves, resulting in opening up a new pastoral frontier in the Chyulu  
 428 Hills. This form of intensification through mechanisation was the exclusive preserve of owners of the  
 429 largest herds. Two types of pastoral systems thus co-exist depending on capacity for motorised water  
 430 transport: one has maintained longer-range transhumance between the upland plains and the Chyulu  
 431 Hills, and the other moves herds between the upland plains and their swamp enclaves in the south  
 432 (Fig. 6). The gradual expansion of agriculture in these swamps, however, is restricting access to this  
 433 shorter-range option.



434  
 435 **Fig. 6.** Mobile livestock seasonal migration patterns between settlements on Mbirikani group ranch  
 436 and the Chyulu Hills.

437 The differences between those two systems seem to be increasing. The largest breeders ( $\geq 100$  heads)  
 438 fatten their adult males (3–4 years) and sell them in the rainy season (April, time of peak body mass).  
 439 Mature females are not sold because they ensure herd growth and milk for household consumption.  
 440 At the opposite end of the spectrum, herders owning less than 10 cows cannot settle for the same  
 441 strategies and are sometimes forced to sell females and calves. This slows herd growth and reduces  
 442 milk output. Such production systems rely more heavily on small ruminants for meat and milk,



443 although larger livestock farmers may also lend cows to smaller livestock farmers so they can meet  
 444 their household dairy needs.

445 A critical development in the historical timeline of Mbirikani is that farmers endowed with sufficient  
 446 financial capital invested in tomato cultivation from the mid-1990s. This cash crop requires  
 447 intermediary costs and manual labour. Some outlay is also needed for establishing a connexion to the  
 448 pipeline. In the swamps, those who cannot afford tomatoes continue to grow maize and beans as  
 449 subsistence crops. Tomatoes are sold primarily for the urban markets of Nairobi and Mombasa, but  
 450 also locally. In the early 21st century, numbers of improved livestock breeds (Borana cattle, Galla  
 451 goats, Dorper sheep) began to increase. Their massive build makes them profitable but they require  
 452 more frequent watering than hardy breeds, more fodder, and have a faster metabolism. Crop  
 453 calendars must adapt to these needs. Some herders owning at least 50 heads have also started to  
 454 build small runoff-harvesting ponds (*eselanke*) (see Suppl. Fig. 2) aimed at extending the period of  
 455 water availability, and for growing one or two additional acres of tomatoes over one or two crop  
 456 cycles. The reservoirs are built on collective rangeland but are privately managed. This informal  
 457 infrastructure ensures a form of intensification while modifying the surface hydrology of the savanna  
 458 ecosystem.

#### 459 4.2 Classification criteria of the group ranch production systems

460 Based on the sample analysed for this study ( $n = 38$ ), nine different production systems labelled PS1  
 461 to PS9, and eight subsystems within those categories, were identified on Mbirikani group ranch in  
 462 2018. The production systems differ according to a number of criteria (Table 3; see Suppl. Table 1 for  
 463 a full version).

464 **Table 3.** Characteristics of the nine production systems (PS) and their variants

Production system code name	Sub-system <sup>1</sup>	No. of CEQU	Cattle herd type (breed)	Migration pattern <sup>2</sup>	Cropping system (no. of acres)
PS1	–	240–360	Improved	To north Chyulu,	Pipeline tomatoes (2)

				owning truck	
PS2	–	65–125	Improved	To north Chyulu	Pipeline tomatoes (4) Maize and tomatoes – swamp- (2)
PS3	PS3a	15–50	Mixed	To north Chyulu	Pipeline tomatoes (2) Maize and tomatoes – swamp- (2)
	PS3b	15–50	Mixed	To north Chyulu	Maize and tomatoes – swamp- (2)
	PS3c	15–50	Mixed	To north Chyulu	Maize, no tomatoes – swamp- (2)
PS4	–	15–65	Mixed	From south plains to Chyulu	Rainfed crops in Chyulu Hills (6) Maize and tomatoes – swamp- (2)
PS5	–	50–100	Mixed	From south plains to Chyulu	Land rented out to other farmers
PS6	–	10–30	Mixed	Towards Amboseli	Pipeline tomatoes (2) Maize and tomatoes – swamp- (2)
PS7	PS7a	3–12	Local zebu	From Chyulu slopes to south Chyulu	Rainfed crops in Chyulu Hills (3)
	PS7b	3–12	Local zebu	From Chyulu slopes to south Chyulu	No farming (farming forbidden, no acres in the lowland)
PS8	–	8–33	Mixed	From Chyulu slopes to south Chyulu	Rainfed crops in Chyulu Hills (10)
PS9	PS9a	6–20	Mixed	No migration	Maize, no tomatoes – swamp- (2)
	PS9b	6–20	Mixed	No migration	Land rented out to other farmers
	PS9c	6–20	Mixed	No migration	Maize and tomatoes – swamp- (2) +4 acres rented from other farmers

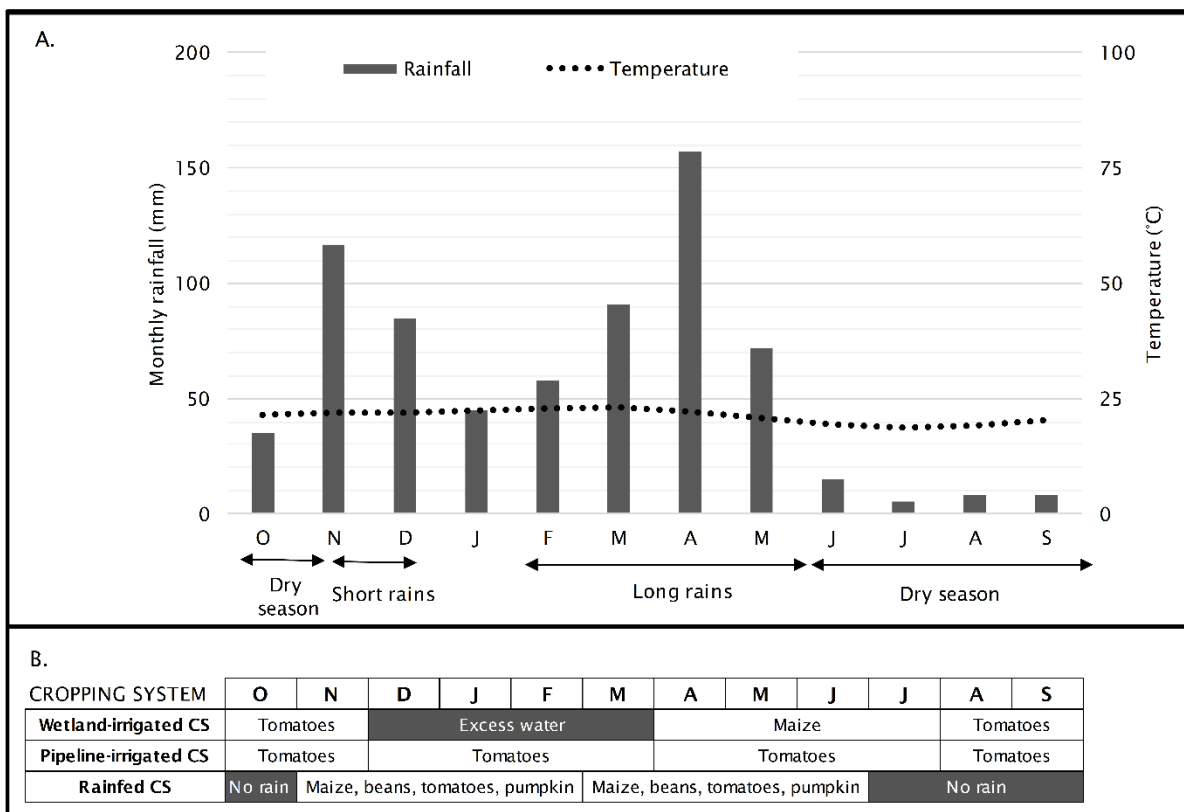
465 Notes. <sup>1</sup> Number of sampled farms belonging to the production systems: PS1 ( $n = 5$ ), PS2 ( $n = 4$ ), PS3a ( $n = 4$ ), PS3b ( $n = 5$ ),  
466 PS3c ( $n = 3$ ), PS4 ( $n = 1$ ), PS5 ( $n = 1$ ), PS6 ( $n = 3$ ), PS7a ( $n = 4$ ), PS7b ( $n = 0$  because this represents the scenario where PS7a  
467 respects the prohibition to farm in the Chyulu Hills), PS8 ( $n = 3$ ), PS9a ( $n = 2$ ), PS9b ( $n = 2$ ), PS9c ( $n = 1$ ).

468 <sup>2</sup> See Fig. 6

469

470 Results highlight sharp inequalities in herd ownership, especially PS1 and PS2, which hold respectively  
471 30 and 10 times more livestock than PS9. Another key finding is that nearly all the PS are jointly  
472 involved in agriculture and pastoralism. Individuals still relying exclusively on pastoralism belong to  
473 PS5, PS7b or PS9b, respectively because they were renting their farmland but gave it up, they stopped  
474 farming after forced eviction from the Chyulu Hills National Park, or could no longer afford the inputs.  
475 The cropping calendar varies as a function of location, because of variability in access to water (Fig. 7).  
476 This calendar highlights an important advantage of pipeline irrigation, which is the possibility to  
477 sustain production throughout the year (three crop cycles). This contrasts with the swamp

478 environments (where drainage ditches would also be required to evacuate excess water during the  
 479 rainy season — hence only one annual crop) and with the rainfed settings (seasonal water shortages).  
 480 We supposed that the Chyulu Hills have the same precipitation regime as in the plains but with  
 481 approximately 20% more monthly rainfall because of greater elevations (summit: ~2000 m). Cropping  
 482 systems located in the swamp areas usually farm the two acres allocated in the 1980s (see Section 4.1  
 483 and Table 2), or more if additional acreage is rented (PS9c). Pipeline-irrigated tomato farmers manage  
 484 between two and four acres of land along the pipeline because there is no *de facto* limitation of land  
 485 along the pipeline. In the Chyulu Hills, Maasai settlers who evaded eviction may farm up to 10 acres  
 486 of purely rainfed crops (the 10-acre ceiling in the Chyulu Hills is a consequence of land allocation  
 487 policies in the 1990s).



488  
 489 **Fig. 7.** Climate diagram and cropping system (CS) calendar. A. Walter-Lieth diagram: rainfall and  
 490 temperature (Amboseli National Park, elevation: ~1000 m; source: Climate-Data.org, 2018). B:  
 491 cropping calendars crafted from qualitative interview data

#### 492 4.2.2. Labour inputs

493 Daily tasks in the fields are usually carried out by non-Maasai sharecroppers<sup>2</sup>. Given that the working  
494 capacity for tomato crops is one acre per sharecropper, the number of sharecroppers is proportional  
495 to the number of acres farmed. Whereas Maasai owners provide the land, seeds, chemical inputs and  
496 pipeline connections, the labourers enhance the crop value. The sharecroppers are usually Kambas  
497 (mostly from Makueni County, on the east side of the Chyulu Hills), Chaggas (from Mt. Kilimanjaro),  
498 and Kikuyus. None have land access rights under the group ranch regime. They are generally hired on  
499 short-term contracts (1 or 2 seasons) and rarely remain affiliated to the same employer because profit-  
500 sharing rules are rarely complied with (from interviews). They make tomato farming profitable for the  
501 Maasai because the value of their labour far exceeds the cost of employing them (which is deducted  
502 from the value added in the calculation of household income; Fig. 10). Costs borne by the landowner  
503 include the sharecroppers' food allowance and the wages paid out to tomato pickers (see footnote 2).  
504 Maize is usually harvested by the sharecroppers, or by Maasai family labour.

505 Herds are traditionally kept by unpaid family labour (children, women, young men), but increasing  
506 rates of school attendance among the Maasai entail the employment of additional labour. Some  
507 households, however, cannot afford these costs and herd pooling remains common practice. At *boma*  
508 level, some Maasai maintain the enclosure fence themselves, while others pay annually for servicing  
509 and repair. If the *boma* is shared, the cost of *boma* maintenance is shared between the household  
510 members.

#### 511 4.2.3. Herd size and composition

512 Mixed herds of cattle and shoats are suited to harnessing a greater array of natural resources, to  
513 enduring different types of hazard, and also provide a diversity of products (milk, meat, animal fat,

---

<sup>2</sup> On Mbirikani ranch, all the farming chores are done by the sharecroppers. The only daily labourers are the tomato pickers (usually carried out by groups of Maasai women, who receive 200 KES for a 70 kg crate). This regime is not necessarily identical on all ranches in the area.

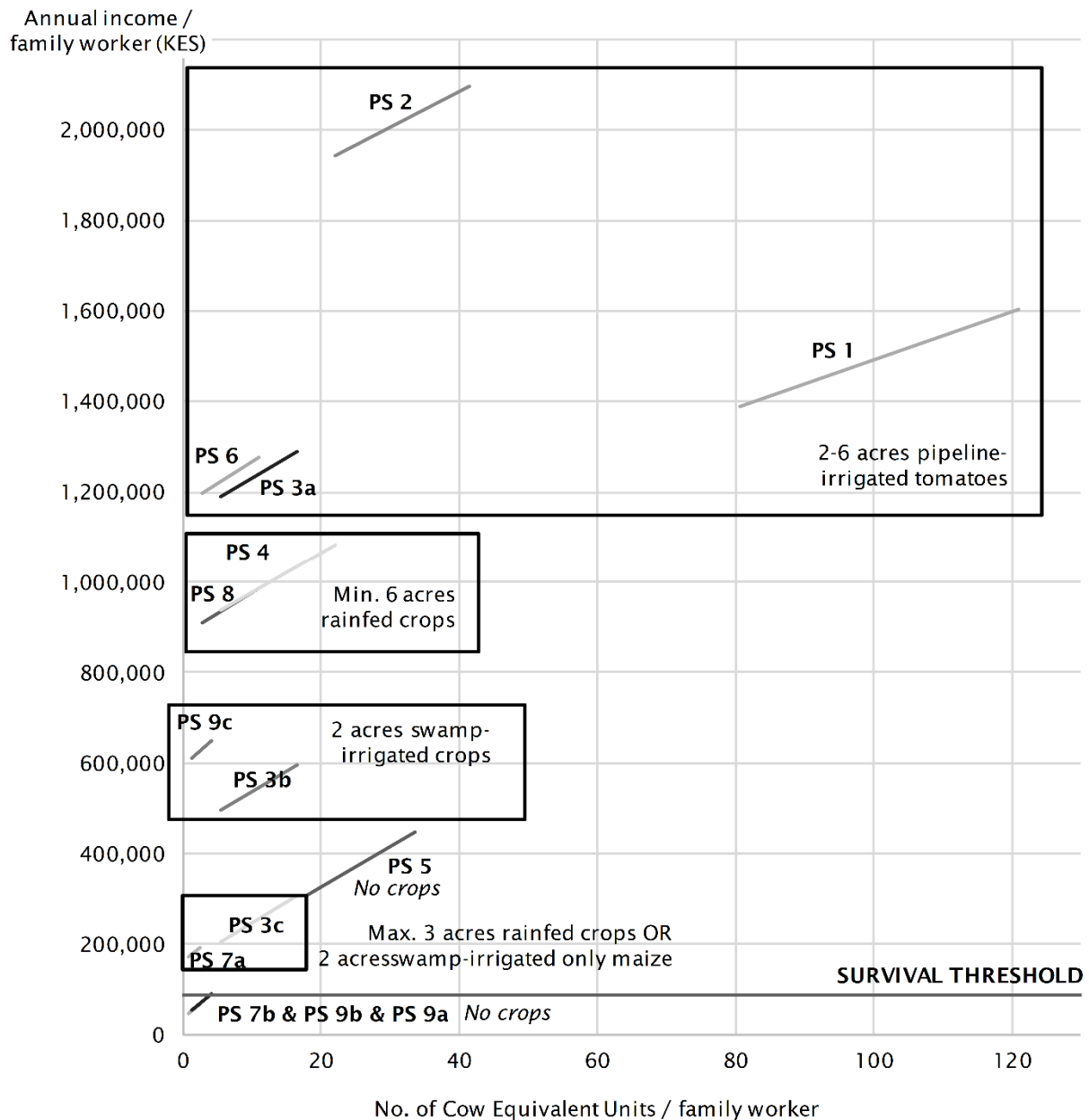
514 livestock offspring, manure for building huts, cash when sold). In terms of herd size, results reveal the  
515 wide gap between the wealthiest (PS1, more than 400 heads) and poorest pastoralists (PS7, less than  
516 15 heads). Most production systems have mixed breed herds, but some have fully adopted improved  
517 breeds (PS1 and PS2). A few herds still consist almost entirely of Zebu (PS7).

#### 518 4.2.4. Herd migration pattern

519 A total of seven migration patterns were identified (Table 3; Fig. 6), among which cost of livestock  
520 watering is a key discriminating factor. Despite being attractive during the dry season because forage  
521 abundance declines on the plain, the Chyulu Hills pastures require particularly costly water  
522 conveyance to the livestock. The migration pattern 'to north Chyulu' and 'from south plains to Chyulu'  
523 (Table 3) is characterised by the highest watering costs because agro-pastoralists have to pay for the  
524 transport of water and for access to a borehole in the latter case. Some agro-pastoralists (e.g., from  
525 PS1) also own a truck: they thus do not pay for transport of water (water is free) but bear the cost of  
526 the annual depreciation of the vehicle (Table 1). The watering costs of the migration pattern 'towards  
527 Amboseli' are zero because livestock can drink from the wetlands they encounter along the way.

#### 528 4.3. Economic performance of the production systems

529 The microeconomic analysis reveals large economic disparities in household income, especially  
530 between the higher-ranking production systems involving pipeline-irrigated tomato farming and the  
531 others (Fig. 8). Just below the top earners are tomato growers based in the swamps and those enjoying  
532 a minimum of six rainfed acres in the Chyulu Hills. The income of families that do not grow tomatoes  
533 or cultivate less than three acres of rainfed crops in the Chyulu Hills lies below, or close to, the survival  
534 threshold. The tomato is thus the game changer.

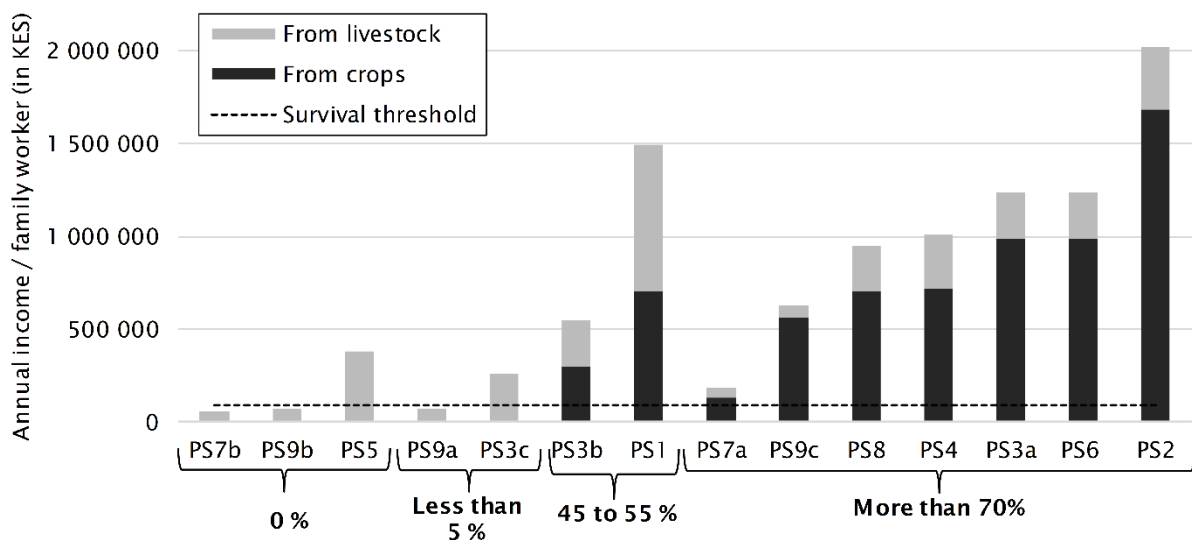


535

536 **Fig. 8.** Annual income of production systems on Mbirikani group ranch according to herd size.

537 We also assessed the relative weight of crop revenue in total household income under each  
 538 production system (Fig. 9). Agriculture, and particularly tomatoes (Fig. 10), shows up as very lucrative  
 539 despite its high intermediary costs (domestic animals, often small stock, consequently have to be sold  
 540 to purchase those inputs). Seven production systems obtain more than 70% of their income from  
 541 crops, and all of them include tomatoes. PS7a involves only three acres of rainfed hillside crops, but  
 542 the relative weight of crops on overall income is ascribable to the very low CEqU score. Two production

543 systems record a range of 35–60% of household income deriving from crops: thus PS1, with two acres  
 544 of pipeline-irrigated tomatoes but a large herd (400–600 CEqU); and PS3b, which farms two acres of  
 545 tomatoes in the wetlands (but only one crop cycle). PS1 members often also grow crops on rented  
 546 land from other group ranches (not documented here). Crops contribute more revenue to PS1  
 547 household incomes, therefore, than in the balance sheet presented here, which is restricted to the  
 548 territory of Mbirikani ranch and calibrated on 2 acres of pipeline-irrigated tomatoes. When restricted  
 549 to maize (PS9a, PS3c), harvest revenue contributes to less than 5% of the total. Lastly, crops contribute  
 550 no income in three cases: PS5, because the land is leased<sup>3</sup> to others; and PS9b and PS7b, because its  
 551 members have no financial capacity to farm, or because farming is forbidden where they reside (e.g.,  
 552 Chyulu Hills).



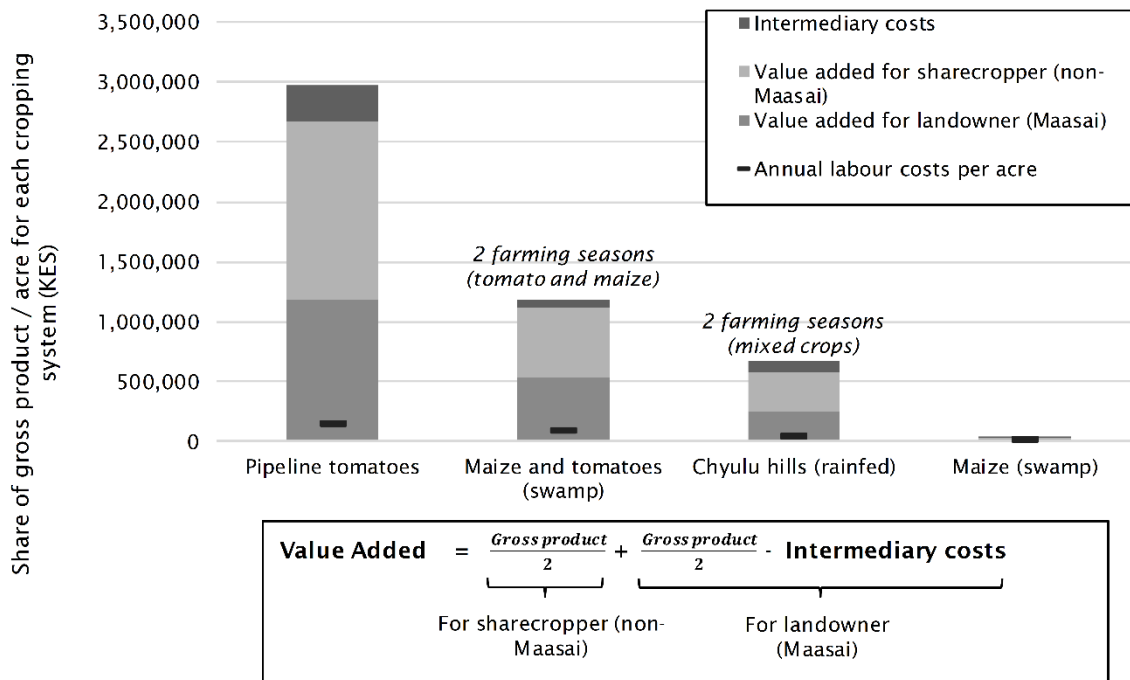
553  
 554 **Fig. 9.** Annual income of production systems on Mbirikani group ranch by source of revenue (crops or  
 555 livestock).

556 **4.4 Economic performance of crops**

557 The value added generated by one acre of pipeline-irrigated tomato crops is overall four times greater  
 558 than one acre of mixed rainfed crops that include tomatoes, and double the value generated by one

<sup>3</sup> Additional revenue received from land leases was not documented and thus not quantified in total income calculations. Only revenue from crop and livestock production was considered.

559 acre of swamp-irrigated tomato and maize crops (Fig. 10). Even though outlay is much greater in the  
 560 pipeline-irrigated tomato system than in the swamp-irrigated tomato and maize or in the mixed crops  
 561 systems, surpluses generated by the pipeline-irrigated tomato system arise because (i) three cropping  
 562 cycles are possible, and (ii) production can occur out-of-season when prices are high, i.e., December  
 563 to July (Suppl. Fig. 5).



564  
 565 **Fig. 10.** Comparison of gross product, intermediary costs, and value added per unit acre for each  
 566 cropping system.

567  
 568 **5. Discussion and outlook**

569 **5.1 Evidence of socio-economic inequalities on the ranch**

570 The identification of nine production systems reveals a large diversity of microeconomic situations  
 571 within the Maasai community, corresponding to as many levels of relative socioeconomic  
 572 vulnerability. The 2017 drought showed that the economic resilience of richer pastoralists hinged on



573 acquiring fodder and cattle feed supplements, thus emulating input-intensive farming methods until  
574 now mostly alien to the local livestock management practices.

575 Homewood et al. (2009) previously revealed that 10% of households around Amboseli owned 45% of  
576 the livestock. It was difficult to establish why some herders possessed larger herds in the first place,  
577 and respondents were evasive about this issue. It is highly likely that other factors relating to  
578 institutional power (political capital) would explain initial livestock accumulation. None of the  
579 economic disparities detected, however, appear to have arisen from dramatic forms of oppression or  
580 from rags-to-riches success stories in the last 70 years. Transformations were essentially circuitous,  
581 piecemeal and incremental, with advantages — once gained through herd size and political power  
582 — maintained and cumulative. The weight of these assets has played an important role in the ability  
583 to cope with future shocks, with disparities always magnified in the context of droughts.

584 The Maasai community is nonetheless well known for its moral economy based on reciprocity and  
585 mutual aid (e.g., (Aktipis et al., 2011; Western and Finch, 1986; Western and Nightingale, 2003).  
586 Lactating cows, for example, are loaned to the needy to secure milk for the family, although at the  
587 same time generating a form of social dependency. These favours are returned in the form of services  
588 (e.g., cattle dipping, herding chores). In a setting where the most remunerative production system  
589 generates twenty times more income per capita than the lowest (Fig. 8), this trading of social capital  
590 throws a thin veil of traditional ethnic solidarity (see Section 2.3) over the growing economic  
591 disparities otherwise highlighted by the data.

## 592 5.2 Revenue from crops in Maasai household income: threats and opportunities

593 Crops today are clearly more profitable than livestock in Mbirikani, as likewise documented in Ethiopia  
594 (62 to 71% of household income; Adunga, 2013) and in Kenya, Tanzania and Uganda (60 to 90%; Rufino  
595 et al., 2013). The profitability of tomato cropping is often advertised online in Kenya (e.g., “how to  
596 become a millionaire through tomato farming”, etc.). At Mbirikani, only owners of large herds manage  
597 to derive substantial income from pastoral activities.

598 Agriculture, however, may not be profitable in the longer term because revenue from tomatoes is  
599 fundamentally conditioned by access to (i) a favorable market (volatility of tomato prices  
600 notwithstanding), (ii) labour (the sharecroppers), and (iii) water. Furthermore, pipeline-irrigated crop  
601 cultivation cannot occur more than ~3 km from the pipeline for the water to reach the fields. It  
602 requires supervision and thus cannot occur far from its attendant *bomas*. The economic rent  
603 associated with the revenue from pipeline-irrigated tomatoes (Fig. 10) is also not necessarily a secure  
604 asset in the longer term because the original purpose of the Nolturesh pipeline was first and foremost  
605 to provide drinking water to remote urban residents. From an economics perspective, pipeline  
606 irrigation therefore incurs an opportunity cost measured by the forgone benefit of allocating water to  
607 tomato crops instead of satisfying the intended urban demand. Water supply is ranked as the top  
608 development priority in Nairobi, Mombasa and Kakamega and concerns all social categories (Gulyani  
609 et al., 2005); as a result, conflicts (recounted in interviews and documented in Kenyan media) arose in  
610 2018 over access rights between Mbirikani group ranch members and the Nolturesh Pipeline  
611 company. Irrigation is usually a high-volume, low-value use of water, so when it competes with urban  
612 uses the opportunity costs are high (Briscoe, 1996). Such conflicts could multiply in the future, raising  
613 the stakes and drawing local agriculture and livestock issues at Mbirikani into a national or even global  
614 minefield. Little is known about hydrological discharges, aquifer recharge rates, and overall  
615 dependability of water for planning purposes in the Greater Amboseli Ecosystem. Such key  
616 information, however, should in the future determine the scope for agricultural expansion in  
617 Amboseli's group ranches, where water is currently being used as an unregulated, open-access  
618 resource.

619 A further threat to the steadiness and viability of cash-crop expansion is that Maasai institutions have  
620 functioned until now under a regime exclusively focused on pastoralism (Fratkin, 1997). Maasai  
621 institutions must therefore adapt to the ongoing processes of livelihood diversification and are  
622 experiencing unprecedented difficulties more widely in the context of group ranch subdivision.  
623 Maintenance of traditional forms of pastoralism may also eventually require external support from

624 the state and/or third-sector organisations to counterbalance the amputation of roaming space by  
625 'fortress' wildlife conservation policies in the last 40 years (see Table 2).

### 626 5.3 The unlikely disappearance of mobile livestock keeping at Mbirikani

627 The importance of tomato crops in total household income is only valid for Maasai residents with  
628 access to irrigation. Furthermore, there was no record in the sample of anyone having entirely  
629 abandoned livestock keeping in order to embrace full-time crop farming. Although reliable data on  
630 total crop acreage were unavailable, values at Mbirikani are small in comparison to rangeland acreage.  
631 Livestock is thus foreseeably the only viable resource for this territory in its majority. In the rainfed  
632 Chyulu Hills, crops rank high in household income only because of the very low CEqU score (PS7a) or  
633 because of larger acreage (10 acres in the case of PS8). As shown in Figure 10, the economic  
634 importance of crops in the rainfed region is not a function of crop type.

635 Crucially, whereas cash revenue from livestock can be replaced by cash revenue from crops, milk is a  
636 non-substitutable resource. This is particularly true for remote areas like Mbirikani, where no dairy  
637 market exists. As well as being culturally ingrained in Maasai society and cosmology (the Maasai  
638 defined themselves as 'iltung' anak loonkisho', meaning 'people of the cattle'), milk is the staple food  
639 and its long-term consumption has allowed the group to maintain unique biological features such as  
640 low cholesterol levels (Biss et al., 1971). What the Maasai eat defines them quite literally as  
641 pastoralists who live off the food of their livestock; their status as predators, hunters or farmers is  
642 subsidiary (Århem, 1989).

643 There is thus little to indicate that recent rural dynamics driven by tomato cultivation are either  
644 unidirectional or irreversible (Babiker, 2002). Cash crop cultivation elsewhere in Kenya, for example,  
645 is far from having deterred the Maasai community from livestock husbandry. At Naroosura group  
646 ranch in Kenya's southern rift valley, for example, Maasai livestock remains an essential safety net in  
647 contexts of low yields or crop market collapse. Crop residue is fed to the cattle, and farming income  
648 allows herd restocking in the wake of drought-related mortality (Pollini and Galaty, 2021). In Laikipia,

649 even though families own far less livestock than twenty years ago, livestock is still the most important  
650 fallback in periods of food scarcity (Ulrich et al., 2012).

651 Examples of strong integration between agriculture and livestock were scarce. One occurrence  
652 consisted in selling sheep or goats in order to buy farm inputs. Another consisted in letting livestock  
653 graze in the fields after harvest, but only in times of drought. No systematic use of animal manure to  
654 fertilize the fields was reported. Re-investment of crop revenue (including revenue from land leases)  
655 into livestock production, and vice versa, was not, however, systematically explored in this  
656 reconnaissance study. Future research may nonetheless reveal further intricacies in the agricultural  
657 economics and ongoing agrarian transformations of Mbirikani ranch.

#### 658 5.4 Impact of wildlife conservation policies on cropping and livestock activities

659 Transhumant pastoralism in southern Kenya has been strongly affected by 20th century wildlife  
660 conservation policies (Unks et al. 2021). The creation of Amboseli and Chyulu national parks in 1974  
661 and 1983, respectively, has amputated the eastern and western extremities of the Amboseli wildlife  
662 dispersion and livestock transhumance corridors, with the Kisongo Maasai thus falling victim to (i) loss  
663 of access to water (Amboseli) and pasture (Chyulu), but also to (ii) unfair compensation for herd  
664 predation in a context of intensified human–wildlife conflict within shrinking rangeland territory (e.g.,  
665 raids from elephants on crops). The creation of group ranches has further constrained the extent of  
666 grazing areas and reduced the flexibility of Maasai pastoralism, which was a key dimension of its  
667 adaptive capacity. Resentment over policies to protect biodiversity, therefore, has reached a high  
668 tidermark (Unks et al. 2021). ‘Fortress’ conservation attitudes initially pointed the finger at herding  
669 practices and large herd sizes, thereby perpetuating the colonial trope about the Maasai livestock  
670 economy being inefficient and motivated by a taste for prestige rather by a sound sense of ecosystem  
671 management (Homewood and Rodgers, 1984). In other pastoral areas, contraction of rangelands has  
672 in fact led to a ‘reproductive squeeze’ where pastoralists overgraze remaining pastures (Zhang et al.,  
673 2021). At Mbirikani today, however, conservation organisations are now attempting new forms of  
674 alliance with the Maasai against the expansion of agriculture. The prospect of fields crowding out

675 rangeland habitat, or at least impeding the free movement of wildlife around critical water access  
676 points and through dispersal corridors — with alarming precedents in the Kitengela area, south of  
677 Nairobi National Park — are providing vivid warnings of unwanted outcomes (Nkedianye et al., 2019;  
678 Said et al., 2016).

679 The intrinsic profitability of agriculture nonetheless poses a strong threat to conservationists because  
680 the strategy for winning over Maasai pastoralists to the cause of wildlife habitat preservation is partly  
681 based on opportunity costs — i.e., attracting Maasai residents to conservation- and tourism-related  
682 jobs with wages that exceed income from livestock and crops. While it is difficult to predict how long  
683 the Amboseli tomato boom is set to endure, conservation NGOs may struggle for some time to outbid  
684 the profitability of tomato cropping. Additionally, while agriculture in Amboseli has until now rarely  
685 been in direct competition with wildlife conservation because the expansion of cash crops is  
686 hampered by access to water, (i) grabbing of water resources by powerful individuals for agriculture  
687 and (ii) landscape fragmentation by fencing both have insidious impacts on key components of wildlife  
688 survival. Strategies for furthering conservation goals are thus limited to finding ways of restricting the  
689 expansion of agriculture, or to re-incentivising cattle transhumance while seeking to reduce shoat  
690 loads, which exacerbate soil degradation. Emphasis on the positive effects of cattle loads on savanna  
691 biodiversity and ecosystem services is one of the evidence-based narratives that can achieve this  
692 (reported by a conservationist working for one of the main NGOs; see also Reid, 2012).

693 Approaching the microeconomics of farming on Mbirikani goup ranch from a historical perspective  
694 (Table 2) has shown how the government's push in favour of ranching as a solution to rangeland  
695 management (1968), followed by 'fortress' conservation (1974, 1983), ended up amputating land use  
696 options for Kisongo Maasai pastoralists and driving them into an accelerated transition from full-time  
697 pastoralism to agro-pastoralism. They are now facing some unforeseen consequences of those policy  
698 choices made barely 50 years ago. Steering the pastoralism–agriculture–wildlife nexus out of this  
699 impasse and towards new viable trajectories is an acute challenge for the near future, with few easy

700 options beyond reopening the national parks to a negotiated coexistence between wildlife and  
701 pastoralism, and perhaps steering subdivision of the four remaining, unsubdivided group ranches of  
702 the area (Fig. 1) towards imaginative and flexible negotiated solutions. Pastoral producers in Kenya  
703 thus continue to face the dilemma of “being caught between new land tenure rules associated with  
704 the dissolution of group ranches and subdivision of communal rangelands, and the unchanged  
705 ecological exigencies of their dryland systems” (BurnSilver and Mwangi, 2007). The pull of agriculture  
706 is a relatively new component to that dilemma, adding to the acuteness and complexity of the issues  
707 facing the sustainability of East-African pastoralism and wildlife conservation.

708

## 709 **6. Conclusion**

710 Maasai pastoralism is continually evolving and is currently integrating cash-crop agriculture. Pastoral  
711 production not only intersects with crop farmers, commodity traders, and other components of the  
712 rural economy, but in southern Kenya it is evolving into a mosaic of agro-pastoral production systems  
713 in which full-time pastoralism is diversifying. While mobile livestock herding is unlikely to disappear,  
714 and while the ongoing transition does not foreshadow any easily predictable or pre-ordained  
715 endpoint, tomato cultivation is transformative because it raises household revenue to much higher  
716 levels than pastoralism. It also undermines conservationist agendas, which commonly endeavour to  
717 make employment in wildlife conservation profitable so that pastoralists continue to engage in  
718 conservation-related strategies (Norton-Griffiths and Southey, 1995). Conservation NGOs, however,  
719 often cannot outcompete irrigated agriculture. This partly explains why Kenya — and Africa more  
720 widely as a result of the park tourism crash during the Covid-19 pandemic years of 2020–2021 — is  
721 seeking new ways of funding conservation through international strategies (pan-African and beyond)  
722 rather than by relying on local but volatile differentials in rural livelihood diversification opportunities.

723

724

725 **Acknowledgements**

726 We thank two anonymous reviewers for their detailed, thoughtful and constructive comments. We  
727 acknowledge the Agence Nationale de la Recherche (ANR, France) for supporting the research  
728 program ANR-16-CE03-0004 MaGNUM.

729

730 **References**

731 Adunga, E., 2013. Factors influencing income level of agro-pastoral communities. *Int. J Soc. Econ.* 40,  
732 207–219. <https://doi.org/10.1108/03068291311291509>

733 Aktipis, C.A., Cronk, L., de Aguiar, R., 2011. Risk-pooling and herd survival: an agent-based model of a  
734 Maasai gift-giving system. *Hum. Ecol.* 39, 131–140. [https://doi.org/10.1007/s10745-010-](https://doi.org/10.1007/s10745-010-9364-9)  
735 9364-9

736 Alary, V., Corniaux, C., Gautier, D., 2011. Livestock's contribution to poverty alleviation: how to  
737 measure it? *World Development* 39, 1638–1648.  
738 <https://doi.org/10.1016/j.worlddev.2011.02.008>

739 Altmann, J., Alberts, S.C., Altmann, S.A., Roy, S.B., 2002. Dramatic change in local climate patterns in  
740 the Amboseli basin, Kenya. *Afr. J. Ecol.* 40, 248–251. [https://doi.org/10.1046/j.1365-](https://doi.org/10.1046/j.1365-2028.2002.00366.x)  
741 2028.2002.00366.x

742 Århem, K., 1989. Maasai food symbolism: the cultural connotations of milk, meat, and blood in the  
743 pastoral Maasai diet. *Anthropos* 84, 1–23.

744 Ariga, J., Jayne, T., 2011. Factors driving the increase in fertilizer use by smallholder farmers in Kenya,  
745 1990-2007. In: Chuham-Pole, P., Angwafo, M., Editors, 2011. *Yes Africa Can - Success Stories*  
746 *from a Dynamic Continent*, The World Bank, Washington D.C.

747 Aryal, S., Maraseni, T., Cockfield, G., de Bruyn, L.L., 2018. Transhumance, livestock mobility and mutual  
748 benefits between crop and livestock production. In: Lichtfouse, E. (Ed.), *Sustainable*

749 Agriculture Reviews 31: Biocontrol, Springer International Publishing, Cham.  
750 [https://doi.org/10.1007/978-3-319-94232-2\\_2](https://doi.org/10.1007/978-3-319-94232-2_2)

751 Aubron, C., Lehoux, H., Lucas, C., 2015. Poverty and inequality in rural India. Reflections based on two  
752 agrarian system analyses in the state of Gujarat. *EchoGéo* 32.  
753 <https://doi.org/10.4000/echogeo.14300>

754 Aubron, C., Noël, L., Lasseur, J., 2016. Labor as a driver of changes in herd feeding patterns: evidence  
755 from a diachronic approach in Mediterranean France and lessons for agroecology. *Ecological*  
756 *Economics* 127, pp. 68-79. <https://doi.org/10.1016/j.ecolecon.2016.02.013>

757 Babiker, M., 2002. Introduction (from decline to survival in East African drylands). In: Babiker, M. (Ed.),  
758 Resource Alienation, Militarisation and Development Case Studies from East African Drylands.  
759 Organization for Social Science Research in Eastern and Southern Africa, Addis Ababa.

760 Behnke, R.H., 1985. Measuring the benefits of subsistence versus commercial livestock production in  
761 Africa. *Agric. Syst.* 16, 109–135. [https://doi.org/10.1016/0308-521X\(85\)90003-4](https://doi.org/10.1016/0308-521X(85)90003-4)

762 Bierschenk, T., Forster, R., 1991. Bierschenk, T., Forster, R., 1991. Rational herdsmen. Economic  
763 strategies of the agropastoral Fulani of Northern Benin. *Appl. Geogr. Dev.* 38, 110–128.

764 Biss, K., Ho, K.-J., Mikkelsen, B., Lewis, L., Taylor, C.B., 1971. Some unique biologic characteristics of  
765 the Masai of East Africa. *N. Engl. J. Med.* 284, 694–699.

766 Blackie, J.R., 1977. Rangeland management and ecology in East Africa. Hodder and Stoughton, London.

767 Boles, O.J.C., Shoemaker, A., Courtney Mustaphi, C.J., Petek, N., Ekblom, A., Lane, P.J., 2019. Historical  
768 ecologies of pastoralist overgrazing in Kenya: long-term perspectives on cause and effect.  
769 *Hum. Ecol.* 47, 419–434. Bond, J., 2014. A holistic approach to natural resource conflict: The  
770 case of Laikipia County, Kenya. *J. Rural Stud.* 34, 117–127.  
771 <https://doi.org/10.1016/j.jrurstud.2014.01.008>

772 Briscoe, J., 1996. Water as an economic good : the idea and what it means in practice. Presented at  
773 the World Congress of the International Commission on Irrigation and Drainage,  
774 Cairo. BurnSilver, S., and Mwangi, E., 2007. Beyond Group Ranch subdivision: collective action



775 for livestock mobility, ecological viability and livelihoods. International Food Policy Research  
776 Institute (IFPRI), CAPRI Working Papers 66.

777 BurnSilver, S.B., Worden, J., Boone, R.B., 2008. Processes of fragmentation in the Amboseli ecosystem,  
778 Southern Kajiado district, Kenya, in: Galvin, K.A., Reid, R.S., Behnke, R.H., Jr, Thompson Hobbs,  
779 N. (eds), *Fragmentation in Semi-Arid and Arid Landscapes*. Springer, Dordrecht, Netherlands,  
780 pp. 225–253.

781 Catley, A., Lind, J., Scoones, I., 2016. The futures of pastoralism in the Horn of Africa: pathways of  
782 growth and change. *Revue Scientifique et Technique de l'OIE* 35, 389–403.  
783 <https://doi.org/10.20506/rst.35.2.2524>

784 Climate-data.org, 2018. Monthly rainfall and temperature dataset – Amboseli – Years of relevance:  
785 1999–2019 [WWW Document]. Climate-data.org. URL [https://fr.climate-](https://fr.climate-data.org/info/sources/)  
786 [data.org/info/sources/](https://fr.climate-data.org/info/sources/) (accessed 10.1.18).

787 Coast, E., 2002. Maasai socioeconomic conditions: a cross-border comparison. *Hum. Ecol.* 30, 79–105.  
788 <https://doi.org/10.1023/A:1014567029853>

789 Cochet, H., 2015. *Comparative Agriculture*. Springer, Netherlands.

790 Cochet, H., 2012. The systeme agraire concept in francophone peasant studies. *Geoforum* 43, 128–  
791 136. <https://doi.org/10.1016/j.geoforum.2011.04.002>

792 Couty, P., Winter, G., 1983. Qualitatif et quantitatif : deux modes d'investigation complémentaires.  
793 *Réflexions à partir des recherches de l'ORSTOM en milieu rural africain*. Brochure AMIRA 1.

794 Davies, J., Hatfield, R., 2007. The economics of mobile pastoralism: a global summary. *Nomadic*  
795 *Peoples* 11, 91–116.

796 Delarue, J., Cochet, H., 2013. Systemic impact evaluation: a methodology for complex agricultural  
797 development projects. The case of a contract farming project in Guinea. *Eur. J. Dev. Res.* 25,  
798 778–796. <https://doi.org/10.1057/ejdr.2013.15>

799 Ellis, J., Galvin, K.A., 1994. Climate patterns and land-use practices in the dry zones of Africa:  
800 comparative regional analysis provides insight into the effects of climate variations.  
801 *BioScience* 44, 340–349. <https://doi.org/10.2307/1312384>

802 Fratkin, E., 2001. East African pastoralism in transition: Maasai, Boran, and Rendille cases. *Afr. Stud.*  
803 *Rev.* 44, 1–25. <https://doi.org/10.2307/525591>

804 Fratkin, E., 1997. Pastoralism: governance and development issues. *Annu. Rev. Anthropol.* 26, 235–  
805 261. <https://doi.org/10.1146/annurev.anthro.26.1.235>

806 Galaty, J.G., 1999. *Grounding pastoralists: law, politics, and dispossession in East Africa*. White Horse  
807 Press.

808 Galaty, J.G., 1992. “The land is yours”: social and economic factors in the privatization, sub-division  
809 and sale of Maasai ranches. *Nomad. Peoples* 30, 26-40.

810 Galvin, K.A., Beeton, T.A., Boone, R.B., BurnSilver, S.B., 2015. Nutritional status of Maasai pastoralists  
811 under change. *Hum. Ecol.* 43, 411–424. <https://doi.org/10.1007/s10745-015-9749-x>

812 Gichohi, N., Warinwa, F., Lenaiyasa, P., Maina, M., Bornham, R., Sambu, D., Muruthi, P., Wasilwa, N.S.,  
813 2014. Long-term monitoring of livestock depredation in Amboseli ecosystem, Kenya. *J. Agric.*  
814 *Nat. Resour.* 1, 186–194.

815 Githumbi, E.N., Kariuki, R., Shoemaker, A., Courtney-Mustaphi, C.J., Chuhilla, M., Richer, S., Lane, P.,  
816 Marchant, R., 2018. Pollen, people and place: multidisciplinary perspectives on ecosystem  
817 change at Amboseli, Kenya. *Frontiers in Earth Science* 5.  
818 <https://doi.org/10.3389/feart.2017.00113>

819 Gulyani, S., Talukdar, D., Kariuki, R.M., 2005. Water for the urban poor: water markets, household  
820 demand and service preferences in Kenya. Water Supply and Sanitation Sector Board  
821 Discussion Paper Series 40.

822 Hodgson, D.L., 1999. Women as children : culture, political economy and gender inequality among  
823 Kisongo Maasai. *Nomad. Peoples* 3, 115–130.

824 Homewood, K., 2009. Policy and practice in Kenya rangelands: impacts on livelihoods and wildlife. In:  
825 Homewood, K., Kristjanson, P., Trench, P.C. (eds), *Staying Maasai? Livelihoods, Conservation*  
826 *and Development in East African Rangelands; Studies in Human Ecology and Adaptation.*  
827 Springer, New York. [https://doi.org/10.1007/978-0-387-87492-0\\_9](https://doi.org/10.1007/978-0-387-87492-0_9)

828 Homewood, K.M., Rodgers, W.A., 1991. *Maasailand ecology: pastoralist development and wildlife*  
829 *conservation in Ngorongoro, Tanzania.* Cambridge University Press.

830 Homewood, K.M., Rodgers, W.-A., 1984. Pastoralism and conservation. *Hum. Ecol.* 12, 431–441.  
831 <https://doi.org/10.1007/BF01531127>

832 Kategile, J.A., Mubi, S., 1993. Future of livestock industries in east and southern Africa. Proceedings of  
833 the workshop held at Kadoma Ranch Hotel, Zimbabwe, 20-23 July 1992. International  
834 Livestock Centre for Africa, Addis Ababa.

835 Kenya Wildlife Service, 2017. Amboseli rainfall database (1968–2017).

836 Kibugi, R.M., 2009. A failed land use legal and policy framework for the African Commons? Reviewing  
837 rangeland governance in Kenya. *J. Land Use* 24, 309–336.

838 Kimani, K., Pickard, J., 1998. Recent trends and implications of group ranch sub-division and  
839 fragmentation in Kajiado District, Kenya. *Geogr. J.* 164, 202–213.  
840 <https://doi.org/10.2307/3060370>

841 King, J.M., Sayers, A.R., Peacock, C.P., Kontrohr, E., 1984. Maasai herd and flock structures in relation  
842 to livestock wealth, climate and development. *Agric. Syst.* 13, 21–56.  
843 [https://doi.org/10.1016/0308-521X\(84\)90054-4](https://doi.org/10.1016/0308-521X(84)90054-4)

844 KNBS, 2018. Basic report on well-being in Kenya based on the 2015/16 Kenya integrated Household  
845 Budget survey (KIHBS). Kenya national Bureau of statistics, Nairobi, Kenya.

846 Krätli, S., Schareika, N., 2010. Living off uncertainty: the intelligent animal production of dryland  
847 pastoralists. *Eur J Dev Res* 22, 605–622. <https://doi.org/10.1057/ejdr.2010.41>

848 Kuria, S.G., Mwaura, J.M., Kinyua, M.G., Nduma, B., Okoti, M., 2015. Adapting dryland livestock  
849 production to meet climate change challenges in Kenya. *International Development Research*

850 Center. [online: <https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/54167/IDL->  
851 [54167.pdf?sequence=1&isAllowed=y](https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/54167/IDL-54167.pdf?sequence=1&isAllowed=y)]

852 Lacoste, M., Lawes, R., Ducourtieux, O., Flower, K., 2018. Assessing regional farming system diversity  
853 using a mixed methods typology: the value of comparative agriculture tested in broadacre  
854 Australia. *Geoforum* 90, 183–205. <https://doi.org/10.1016/j.geoforum.2018.01.017>

855 Landais, E., 1994. Des rizières et des vaches. *Cahiers d’Etudes africaines* 34, 707–716.

856 Lesorogol, C.K., 2008. Land privatization and pastoralist well-being in Kenya. *Development and Change*  
857 39, 309–331. <https://doi.org/10.1111/j.1467-7660.2007.00481.x>

858 Lewis, A., 2015. Amboseli landscapes : maasaï pastoralism, wildlife conservation and natural resource  
859 management in Kenya, 1944-present. PhD thesis, Michigan State University.

860 Little, P.D., McPeak, J.G., Barrett, C.B., Kristjanson, P., 2008. Challenging orthodoxies: understanding  
861 poverty in pastoral areas of East Africa. Social Science Research Network, Rochester, NY.

862 Little, P.D., Smith, K., Cellarius, B.A., Coppock, D.L., Barrett, C., 2001. Avoiding disaster: diversification  
863 and risk management among East African herders. *Development and Change* 32, 401–433.  
864 <https://doi.org/10.1111/1467-7660.00211>

865 McCabe, J.T., Leslie, P.W., DeLuca, L., 2010. Adopting cultivation to remain pastoralists: the  
866 diversification of Maasai livelihoods in Northern Tanzania. *Hum. Ecol.* 38, 321–334.  
867 <https://doi.org/10.1007/s10745-010-9312-8>

868 Moritz, M., 2010. Crop–livestock interactions in agricultural and pastoral systems in West Africa.  
869 *Agriculture and Human Values* 27, 119–128. <https://doi.org/10.1007/s10460-009-9203-z>

870 Morris, J.R., 1988. Interventions for African pastoral development under adverse production trends  
871 (No. 16). African Livestock Policy Analysis Network Paper.

872 Ndagala, D.K., 1992. Territory, pastoralists, and livestock : resource control among the Kisongo  
873 Maasai. *Acta Universitatis Upsaliensis*, Uppsala University.

874 Njeru, E.H., 1984. The farming herders: irrigation, reciprocity and marriage among the Turkana  
875 pastoralists of north - Western Kenya. PhD thesis, University of California Santa Barbara.

876 Nkedianye, D.K., Ogutu, J.O., Said, M.Y., Kifugo, S., de Leeuw, J., Van Gardingen, P., Reid, R.S., 2019.  
877 Livestock-wealth inequalities and uptake of crop cultivation among the Maasai of Kenya and  
878 Tanzania. *World Development Perspectives* 14, 100–106.  
879 <https://doi.org/10.1016/j.wdp.2019.02.017>

880 Norton-Griffiths, M., Southey, C., 1995. The opportunity costs of biodiversity conservation in Kenya.  
881 *Ecological Economics* 12, 125–139. [https://doi.org/10.1016/0921-8009\(94\)00041-S](https://doi.org/10.1016/0921-8009(94)00041-S)

882 Ntiati, P., 2002. Group ranches subdivision study in Loitokitok division of Kajiado District, Kenya  
883 (Working Paper). International Livestock Research Institute, Nairobi.

884 Ojwang', G. O., Wargute, P. W., Said, M. Y., Worden, J. S., Davidson, Z., Muruthi, P., Kanga, E., Ihwagi,  
885 F., Okita-Ouma, B., 2017. Wildlife migratory corridors and dispersal areas: Kenya rangelands  
886 and coastal terrestrial ecosystems (Kenya vision 2030), Kenya Rangelands and Coastal  
887 Terrestrial Ecosystems. Ministry of Environment and Natural Resources, Nairobi, Kenya.

888 Okello, M.M., D'Amour, D.E., 2008. Agricultural expansion within Kimana electric fences and  
889 implications for natural resource conservation around Amboseli National Park, Kenya. *Journal*  
890 *of Arid Environments* 72, 2179–2192. <https://doi.org/10.1016/j.jaridenv.2008.07.008>

891 Peacock, C.P., 1987. Herd movement on a Maasai group ranch in relation to traditional organisation  
892 and livestock development. *Agricultural Administration and Extension* 27, 61–74.  
893 [https://doi.org/10.1016/0269-7475\(87\)90018-3](https://doi.org/10.1016/0269-7475(87)90018-3)

894 Peron, X., 1995. L'occidentalisation des Maasai du Kenya : Privatisation foncière et déstructuration  
895 sociale. L'Harmattan, Paris.

896 Pollini, J., Galaty, J. G., 2021. Resilience through adaptation: innovations in Maasai livelihood  
897 strategies. *Nomadic Peoples* 25, 278–311. <https://doi.org/10.3197/np.2021.250206>

898 Powell, J.M., Williams, T.O., 1994. An overview of mixed farming systems in sub-Saharan Africa. In:  
899 Powell, J.M., Fernandez-Rivera, S., Williams, T.O., Renard, C. (eds), *Livestock and sustainable*  
900 *nutrient cycling in mixed farming systems of sub-saharan Africa*. Proceedings of an

901 international conference, ILCA (International Livestock Centre for Africa), Addis Ababa, pp.  
902 21–36.

903 Reid, R., 2012. *Savannas of our birth: People, Wildlife, and Change in East Africa*. University of  
904 California Press.

905 Ridder, R. de, Keulen, H. van, Seligman, N.G., Neate, P.J.H., 1986. Modelling of extensive livestock  
906 production systems. Proceedings of the ILCA/ARO/CABO Workshop, Aro, Bet Dagan, Israel 5-  
907 9 February 1985. ILCA, Addis Ababa.

908 Rufino, M.C., Thornton, P.K., Ng'ang'a, S.K., Mutie, I., Jones, P.G., van Wijk, M.T., Herrero, M., 2013.  
909 Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty.  
910 *Agriculture, Ecosystems & Environment* 179, 215–230.  
911 <https://doi.org/10.1016/j.agee.2013.08.019>

912 Rutten, M., 2005. *Shallow wells: A sustainable and inexpensive alternative to boreholes in Kenya*. ASC  
913 Working Paper Series 30.

914 Rutten, M., 1992. *Selling wealth to buy poverty: The process of the individualization of landownership*  
915 *among the Maasai pastoralists of Kajiado District, Kenya, 1890-1990*. Verlag, Saarbrücken.

916 Said, M.Y., Ogutu, J.O., Kifugo, S.C., Makui, O., Reid, R.S., Leeuw, J. de, 2016. Effects of extreme land  
917 fragmentation on wildlife and livestock population abundance and distribution. *Journal for*  
918 *Nature Conservation* 34, 151–164. <https://doi.org/10.1016/j.jnc.2016.10.005>

919 Salzman, P.C., 1980. *When nomads settle: processes of sedentarization as adaptation and response*.  
920 Praeger Publishers, New York.

921 Scarpa, R., Ruto, E., Kristjanson, P., Radeny, M., Drucker, A., Rege, J., 2003. Valuing indigenous cattle  
922 breeds in Kenya: an empirical comparison of stated and revealed preference value estimates.  
923 *Ecological Economics* 45, 409–426. [https://doi.org/10.1016/S0921-8009\(03\)00094-6](https://doi.org/10.1016/S0921-8009(03)00094-6)

924 Scoones, I., 2021. Beyond the 'Balance of Nature': pastoralists' alternative perspectives on  
925 sustainability. PASTRES blog [[https://pastres.org/2021/04/30/beyond-the-balance-of-nature-](https://pastres.org/2021/04/30/beyond-the-balance-of-nature-pastoralists-alternative-perspectives-on-sustainability/)  
926 [pastoralists-alternative-perspectives-on-sustainability/](https://pastres.org/2021/04/30/beyond-the-balance-of-nature-pastoralists-alternative-perspectives-on-sustainability/)].

927 Scoones, I., 2020. Pastoralists and peasants: perspectives on agrarian change. *Journal of Peasant*  
928 *Studies* 48, 1–47.

929 Scoones, I., 1995. Living with uncertainty: new directions in pastoral development in Africa. Institute  
930 Of Development Studies, London.

931 Scoones, I., Graham, O., 1994. New directions for pastoral development in Africa. *Development in*  
932 *Practice* 4, 188–198. <https://doi.org/10.1080/096145249100077821>

933 Spear, T.T., Waller, R.D., 1993. *Being Maasai: Ethnicity & Identity in East Africa*. James Currey  
934 Publishers.

935 Stavi, I., Roque de Pinho, J., Paschalidou, A.K., Adamo, S.B., Galvin, K., de Sherbinin, A., Even, T.,  
936 Heaviside, C., van der Geest, K., 2021. Food security among dryland pastoralists and  
937 agropastoralists: The climate, land-use change, and population dynamics nexus. *The*  
938 *Anthropocene Review*. <https://doi.org/10.1177/20530196211007512>

939 Swallow, B.M., Bromley, D.W., 1995. Institutions, governance and incentives in common property  
940 regimes for African rangelands. *Environmental and Resources Economics* 6, 99–118.  
941 <https://doi.org/10.1007/BF00691679>

942 Swynnerton, 1954. A plan to intensify the development of African agriculture in Kenya. Colony and  
943 Protectorate of Kenya, Nairobi, Kenya.

944 Tolera, A., Abebe, A., 2007. Livestock production in pastoral and agro-pastoral production systems of  
945 southern Ethiopia. *Livestock Research for Rural Development* 19.

946 Ulrich, A., Ifejika Speranza, C., Roden, P., Kiteme, B., Wiesmann, U., Nüsser, M., 2012. Small-scale  
947 farming in semi-arid areas: Livelihood dynamics between 1997 and 2010 in Laikipia, Kenya. *J.*  
948 *Rural Stud.* 28, 241–251. <https://doi.org/10.1016/j.jrurstud.2012.02.003>

949 Unks, R., Goldman, M., Mialhe, F., Roque de Pinho, J., 2021. "People should also look after the people":  
950 relational values of wildlife and collectively titled land in Ilkisongo Maasai group ranches in  
951 Southern Kenya. *Ecology and Society* 26(3):28. <https://doi.org/10.5751/ES-12539-26032>

952 Veit, P., 2011. Rise and fall of group ranches in Kenya. World Resources Institute (WRI), Landesa Rural  
953 Development Institute.

954 Waller, R., 1988. Emutai: crisis and response in Maasailand 1883–1902. In: Johnson, D.H., Anderson,  
955 D.M., Editors, *The Ecology of Survival: Case Studies from North African History*. Routledge.

956 Weesie, R., García, A., 2018. From herding to farming under adaptation interventions in Southern  
957 Kenya: a critical perspective. *Sustainability* 10 (12), 4386.  
958 <https://doi.org/10.3390/su10124386>

959 West, P., Igoe, J., Brockington, D., 2008. *Parks and peoples: the social impact of protected areas*. *Annu.*  
960 *Rev. Anthropol.* 35, 261–277. <https://doi.org/10.1146/annurev.anthro.35.081705.123308>

961 Western, D., 1997. *In the dust of Kilimanjaro*. Island Press, Washington D.C.

962 Western, D., Finch, V., 1986. Cattle and pastoralism: Survival and production in arid lands. *Hum. Ecol.*  
963 14, 77–94. <https://doi.org/10.1007/BF00889211>

964 Western, D., Nightingale, D.M., 2003. Environmental change and the vulnerability of pastoralists to  
965 drought: a case study of the Maasai in Amboseli, Kenya. UNEP, Nairobi.

966 Western, D., Sindiyo, D.M., 1972. The status of the Amboseli rhino population. *Afr. J. Ecol.* 10, 43–57.  
967 <https://doi.org/10.1111/j.1365-2028.1972.tb00857.x>

968 Woodhouse, P., 2003. African enclosures: a default mode of development. *World Development* 31,  
969 1705–1720.

970 Zaal, F., 2011. Pastoral integration in East African livestock markets: linkages to the livestock value  
971 chain for Maasai pastoral subsistence and accumulation. In: Le Heron, R., Gertel, J. (eds),  
972 *Economic Spaces of Pastoral Production and Commodity Systems, Markets and Livelihoods*.  
973 Routledge, London, pp. 107–126.

974 Zhang, R., Yeh, E.T., Tan, S., 2021. Marketization induced overgrazing: The political ecology of  
975 neoliberal pastoral policies in Inner Mongolia. *J. Rural Stud.* 86, 309–317.  
976 <https://doi.org/10.1016/j.jrurstud.2021.06.008>

977