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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

26 **1. Introduction**

26

27 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).

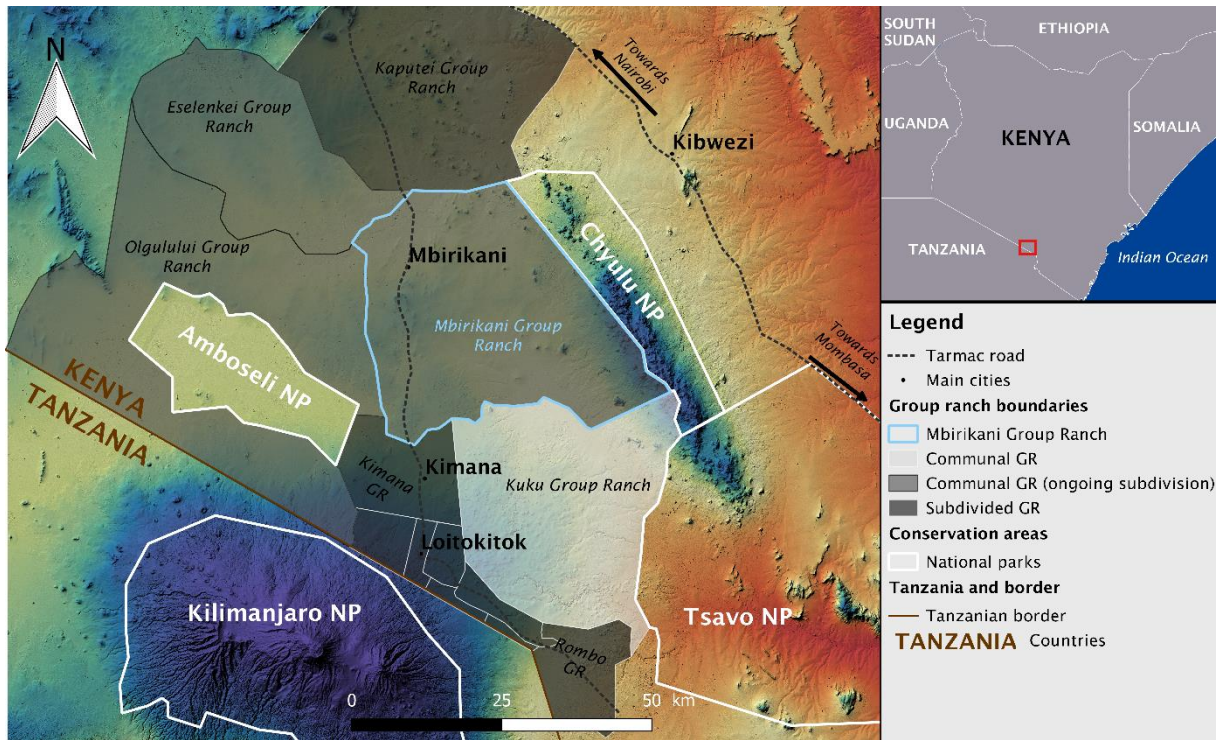
111 The pastoralist–peasant dichotomy having thus mostly outlived its relevance in many parts of the
112 world (Scoones, 2020), here we go beyond idealised anthropological categories or simplistic models
113 about rangeland management by recognising that mixed livelihood strategies exist among the Kisongo
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**

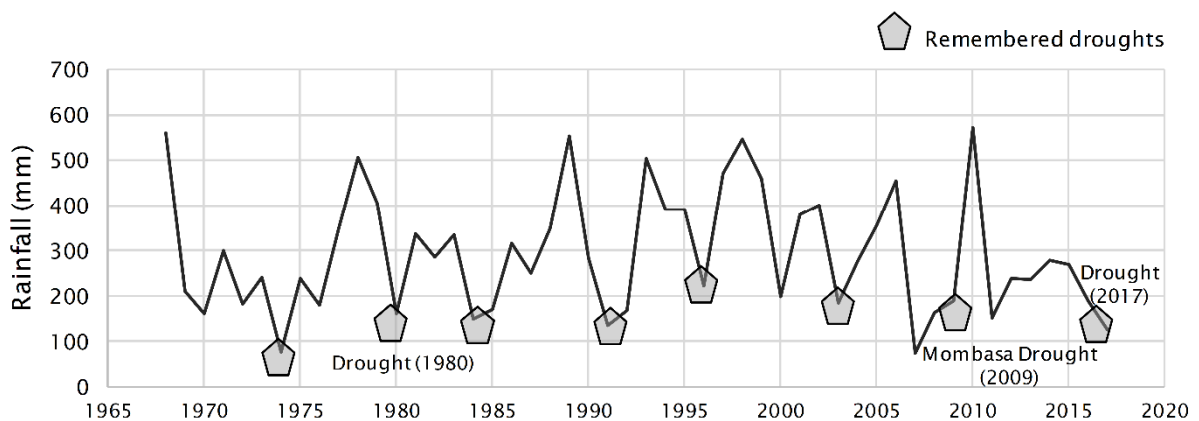
124 2.1. Physical landscape

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.



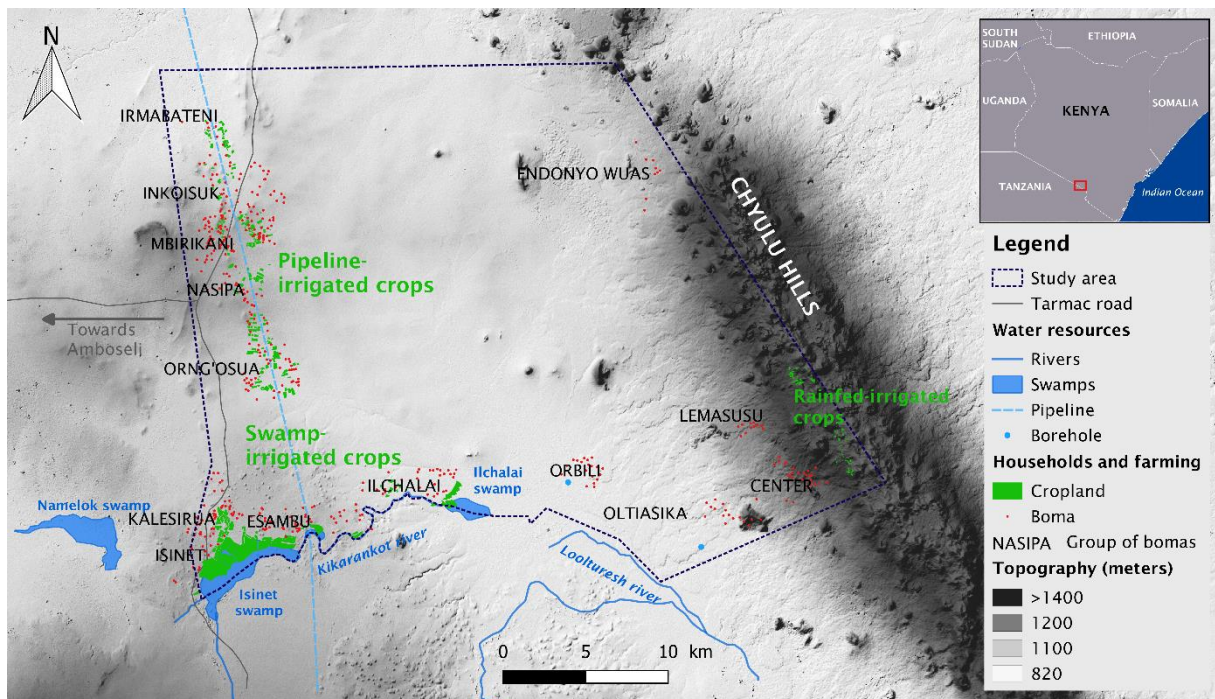
133
 134 **Fig. 1.** Study area location map. Topography generated from the ALOS World 3D Digital Elevation
 135 Model (ground resolution ~30 m)



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 km², 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 km²), 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).

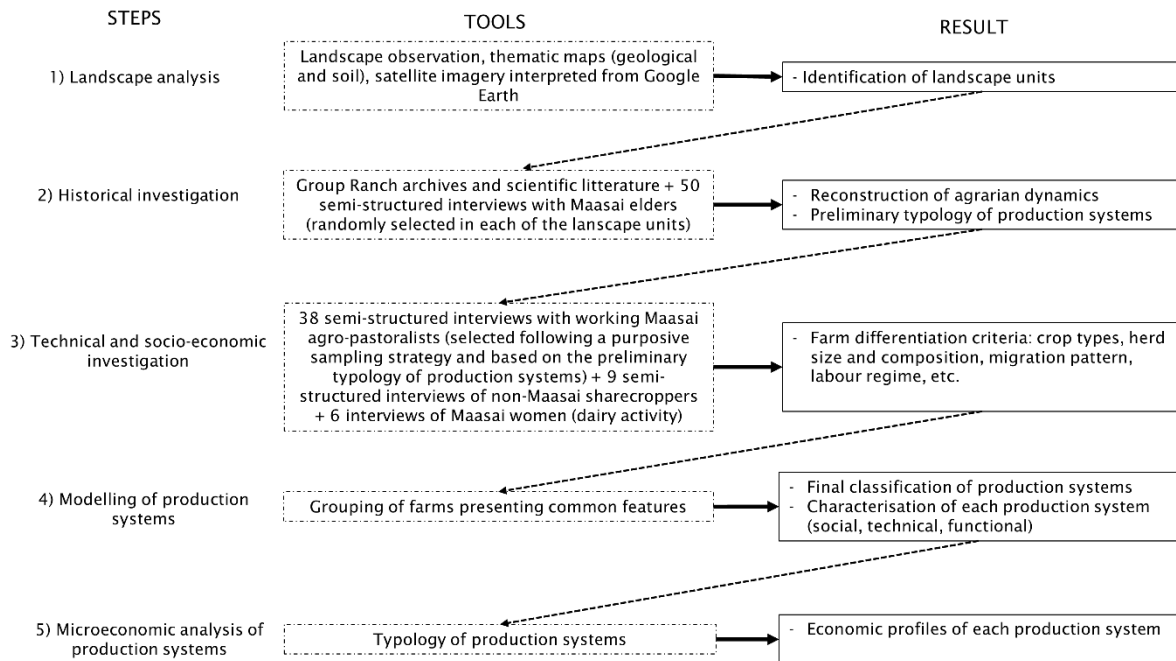
231 Livestock is living capital (Ridder et al., 1986). It provides goods consumed by the household, liquidities
232 from sales, or gifts (a currency in social capital). The overarching economic rationale of the system
233 consists in maximising milk production and herd size in order to cushion the impacts 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_{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/CEqU¹).

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

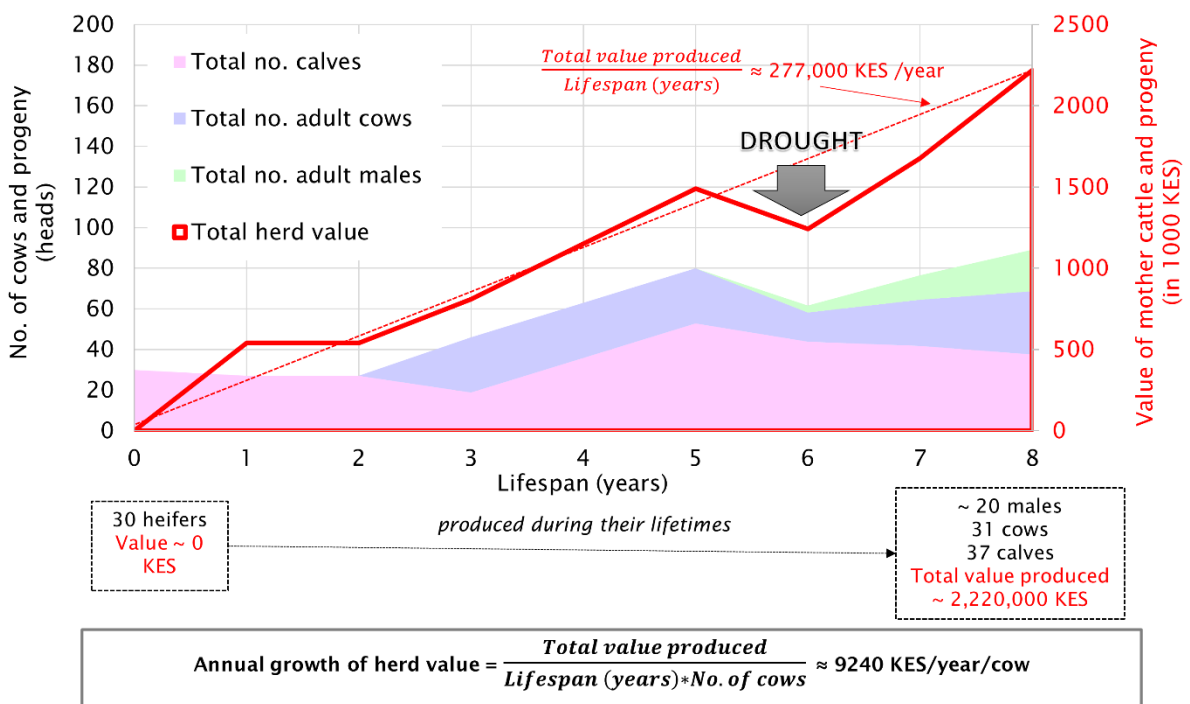
333 GP_{milk} equals a woman's milk harvest multiplied by the number of women in the household. There are
334 no outlets (e.g., dairy cooperatives) for selling milk locally. Household size thus sets a ceiling on
335 production needs. Maasai women use a calabash (*empokori*) to collect milk. One *empokori* 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

¹ 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

	Intermediary costs	Annual depreciation of fixed capital (wear and tear)
Livestock system	Watering of livestock	Truck (for livestock watering)
	Veterinary costs	Maintenance of <i>boma</i> fence
Cropping system	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 ¹ 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. ¹ 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.

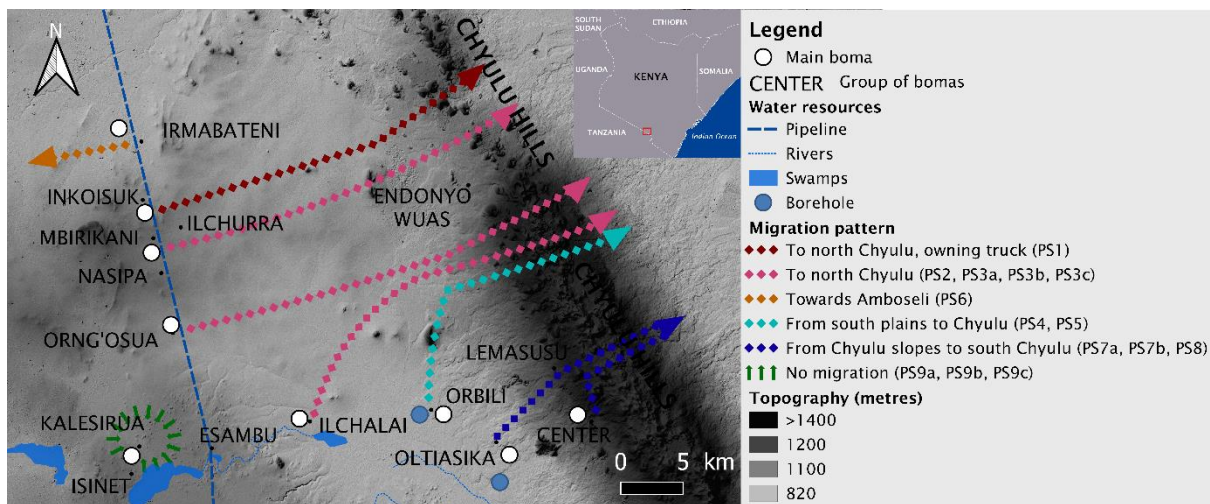
406 • The successive droughts of the early 1980s further led to the allotment of two acres of swamp
407 land per male ranch member. This process, however, was not a legally valid group ranch land
408 subdivision because the issued allotment letters were not recognised by the Kenyan state.
409 Cropping 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 (≥ 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 ¹	No. of CEQU	Cattle herd type (breed)	Migration pattern ²	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

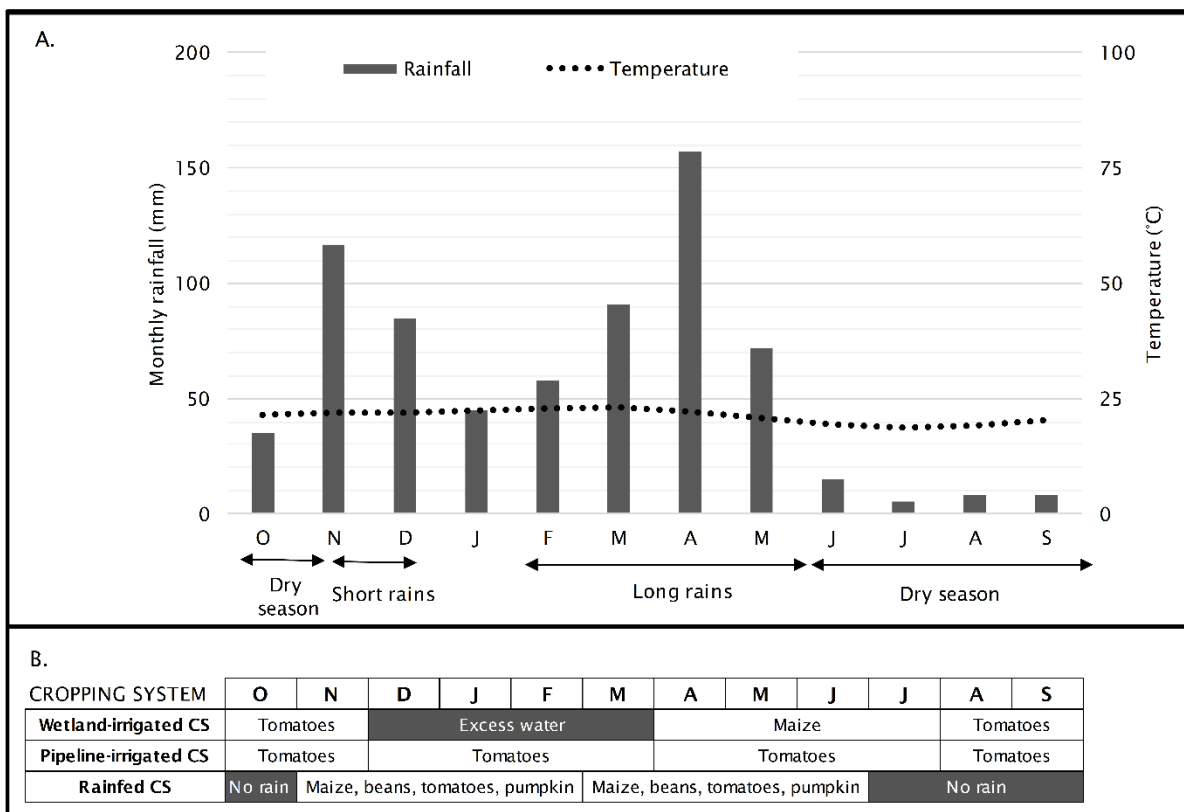
465 Notes. ¹ Number of sampled farms belonging to the production systems: PS1 ($n = 5$), PS2 ($n = 4$), PS3a ($n = 4$), PS3b ($n = 5$),
466 PS3c ($n = 3$), PS4 ($n = 1$), PS5 ($n = 1$), PS6 ($n = 3$), PS7a ($n = 4$), PS7b ($n = 0$ because this represents the scenario where PS7a
467 respects the prohibition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

468 ² 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 sharecroppers². 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,

² 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.

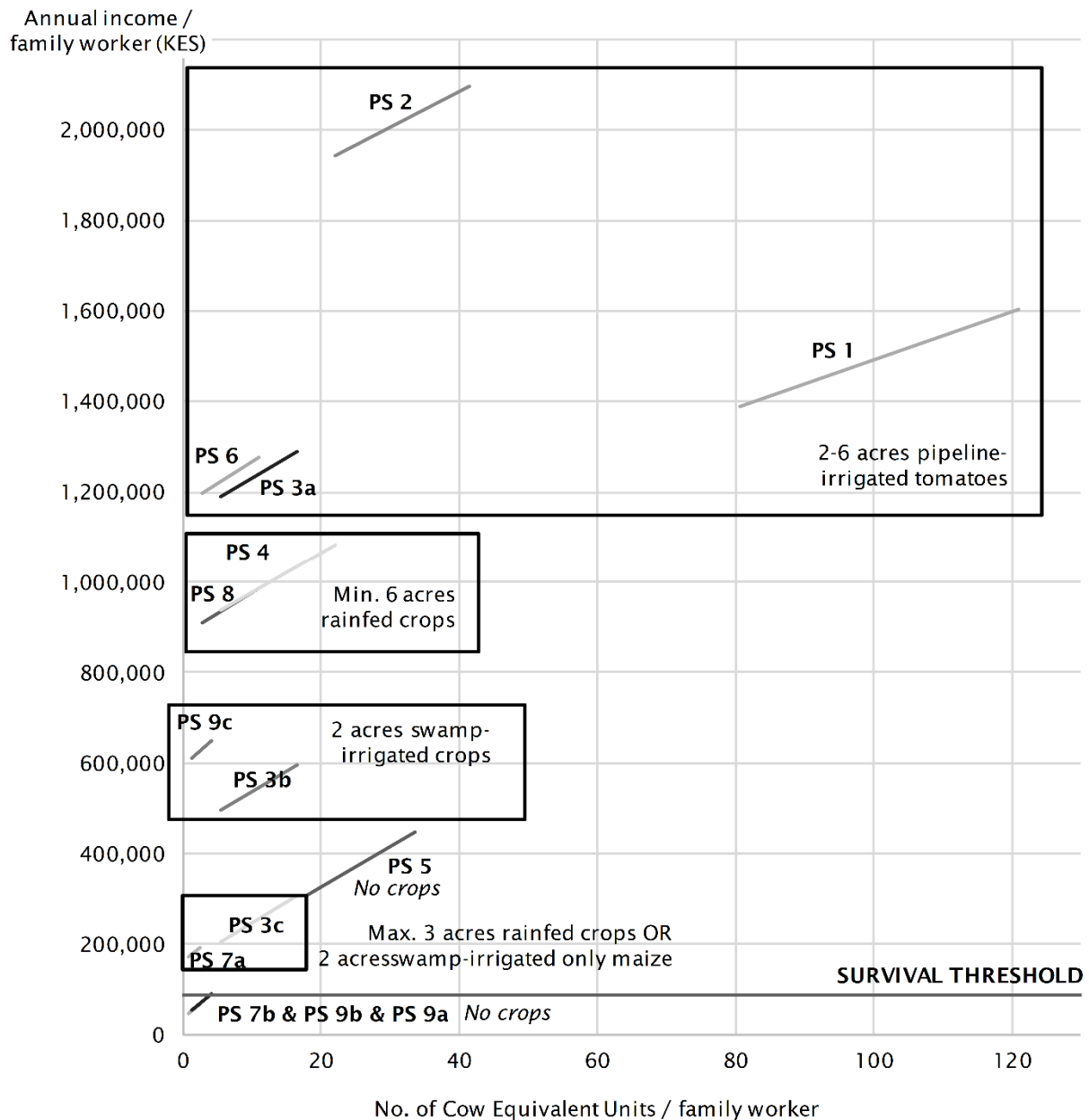
514 livestock offspring, manure for building huts, cash when sold). In terms of herd size, results reveal the
515 wide gap between the wealthiest (PS1, more than 400 heads) and poorest pastoralists (PS7, less than
516 15 heads). Most production systems have mixed breed herds, but some have fully adopted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

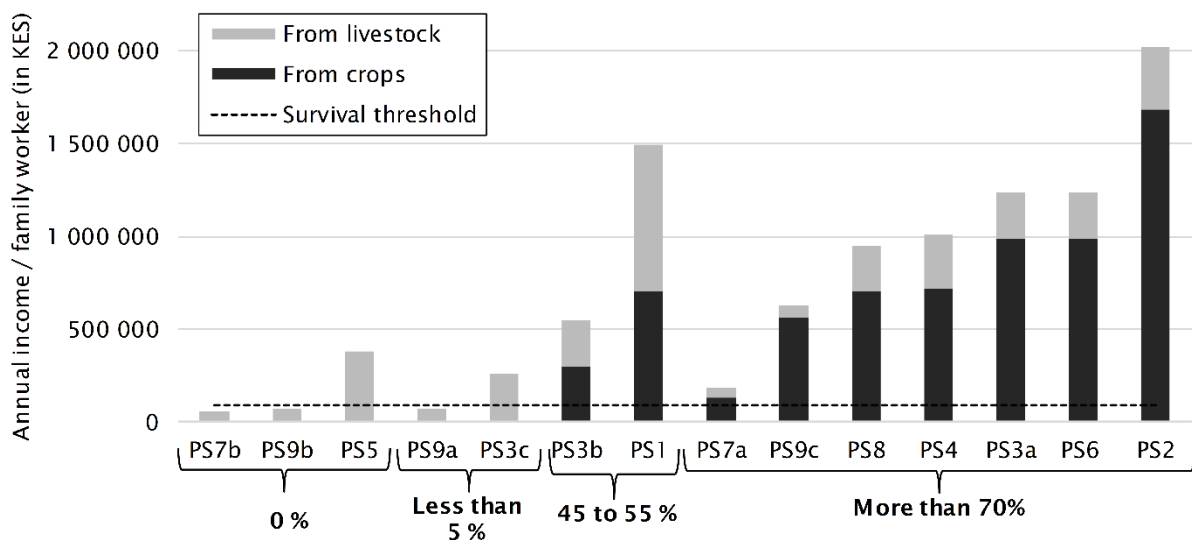


535

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 leased³ 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).



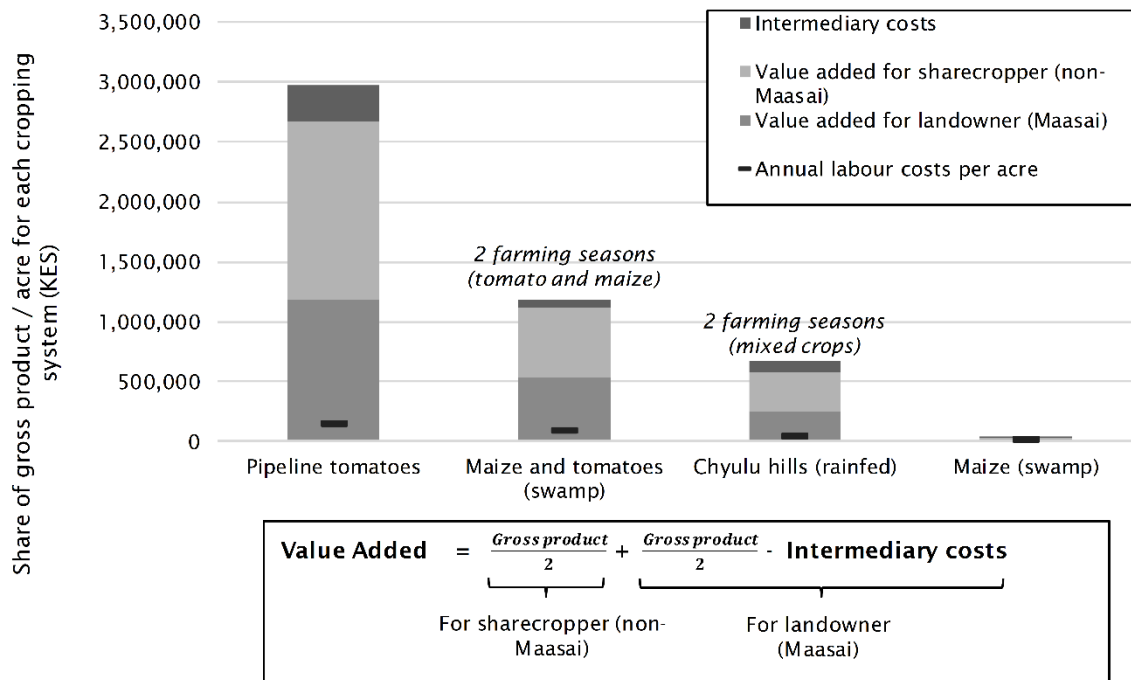
553
 554 **Fig. 9.** Annual income of production systems on Mbirikani group ranch by source of revenue (crops or
 555 livestock).

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

³ 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

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729

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