A community-based evaluation of population growth and agro-pastoralist resilience in Sub-Saharan drylands

Alfred Burian[a,b], Rebecca Karaya[c], Julia E. V. Wernersson[d,e], Mikael Egberth[f,g], Benjamin Lokorwa[h], Gert Nyberg[f]

[a] Sustainability Research Center, University of Derby, Kedleston Rd, Derby DE22 1GB, U.K.

[b] Department for Ecology, Environment and Plant Sciences, Stockholm University, 106 91 Stockholm, Sweden.

[c] Agriculture Economics and Extension Department; Karatina University, Karatina University, Main Campus, Kagochi, Karatina, Nyeri, P.O. Box 1957-10101 Kenya.

[d] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, DK-1958 Frederiksberg C, Denmark.

[e] International Livestock Research Institute (ILRI), P.O. Box 30709, Nairobi 00100, Kenya.

[f] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden.

[g] Department of Forest Resource Management, Swedish University of Agricultural Sciences, Sciences, 901 83 Umeå, Sweden.

[h] Vi Agroforestry Reigonal Office, P.O Box 457 67, 00100 Nairobi, Kenya

First author is corresponding author – email: flinserl@hotmail.com

Abstract

Human population growth is considered together with climate warming as major driver of change in Sub-Saharan Africa. Research on the implications of increased population densities often utilises community knowledge but without incorporating the view of local stakeholders. In this study, we applied a community-centred approach to direct and indirect consequences of population growth in drylands of north-western Kenya. Combined social, agricultural and geo-spatial analyses allowed us to identify major system transitions, determine their linkage to population growth and deduce consequences for local livelihoods and community resilience.

Community-members reported positive and negative consequences of fourfold population growth since 1974 but evaluated its overall effect as clearly beneficial. This overall positive effect was based on both, positive developments and the successful mitigation of potential system stressors. First, food security was maintained despite high growth rates because a shift from migratory pastoralism to a more labour-intensive agro-pastoralist system helped to increase agricultural productivity. Additionally, land-use changes were linked to land privatisation and improved erosion protection on private land, decoupling population growth from environmental degradation.

We, however, detected also early warning signs of reduced community resilience as households were unable to fully recover livestock densities after catastrophic events. A population-growth driven reduction in household land-sizes and the decreased monetary value of agricultural production were identified as drivers of this development. The extrapolation of our results to establish a general relationship between population densities, land-use and household resilience in Sub-Saharan drylands suggest that further system transformations will be required to ensure regional food-security.

1. Introduction

Human population in Sub-Saharan Africa is expected to show average annual growth rates of 2% and result in an increase by one billion people between 2015 and 2050, doubling the current population within the next 35 years (UNPD, 2015). Past population growth in Sub-Saharan Africa has been linked to economic challenges and contributed to an absolute increase of people living in extreme poverty (World-Bank-Group, 2016). Consequently, Sub-Saharan Africa shows stagnant poverty rates since the early 1990s and currently hosts half of the world's population with an income of less than 1.90$ day^{-1} (World-Bank-Group, 2016).

Local demographic growth will likely be accompanied by climatic changes above global rates (IPCC, 2014; Thornton et al., 2014) and mean temperature rises of 2.5 to 6 ˚C until the end of the century (Niang et al., 2014). Even more important than net changes might be projected increases in inter-annual and inter-seasonal variability (IPCC, 2012). Higher climatic fluctuations and associated changes in the frequency and severity of heat stress and droughts (Dai, 2011; Trenberth et al., 2014) are substantially understudied (Thornton et al., 2014) but bear severe consequences for the provision of ecosystem services (Rowhani et al., 2011; Vasseur et al., 2014). Thus, a crucial question determining future development trajectories is how human population growth may affect the resilience of local communities to withstand extreme climatic events.

In arid and semi-arid regions, which account for 56% of Sub-Saharan Africa (Otte and Chilonda, 2002) and host a third of its population (FAO, 2000), traditional land-management practices are well adapted to high climate variability. Households predominantly engaged in migratory pastoralism and could thereby mitigate resource fluctuations (Bollig, 2006; Turner et al., 2014). Common landownership and the governance of rangelands by chiefs and elders facilitated flexible and relative drought resilient land management (Smucker and Wisner, 2008).

In the past decades, however, many pastoralist communities throughout Sub-Saharan Africa have reduced migratory practices, privatized community-owned land and switched to mixed agro-pastoralist land-uses (Jones and Thornton, 2009). Drivers of such shifts are diverse (Lesorogol, 2008), but higher population densities was a prerequisite to replace extensive practices by more labor-intensive land management techniques (Boyd and Slaymaker, 2000; Goodhue and McCarthy, 2009; Tiffen et al., 1994). Further, pastoralism and common land tenure has frequently been related to overgrazing and was long viewed as backward practice impeding development (Benjaminsen et al., 2006; Wernersson, 2018). Hence, many governments in East and South Africa endorsed sedentarisation and privatization to stimulate agricultural production and facilitate an easier administration of rural areas (Eriksen and Silva, 2009; Smucker and Wisner, 2008).

The implications of such land-use changes and population increases are strongly dependent on a number of different system properties (Maystadt and Duranton, 2014; Siedenburg, 2006; Tiffen et al., 1994). Key-factors supporting an overall positive development are (i) the suitability of the area to grow cash crops such as coffee or tea, (ii) the proximity to local and national markets, (iii) a moderate scarcity of land that promotes soil and water conservation measures, and (iv) policy support to prevent the collapse of social structures and institutions (Boyd and Slaymaker, 2000). If socio-ecological systems do not meet these criteria, population growth and associated reductions in the household land-sizes can trigger overexploitation of ecosystem services, environmental degradation and reduced drought resistance (Konig et al., 2013; Shiferaw et al., 2014). Together with the negative effects of habitat fragmentation (Hobbs et al., 2008), these developments increase the risk of poverty traps and decrease the adaptive potential of households (Barrett and Swallow, 2006).

The overall impact of privatisation, sedentarisation and population growth is further mediated by trade-offs at the household level. A switch to mixed agro-pastoralist systems may for example enhance average yearly production but increase drought vulnerability (Delgado et al.; Tache and Oba, 2010) and increase inequalities between rich and poor households (Lesorogol, 2003, 2008). Such trade-offs are often highly complex and can arguably best be evaluated by community members. Nevertheless, management decisions are frequently made at supra-regional levels with little or no community involvement (Behnke and Kerven, 2013; Whitfield and Reed, 2012). Furthermore, scientific studies might utilise community knowledge but even thorough assessments often fail to properly incorporate the view of local stakeholders in trade-off evaluation (Dietz et al., 2009).

Our aim in this study was to assess the impacts of past population growth on agricultural practices and socio-ecological dynamics in a small and relative homogenous area in West Pokot, Kenya. We combined complementing analyses of village maps, focus group discussions, on-farm interviews and satellite images to address the following specific objectives: (i) Identify major positive and negative socio-ecological developments in the last 30 years from a community perspective, (ii) determine if and how they were related to population growth and (iii) evaluate potential effects for drought resilience at the household level.

2. Methods

2.1 Site description

Our study area was the *sub-location* Pserum of West Pokot County in the Northern Rift Valley. The region is characterized by a semi-arid climate with a long-term average of 700 mm annual precipitation, monthly average temperatures between 20 and 22 ˚C and an elevation of 1600 – 1700 m (NDMA, 2014; Nyberg et al., 2015). Soils are heterogeneous but are mainly characterized as fragile and infertile (FAO, 2006). Prognoses of future climate conditions predict minor changes in average length of the growing season but substantial increases of inter-annual rainfall variability (IPCC, 2012).

Households belong predominantly to the people of Pokot and largely rely on subsistence agriculture as the agricultural sector provides food and cash needs for approximately 90 percent of the population (County Development Plan, 2012). Connectivity to urban centres is low with travel times of >5 hrs to large markets in Kisumu and Nairobi. Since the 1980s, a transition of land tenure has been noticed, community land has been privatized and seasonal livestock migrations reduced (Nyberg et al., 2015). The Kenyan government has in the past supported privatisation (Lengoiboni et al., 2010) and the NGO Vi-Agroforestry promoted during the late 1980s and early 1990s the construction of life-fences in the region, a measure often linked to privatisation (Wairore et al., 2016). Our study was focused on a relatively small area of ~10 km^2 because at larger scales, a high spatial heterogeneity in land tenure and management is typical for West Pokot and many rural communities in East Africa (Oostendrop and Zaal, 2012).

2.2 Data collection

Data on changes in population density, agricultural practices socio-economic conditions over time were collected through (i) qualitative interviews, (ii) gender-separated focus group discussions and (iii) semi-structured interviews between 12.2014 and 10.2015. Qualitative interviews were held with 10 selected key-informants, a vice-chief, a teacher, a catechist, an employee of a regional NGO and three male and three female farmers from different age classes (range: 18 to 68). Informants were interviewed on their opinion of social, ecological and economic effects of past population growth, which provided a baseline for designing questionnaires used in semi-structured interviews.

A total of six focus group discussions were organised in three villages. In each location, focus group discussions for 7-13 female and male participants was organized. Participants were encouraged to discuss the effects of population growth on their livelihoods and jointly identified the most important positive and negative consequences. Thereafter, a voting processes helped to determine the relative importance of positive and negative livelihood changes. Each participant could freely distribute five votes between beforehand identified positive and negative consequences of population growth, respectively (Two separate polls, multiple casts for one effect were possible).

Focus group participants further mapped the distribution of households in their village in 1975-1980 and during present days. Village size ranged between 1.9 to 2.6 km^2. Male farmers had a very detailed knowledge of past and present livestock numbers and crop plantation sizes of different households, which allowed us to collect estimates of people, life-stock and crop plantations per household.

Semi-structured, on-farm interviews were conducted with 30 households along two predefined transect lines. Interviews were made with either female or male household heads (12 f, 18 m) and households, which participated in focus group discussions, were excluded to prevent double assessments. Interviewees were asked to state the reasons for changes in (i) life-stock numbers, (ii) crop growing areas and (iii) vegetation cover and soil fertility. Interviewees enumerated changes since 1990, a time period also younger farmers could refer to. Questionnaires and detailed results are presented in appendix 1.

2.3 Geo-spatial analyses

Village maps created in focus group discussions were georeferenced to determine their exact size and position. The degree of land privatisation and habitat fragmentation was quantified by counting the number of fence crossing along virtually created transect lines within village boundaries. Therefore, a net of transect lines with 500 m grid length was laid in Google Earth Pro over high-resolution satellite images of 2002 and 2014, the only two years for which suitable images were available, and the number of fence crossings per km transect was counted (see supplementary information, Fig. S1). A 2.5 km transect walk to ground-truth satellite-based fence quantification revealed a 94% accuracy of fence identification.

Further, we aimed to test whether there was a relationship between population densities of sub-locations in West-Pokot and the degree of land privatisation. We first selected 12 sub-locations with similar, elevation and average annual rainfall to Pserum (NDMA, 2014; Table

S1) and then randomly selected 3-6 areas with a size of 1.9 km^2. We then repeated the quantification of fence crossings per km transect line as described above. This allowed us relate population densities in sub-location to the number of fence crossings km^{-1} transect line (see 2.4 for details).

Satellite images were further used to quantify the length of gullies in three randomly selected areas in Pserum (total area of 27.6 km^2, see Table S2 for coordinates). We defined gullies by the presence of erosion signs such as bare soil or erosion flutes. However, a smooth transition between gullies and seasonal rivers complicate their categorisation. To improve the accurateness of our satellite analysis, we hence used GPS ground survey data of gully occurrence in a 2.5 km^2 area for method calibration (see section S1 for further details).

2.4 Conceptual and statistical assessments

We synthesized the information generated in different approaches by creating a causal loop diagram of socio-economic relationships in the study area. The diagram illustrates the relationships between *key system variables* and important *external drivers*. Key system variables represent factors, which strongly affect local livelihoods and can be altered by internal system dynamics. External drivers affect system variables, but are largely unaffected by changes of internal dynamics. We reviewed the complexity of the causal loop diagram and only maintained variables and links for which strong evidence was available. We, therefore, acknowledge that system dynamics are potentially more complex and our analysis represent a simplified version of real interaction structures. Further, we want to state that we combined information from analyses with different time frames. Under ideal conditions, we would have recorded multiple data points over time and used identical investigation periods. However, each method had its specific limitations and data availability from West-Pokot County is generally very low. Hence, we attempted to compensate data insufficiencies by the combination of different methods and time scales during the compilation of our causal loop diagram.

We assessed differences between past and present (i) number of people, (ii) livestock and (iii) the area of crop plantations per household with paired Welch's t-tests. Relationships between these factors were explored in partial correlation analysis, which included village identity and year as covariates to account for systematic differences over time and space. We tested for normal distribution of variables and applied data transformations whenever necessary. Further, we compared the variance homogeneity of livestock and crop plantation possessions in 1975 and 2015 using Flinger's variance test for samples with unequal sample sizes to evaluate how the distribution of wealth within communities changed over time. The relationship between population densities and the number of fence-crossing per km transect line in sub-locations was analysed in a linear regression. Two models, one with log-log transformed data and one with untransformed data were created and compared using the Akaike Information Criterion (AIC) to determine whether the relationship was better described by linear or exponential models. Residuals were controlled for autocorrelation, variance homogeneity and the occurrence of other patterns. All statistical analyses were performed using the software program R (R Development Core Team, 2018).

3. Results

3.1 Positive and negative dimensions of demographic change

Governmental census data indicates high and continuous population growth rates of 3.22% per year since the 1979 in West-Pokot. Community members stated that population growth was related to a broad spectrum of social, ecological and economic developments (Fig. 1; see Fig. S3 for gender specific results). While both, positive and negative implications were reported, there was a broad consensus among community members that the overall effect of past population growth was clearly positive.

Most important positive effects of population growth were infrastructure improvements and better market access, which received 22 and 16% of positive votes, respectively. Landscape restoration, due to the construction of life fences and land privatization, was also seen as indirect result of population growth and were considered as slightly more important than cultural and religious effects of population growth (Fig. 1A). A major negative impact of population growth was decreased drinking water availability (28% of negative votes), which was mainly attributed to lower water quality. In contrast to the restoration of private land, farmers stated that higher population pressure led to the further degradation of community land and the reduction of on-farm soil fertility, which together received 18% of negative votes. Further negative effects of population growth were higher economic pressures due to life-style changes (17%) and decreased household land sizes (16%).

3.2 Changed agricultural practices

While average household size varied around 8.7 persons and showed no significant change over time ($df = 35$, $p = 0.65$), livestock numbers drastically decreased in average households (Fig. 2). Stock sizes of cattle, sheep and goats all declined by >80% resulting in a drop from 91 to 10 tropical livestock units (TLU) household^{-1} between 1975 and 2015. The area used for crop production, on the other hand, increased significantly from 1.4 to 2.5 ha household^{-1} ($df = 46$, $p < 0.01$). Such an increase represented an augmentation of the relative contribution of crop plantations to total farm area from 5.6 to 37.0%.

Stock sizes of cattle, goats and sheep were all positively correlated ($r > 0.64$, $p < 0.001$) and relative contributions of cattle to livestock increased with total livestock numbers household^{-1} ($r = 0.34$, $p < 0.001$). The number of persons household^{-1} was positively related to total livestock sizes and the crop plantation areas household^{-1} ($r > 0.18$; $p < 0.01$). The relative frequency of the main crop types changed over time with maize increasing and millet and sorghum decreasing ($df = 36$, $p < 0.001$; Table 1). Innovations in husbandry were the introduction of poultry (16.3 ± 9.0 chicken per household) and non-native livestock breeds. Non-native breeds, which require more resources and intensive care, were considered to be of major importance by 27% and of minor or no importance by 46 and 27% of interviewees, respectively. Analyses of the relative distribution of livestock and crop area among households revealed that inequality in the distribution of total livestock was higher in 2015 (Fligner-Killeen test; p <0.001). No significant differences in the distribution of crop plantation area was found between years (p = 0.11).

A major characteristic of changed agricultural practices was the construction of fences and consequent habitat fragmentation. Satellite-based analyses revealed that the number of fence crossing per transect distance increased significantly between 2002 and 2014 (Fig. 3A; paired t-test, $df = 2$, $p = 0.02$). Yearly growth rates of 2.74%, however, were not significantly different from yearly population growth rates (paired t-test, $df = 2$, $p = 0.50$). Further, there was significant positive effect of population densities on habitat fragmentation in sub-location with comparable climatic conditions across West-Pokot ($\log(y) = 1.2 \log(x) - 3.7$; $r^2 = 0.72$; $p < 0.001$). A model using logged data had a substantially lower AIC than the model using untransformed data (48 vs 13), indicating that there was an exponential relationship between population densities and the number of fences in an area (Fig. 3B). Satellite analyses also demonstrated the progression of erosion in the region. The length of gullies per area increased significantly from 1700m km^{-2} in 2002 to 2000m km^{-2} in 2014 (paired t-test, $T_2 = 6.5$, $p = 0.03$; Fig. 3A).

3.3 Changing internal system dynamics

Drivers of changes in agricultural practices were analysed in semi-structured interviews (Fig. 4). Farmers stated (i) decreased land size $household^{-1}$, (ii) disasters such as diseases and droughts, and (iii) health and education cost related life-stock sales (economic pressures) as main causes of reduced livestock herds. Fewer community grazing areas and the abandonment of seasonal livestock migrations were also considered, but only by <30% of interviewees (Fig. 4A). The most important explanation for increased crop plantation was the need to compensate for lower livestock herd sizes $household^{-1}$. Improved market, mechanization and an improved farming knowledge were mentioned by >40% of interview partners.

We summarised results in a causal loop diagram (Fig. 5) to conceptualise how population growth and several external drivers (e.g. climatic change, governmental and NGO activities) affected system dynamics. A major system transition was the switch from migratory pastoralism to mixed agro-pastoralism, which was mainly driven by (i) reduced land-size per household, (ii) land privatisation and (iii) higher economic pressure on households. While shifts in agricultural land-use were evaluated as relatively neutral by community members and associated to negative and positive developments (e.g. benefits of sedentary life style vs. livestock losses, Fig 1), our analysis revealed warning signs of reduced household resilience. A combination of pulse (droughts and diseases) and press disturbances (economic pressure) were major reasons for livestock declines and suggest that lower land-sizes but also increased reliance on crop production have weekend the potential of households to recover after catastrophic events.

4. Discussion

Population growth in Sub-Saharan Africa, which is projected to be sustained at a high level during future decades (UNPD, 2015), has frequently been accompanied by major system transitions (Biazin and Sterk, 2013; Rufino et al., 2013). We revealed that the consequences of past population growth in the drylands of north-western Kenya was overall evaluated as positive by local communities. Nevertheless, we also detected early warning signs for decreasing socio-economic resilience and the potential of future population growth to destabilise households facing a warmer and more variable climate.

4.1 Positive impact of past population growth

The overall positive impact of past population growth on local livelihoods was based on a range of diverse factors. Community members considered infrastructure development (e.g. roads, schools, health institutions) and the growth of local market as major improvements, and thereby highlighted factors, which are frequently considered as crucial for rural development (Eriksen and Silva, 2009; Shiferaw et al., 2014). However, the overall positive effect of population growth resulted not only rely from beneficial developments but was also based on the prevention of major negative development trajectories.

A fundamental challenge in many African drylands are food insecurities (Douxchamps et al., 2016), which are often fuelled by population growth (Thornton et al., 2009) and intensified drought as result of climate change (Trenberth et al., 2014). In our study area, however, food security was not an issue and received only a single vote as negative effect of population growth. A prerequisite for maintaining a sufficient calorie production per household despite the shrinking land-sizes was a transition from migratory pastoralism to agro-pastoralist systems.

While TLU fell from 10.5 to 1.3 person^{-1} and hence dropped below the threshold of 4.5 TLU person^{-1} to guarantee pastoralist food security (Fratkin and Roth, 1990; Luisgi, 1983), increased crop plantation substantially supplemented food production. This successful compensatory mechanism stands in contrasts to case studies from Northern Kenya and Southern Ethiopia where agro-pastoralists are often not able to sustain their own livelihoods (Fratkin et al., 2004; Tache and Oba, 2010). Factors contributing to higher success rates in Pserum were probably comparatively high rainfall levels (~600-700mm), spreading agricultural mechanisation and the knowledge of local farmers on crop cultivation techniques. Despite a generally large variability at the household level (Oostendrop and Zaal, 2012), the application of manure, the use of crop residues as animal fodder and the plantation of trees to prevent erosion were widely established (Wairore et al., 2016; Wernersson, 2018) and likely contributed to improved local food security.

A second major factor was the decoupling of population growth from landscape degradation. In many regions, increased human population pressure has been related to over-utilisation of ecosystem services, soil erosion and deforestation (Boyd and Slaymaker, 2000; Konig et al., 2013). On the contrary, community members in our target region related population growth with improved land conservation (Fig. 1), revealing similarities to

Machakos in Central Kenya (Tiffen et al., 1994). Just as in Machakos, which is often referred to as model for land management at high population densities (Siedenburg, 2006), moderate land scarcity and increased labour availability motivated soil conservation efforts and reduced erosion in our study area. Land conservation efforts were, however, much stronger linked to production for subsistence and regional markets, which contrast the situation in Machakos where the importance of cash crops and the proximity to large markets in Nairobi are frequently highlighted (Boyd and Slaymaker, 2000; Oostendrop and Zaal, 2012).

4.2 Considerations of household resilience

Despite the overall positive effect of population growth on local livelihoods, we recorded early warning signs of decreasing household resilience. Changes in agricultural practices such as the introduction of more resource-demanding animal breeds were not sufficient to explain decreased livestock densities. Instead, farmers stated press and pulse disturbances as major reasons for lower livestock numbers household^{-1} (Fig. 4). Livestock sales represents the main income source and an important drought-coping mechanism for many agro-pastoralists (Perez et al., 2015; Smucker and Wisner, 2008). Hence, the inability of farmers to re-establish stock sizes after catastrophic events reflects a lowered adaptive potential and shock-resistance.

A decreased household resilience was probably the result of several interconnected factors. First, privatisation and agricultural land-use changes were linked to habitat fragmentation (Fig. 3A) - a prerequisite for agricultural intensification that is, however, linked to trade-offs (Hobbs et al., 2008). Key resources for livestock keeping such as water wells or dry- and wet-season grazing grounds are often spatially separated (Pearson et al., 2016; Wernersson, 2018). The spatial separation of these production resources may cause a general decrease in agricultural productivity (Hobbs et al., 2008). Further, privatisation and habitat fragmentation restrict or eliminate the possibility that pastoralists migrate with their livestock (Turner et al., 2014). Switches from common to private land tenure, consequently, reduce spatial integration of resource use and may increase drought vulnerability (Smucker and Wisner, 2008; Tache and Oba, 2010).

While households managed to maintain food security by compensating decreasing livestock numbers through higher crop production, reductions in the monetary value of production are more difficult to mitigate. Maize yields usually range around or below 1t ha^{-1} $year^{-1}$ in Pserum (Benjamin Lokorwa, personal observation) and are low compared to other tropical regions (Shiferaw et al., 2014). The observed plot extension by 1.1 ha $household^{-1}$ therefore only led to an estimated increase in the monetary value of production by 330 US$ $household^{-1}$ $year^{-1}$ (2015 maize price level; Levin and Vimefall, 2015) if productivity remained unchanged. The annual monetary production per TLU in Sub-Saharan drylands ranges around 240 US$ (Behnke and Kerven, 2013, see S2 for details of calculation). Based on these estimations, the observed decrease of 87 TLU $household^{-1}$ would have resulted in a monetary production loss of >20 000 US$ $household^{-1}$ $year^{-1}$. Such calculations should be interpreted with caution because (i) livestock productivity has likely changed over time and (ii) pastoralist communities were much less commercialised 40 years ago. Nevertheless, these numbers highlight that livestock generates still today most of household revenues (Nyberg *et al.* 2015). A further reduction in land size and TLU $household^{-1}$ would not necessarily reduce food security but almost certainly result in a decrease of household revenues. Lower income and financial reserves would substantially deteriorate the potential of households to undergo self-initiated transformation, a crucial component of resilience when adaptations alone do not suffice to mitigate negative effects (Folke et al., 2010). Consequently, further reductions in household income is an alarming sign in face of projected climatic changes (Niang et al., 2014).

Finally, community resilience is tied to the distribution of wealth distributions (Douxchamps et al., 2016). Smucker and Wisner (2008) revealed that wealthier households in Central Kenya had access to a larger number and more successful drought mitigation strategies. Further, Lesorogol (2009) highlighted the importance of livestock sales as drought coping strategy. We found in our study an increase in the variability of livestock possession after the switch in agricultural land-uses. While in 1975 the richest quartile owned 43% of total livestock, this number raised to 58% in 2015. As agricultural revenues are mostly generated by livestock keeping (Nyberg *et al.* 2015) and income from off-farm activities is low (County Development Plan, 2012), wealth inequalities have likely increased. A further shrinking of livestock numbers may endanger especially poor households and reduce their capacity for self-sustained recovery (Barrett and Swallow, 2006; Eriksen and Silva, 2009; McCabe et al., 2010).

4.3 Potential future trajectories

Past population growth went hand in hand with a number of fundamental socio-ecological changes (e.g. land-use transitions, infrastructure developments) in most Sub-Saharan dryland regions (e.g. Jones and Thornton, 2009). Without doubt, the complexity of interdependencies and feed-back loops between different factors turn the identification of causal drivers into a challenging task. However, we argue that system simplifications are an essential step to evaluate potential future development trajectories and therefore developed in the following section hypotheses for the relationship between population densities and other key factors.

In our study area, the vast majority of households are, just as in most Sub-Saharan dryland areas, based on agricultural income. In such a context, population growth necessarily leads either to a decrease of the available community grazing area per person or to a subdivision of farms under private land tenure (Masters et al., 2013). Traditional, community-based land management represents a socio-ecological system that is well adapted to variable climatic conditions (Jones and Thornton, 2009; Morton, 2007). Consequently, traditional systems first have to be destabilised before land-use changes may occur. We suggest that reductions in grazing areas per person with population growth eventually results in decreased food security (Fig. 6) and that unreliable food supply represents a major driver of land privatisation, agricultural intensification and habitat fragmentation. Certainly, also other factors such as immigration of farmers, government policies or the activity of NGOs may trigger to land-use changes (Lesorogol, 2008; McCabe et al., 2010). However, both, our synthesis of interview data (Fig. 5) and the results of GIS-based analyses (Fig. 3B) indicate that population densities also play an important role.

While a switch to more labour intensive agro-pastoralist systems can result in substantial productivity increases (Tiffen et al., 1994), land-use changes also may also affect system resilience. The spatial integration of resources in traditional systems based on seasonal livestock migration is characterised by an initially high household stress resistance (Jones and Thornton, 2009; Morton, 2007). However, especially at high population densities, self-enforcing feed-back loops can lead to overgrazing and ecosystem degradation (Hardin, 1968). Agro-pastoralism, on the other hand, represents an agricultural diversification and as crop production and pastoralism have different drought-sensitive periods during annual cycles, a switch in land-use practices may temporarily increase drought resilience (Fig. 6; Biazin and Sterk, 2013).

Though, further population growth will also in a privatised agriculture-based systems eventually lead to food shortages unless productivity is increased simultaneously. Agricultural advances such as the introduction of improved varieties certainly have the potential to achieve productivity increases (Havlik et al., 2014; Shiferaw et al., 2014). Yet, once household land sizes fall below a crucial level even highly diversified and well-managed systems are not self-sustainable and become dependent on food subsidies (Conelly and Chaiken, 2000). Further, a shortage of financial reserves results in increased drought vulnerability (Fig. 6). Therefore, the prevention of such negative development trajectories in the face of ongoing population growth will require further system transformations. Possibilities include the introduction of irrigation-based agriculture (Enfors, 2013) or agricultural mechanisation and parallel increase of off-farm job opportunities (Bryceson, 1996). Such system transformation are, however, often linked to substantial transformation costs (Marshall, 2013) and local communities will not be capable to cover these costs if transition processes are delayed and household incomes drop below critical threshold levels.

Acknowledgments

We thank William Libusi and the team of the NGO Vi Agroforestry in Kitale for their help in the field. Further, we are very grateful to Evelyn Koskei for providing us with the population density data from the Kenyan population census in 2009. This work have been conducted as part of the research network Triple L, Land, Livestock and Livelihood, partly funded through the Swedish Research Council, VR/SRL 348-2014-4288-E0428801.

References

Barrett, C.B., Swallow, B.M., 2006. Fractal poverty traps. World Dev 34, 1-15.

Behnke, R.H., Kerven, C., 2013. Counting the costs: replacing pastoralism with irrigated agriculture in the Awash Valley, north-eastern Ethiopia. IIED London.

Benjaminsen, T.A., Rohde, R., Sjaastad, E., Wisborg, P., Lebert, T., 2006. Land reform, range ecology, and carrying capacities in Namaqualand, South Africa. Annals of the association of american geographers 96, 524-540.

Biazin, B., Sterk, G., 2013. Drought vulnerability drives land-use and land cover changes in the Rift Valley dry lands of Ethiopia. Agriculture, Ecosystems & Environment 164, 100-113.

Bollig, M., 2006. Risk management in a hazardous environment: A comparative study of two pastoral societies. Springer, New York, USA.

Boyd, C., Slaymaker, T., 2000. Re-examinin the '*More People, Less Erosion*' hypotheis: Special case or wider trend? . ODI NAtural Resource Perspectives No. 63. London: Overseas Development Institute.

Bryceson, D.F., 1996. Deagrarianization and rural employment in sub-Saharan Africa: a sectoral perspective. World Dev 24, 97-111.

Conelly, W.T., Chaiken, M.S., 2000. Intensive farming, agro-diversity, and food security under conditions of extreme population pressure in Western Kenya. Hum Ecol 28, 19-51.

Dai, A.G., 2011. Drought under global warming: a review. Wires Clim Change 2, 45-65.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., Curbois, C., Livestock to 2020. The next food revolution. Food, Agriculture and Environment Discussion Paper 28.

Dietz, A.J., Gunning, J.W., Bos, A.K., Zuiderwijk, A., 2009. Optimistic determinism or explaining a miracle, In: Zaal, F., Burger, K. (Eds.), Sustainable land management in the tropics: Explaining the miracle. Ashagte Publishing, Farnham, pp. 1-20.

Douxchamps, S., Van Wijk, M.T., Silvestri, S., Moussa, A.S., Quiros, C., Ndour, N.Y.B., Buah, S., Some, L., Herrero, M., Kristjanson, P., Ouedraogo, M., Thornton, P.K., Van Asten, P., Zougmore, R., Rufino, M.C., 2016. Linking agricultural adaptation strategies, food security and vulnerability: evidence from West Africa. Reg Environ Change 16, 1305-1317.

Enfors, E., 2013. Social-ecological traps and transformations in dryland agro-ecosystems: Using water system innovations to change the trajectory of development. Global Environ Chang 23, 51-60.

Eriksen, S., Silva, J.A., 2009. The vulnerability context of a savanna area in Mozambique: household drought coping strategies and responses to economic change. Environ Sci Policy 12, 33-52.

FAO, 2000. Land resource potential and constraints at regional and country levels, World Soil Resources Report, Rome.

FAO, 2006. Country Pasture/Forage Resource Profiles: Kenya. Food and Agriculture Organization. Edited by J. M. Suttie and S. G. Reynolds. Apollo Bwonya Orodho. See http://www.fao.org/ag/AGP/AGPC/doc/Counprof/kenya/Kenya.htm#2.3.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockstrom, J., 2010. Resilience Thinking: Integrating Resilience, Adaptability and Transformability. Ecol Soc 15.

Fratkin, E., Roth, E.A., 1990. Drought and economic differentiation among Ariaal pastoralists of Kenya. Hum Ecol 18, 385-402.

Fratkin, E., Roth, E.A., Nathan, M.A., 2004. Pastoral sedentarization and its effects on Children's diet, health, and growth among rendille of northern Kenya. Hum Ecol 32, 531-559.

Goodhue, R.E., McCarthy, N., 2009. Traditional property rights, common property, and mobility in semi-arid African pastoralist systems. Environ Dev Econ 14, 29-50.

Hardin, G., 1968. The tragedy of the commons. Science 162, 1243-1248.

Havlik, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M.C., Mosnier, A., Thornton, P.K., Bottcher, H., Conant, R.T., Frank, S., Fritz, S., Fuss, S., Kraxner, F., Notenbaert, A., 2014. Climate change mitigation through livestock system transitions. P Natl Acad Sci USA 111, 3709-3714.

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

IPCC, 2012. Managing the risks of extreme events and disasters to advance climate change adaptation, In: Field, C.B., Barros, V., T.F., S., al., e. (Eds.), A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, NY, USA.
IPCC, 2014. Climate Change 2014 - Synthesis Report. International Panel on Climate Change, see http://ipcc.ch/report/ar5/syr/.
Jones, P.G., Thornton, P.K., 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environ Sci Policy 12, 427-437.
Konig, H.J., Uthes, S., Schuler, J., Zhen, L., Purushothaman, S., Suarma, U., Sghaier, M., Makokha, S., Helming, K., Sieber, S., Chen, L., Brouwer, F., Morris, J., Wiggering, H., 2013. Regional impact assessment of land use scenarios in developing countries using the FoPIA approach: Findings from five case studies. J Environ Manage 127, S56-S64.
Lengoiboni, M., Bregt, A.K., van der Molen, P., 2010. Pastoralism within land administration in Kenya-The missing link. Land Use Policy 27, 579-588.
Lesorogol, C.K., 2003. Transforming institutions among pastoralists: Inequality and land privatization. Am Anthropol 105, 531-541.
Lesorogol, C.K., 2008. Land privatization and pastoralist well-being in Kenya. Dev Change 39, 309-331.
Lesorogol, C.K., 2009. Asset Building Through Community Participation: Restocking Pastoralists Following Drought in Northern Kenya. Soc Work Public Hlth 24, 178-186.
Levin, J., Vimefall, E., 2015. Welfare impact of higher maize prices when allowing for heterogeneous price increases. Food Policy 57, 1-12.
Luisgi, W.J., 1983. Integrated Resource Assessment and Management Plan for Western Marsabit District, Northern Kenya., UNESCO-IPAL. Integrated Resource Assessment Part 1. UNESCO, Nairobi.
Marshall, G.R., 2013. Transaction costs, collective action and adaptation in managing complex social-ecological systems. Ecol Econ 88, 185-194.
Masters, W.A., Djurfeldt, A.A., De Haan, C., Hazell, P., Jayne, T., Jirstrom, M., Reardon, T., 2013. Urbanization and farm size in Asia and Africa: Implications for food security and agricultural research. Glob Food Secur-Agr 2, 156-165.
Maystadt, J.-F., Duranton, G., 2014. The development push of refugees: Evidence from Tanzania. Journal of Economic Geography.
McCabe, J.T., Leslie, P.L., DeLuca, L., 2010. Adopting Cultivation to Remain Pastoralists: The Diversification of Maasai Livelihoods in Northern Tanzania. Hum Ecol 38, 321–334.
Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. P Natl Acad Sci USA 104, 19680-19685.
NDMA, 2014. National Drought Management Authority West Pokot County. Drought monthly bulletin for July 2014. Available at: http://reliefweb.int/sites/ reliefweb.int/files/resources/West_Pokot-July-2014.pdf. Accessed 31 Oct 2018, In: County., N.D.M.A.W.P. (Ed.).
Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa, In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability, Pt B: Regional Aspects. Cambridge University Press,, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.
Nyberg, G., Knutsson, P., Ostwald, M., Öborn, I., Wredle, E., Otieno, D.J., Mureithi, S., Mwangi, P., Said, M.Y., Jirström, M., 2015. Enclosures in West Pokot, Kenya: Transforming land, livestock and livelihoods in drylands. Pastoralism 5, 1-12.
Oostendrop, R., Zaal, F., 2012. Farm- and household-level drivers of agricultural innovation in machakos and Kitui districts, Kenya, In: Zaal, F., Burger, K. (Eds.), Sustainable land management in the tropics: Explaining the miracle. Ashagte Publishing, Farnham, pp. 45-64.
Otte, M.J., Chilonda, P., 2002. Cattle and small ruminant systems in sub-Saharan Africa: A systematic review. FAO, Rome.

Pearson, A.L., Zwickle, A., Namanya, J., Rzotkiewicz, A., Mwita, E., 2016. Seasonal shifts in primary water source type: a comparison of largely pastoral communities in Uganda and Tanzania. International journal of environmental research and public health 13, 169.

Perez, C., Jones, E.M., Kristjanson, P., Cramer, L., Thornton, P.K., Forch, W., Barahona, C., 2015. How resilient are farming households and communities to a changing climate in Africa? A gender-based perspective. Global Environ Chang 34, 95-107.

Plan, C.D., 2012. For Turkana, West Polot, Samburu, and Baringo 2013-2017. Retrieved from Rift Valley Province.

R Development Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rowhani, P., Lobell, D.B., Linderman, M., Ramankutty, N., 2011. Climate variability and crop production in Tanzania. Agr Forest Meteorol 151, 449-460.

Rufino, M.C., Thornton, P.K., Ng'ang'a, S.K., Mutie, I., Jones, P.G., van Wijk, M.T., Herrero, M., 2013. Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty. Agr Ecosyst Environ 179, 215-230.

Shiferaw, B., Tesfaye, K., Menale, K., Abate, T., Prasanna, B.M., Menkir, A., 2014. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. Weather and Climate Extremes 3, 67-79.

Siedenburg, J., 2006. The Machakos case study: Solid outcomes, unhelpful hyperbole. Development Policy Review 24, 75-85.

Smucker, T.A., Wisner, B., 2008. Changing household responses to drought in Tharaka, Kenya: vulnerability, persistence and challenge. Disasters 32, 190-215.

Tache, B., Oba, G., 2010. Is Poverty Driving Borana Herders in Southern Ethiopia to Crop Cultivation? Hum Ecol 38, 639-649.

Thornton, P.K., Ericksen, P.J., Herrero, M., Challinor, A.J., 2014. Climate variability and vulnerability to climate change: a review. Glob Chang Biol 20, 3313-3328.

Thornton, P.K., van de Steeg, J., Notenbaert, A., Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agr Syst 101, 113-127.

Tiffen, M., Mortimore, M., Gichuki, F., 1994. More People Less Erosion - Environmental Recovery in Kenya. John Wiley & Sons, Chichester, UK.

Trenberth, K.E., Dai, A.G., van der Schrier, G., Jones, P.D., Barichivich, J., Briffa, K.R., Sheffield, J., 2014. Global warming and changes in drought. Nature Climate Change 4, 17-22.

Turner, M.D., McPeak, J.G., Ayantunde, A., 2014. The Role of Livestock Mobility in the Livelihood Strategies of Rural Peoples in Semi-Arid West Africa. Hum Ecol 42, 231-247.

UNPD, 2015. Probabilistic population projections based on the World Population Prospects: The 2015 Revision. United Nations Population Division, see http:/esa.un.org/unpd/ppp/.

Vasseur, D.A., DeLong, J.P., Gilbert, B., Greig, H.S., Harley, C.D.G., McCann, K.S., Savage, V., Tunney, T.D., O'Connor, M.I., 2014. Increased temperature variation poses a greater risk to species than climate warming. P R Soc B 281.

Wairore, J.N., Mureithi, S.M., Wasonga, O.V., Nyberg, G., 2016. Benefits Derived from Rehabilitating a Degraded Semi-Arid Rangeland in Private Enclosures in West Pokot County, Kenya. Land Degrad Dev 27, 532-541.

Wernersson, J.E.V., 2018. Rethinking identity in adaptation research: Performativity and livestock keeping practices in the Kenyan drylands. World Dev accepted.

Whitfield, S., Reed, M., 2012. Participatory environmental assessment in drylands: introducing a new approach. Journal of Arid Environments 77, 1-10.

World-Bank-Group, 2016. Poverty and Shared Prosperity 2016: Taking on Inequality. The World Bank, see http://www.worldbank.org/en/publication/poverty-and-shared-prosperity.

Table 1: Changes in relative frequencies of main crop types in Pserum.

Year	Maize [%]	Millet [%]	Sorghum [%]
1975	28	43	29
2015	82	12	6

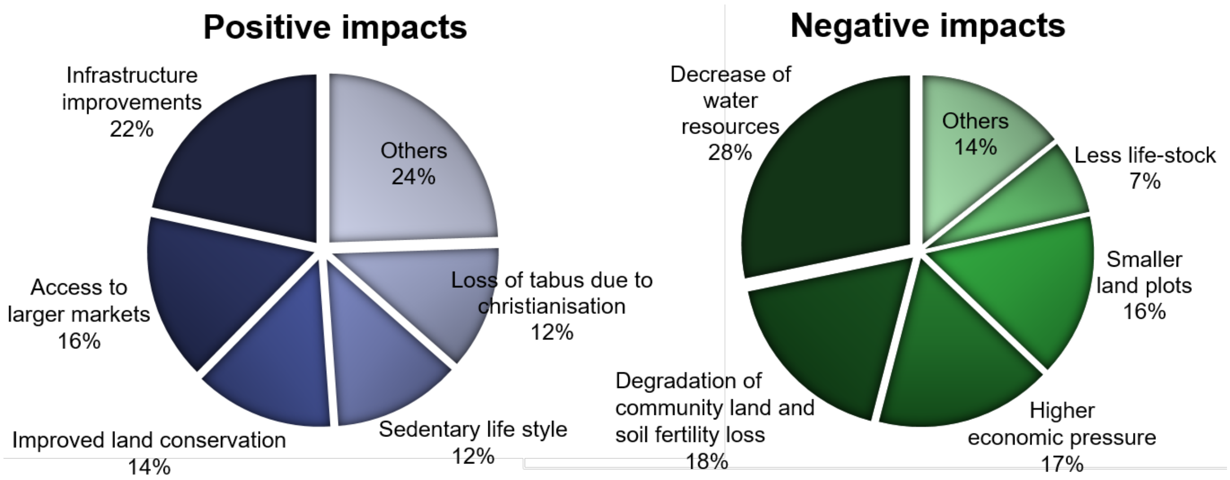

Fig. 1: Distribution of community votes between positive (**A**) and negative (**B**) effects of population growth on a self-defined range of social, ecological and environmental factors.

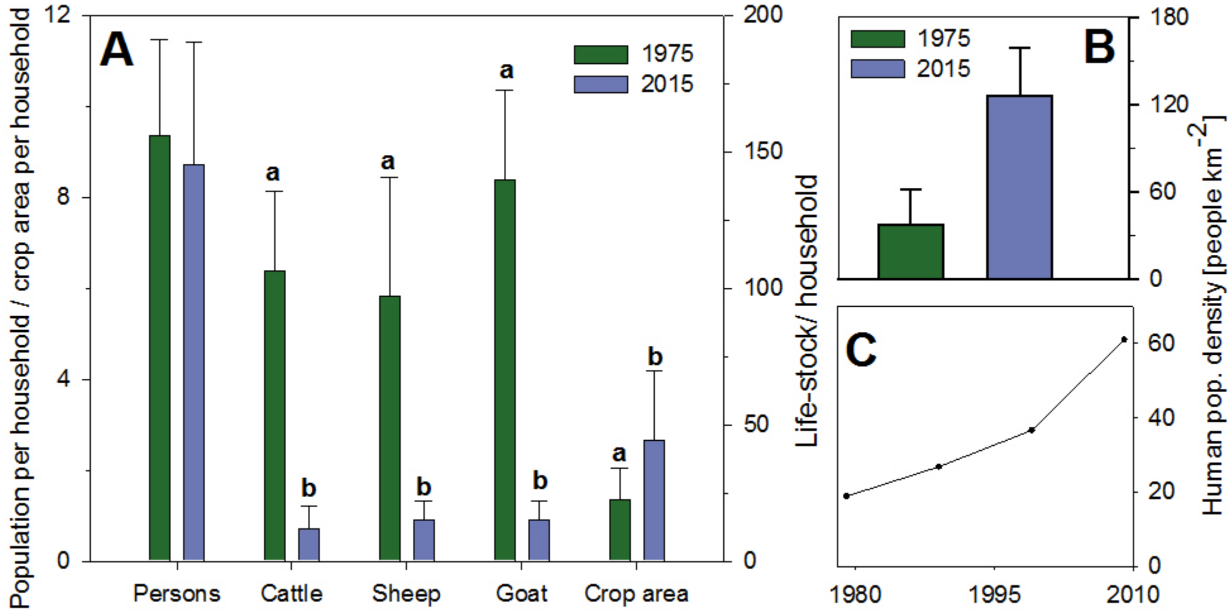

Fig. 2: Changes in livestock sizes, crop production and human demographics over time. (**A**) Number of persons, different livestock species and crop plantation area per household. Error bars indicate standard deviations of household data ($n_{1975} = 25$, $n_{2015} = 83$), letters denote significant differences between years. (**B**) Human population density in the location of Pserum and (**C**) in the county of West Pokot. Data was derived from village maps (**A-B**) and from governmental population census (**C**).

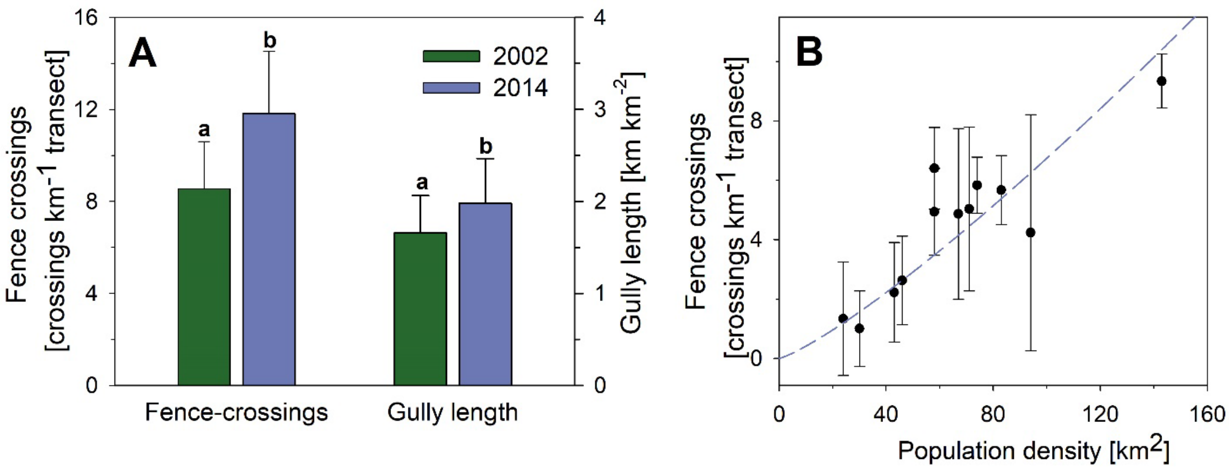

Fig. 3: The number of fence crossings per transect distance as indicator of landscape fragmentation and the length of gullies per km^2 in 2002 and 2014 in Pserum. Letters denote significant differences between years (paired t-tests), error bars represent standard deviations.

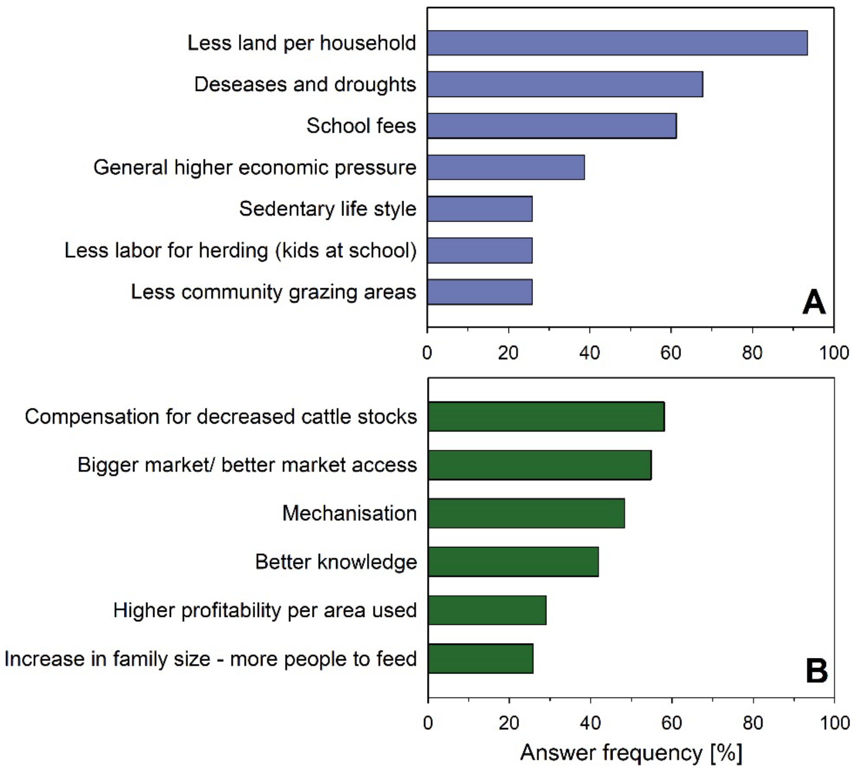

Fig. 4: Drivers of (**A**) decreased livestock numbers and (**B**) increased crop plantation area stated by farmers in household interviews. Interviewees were encouraged to express all relevant drivers of change. Answerers stated in more >25% of interviews were included.

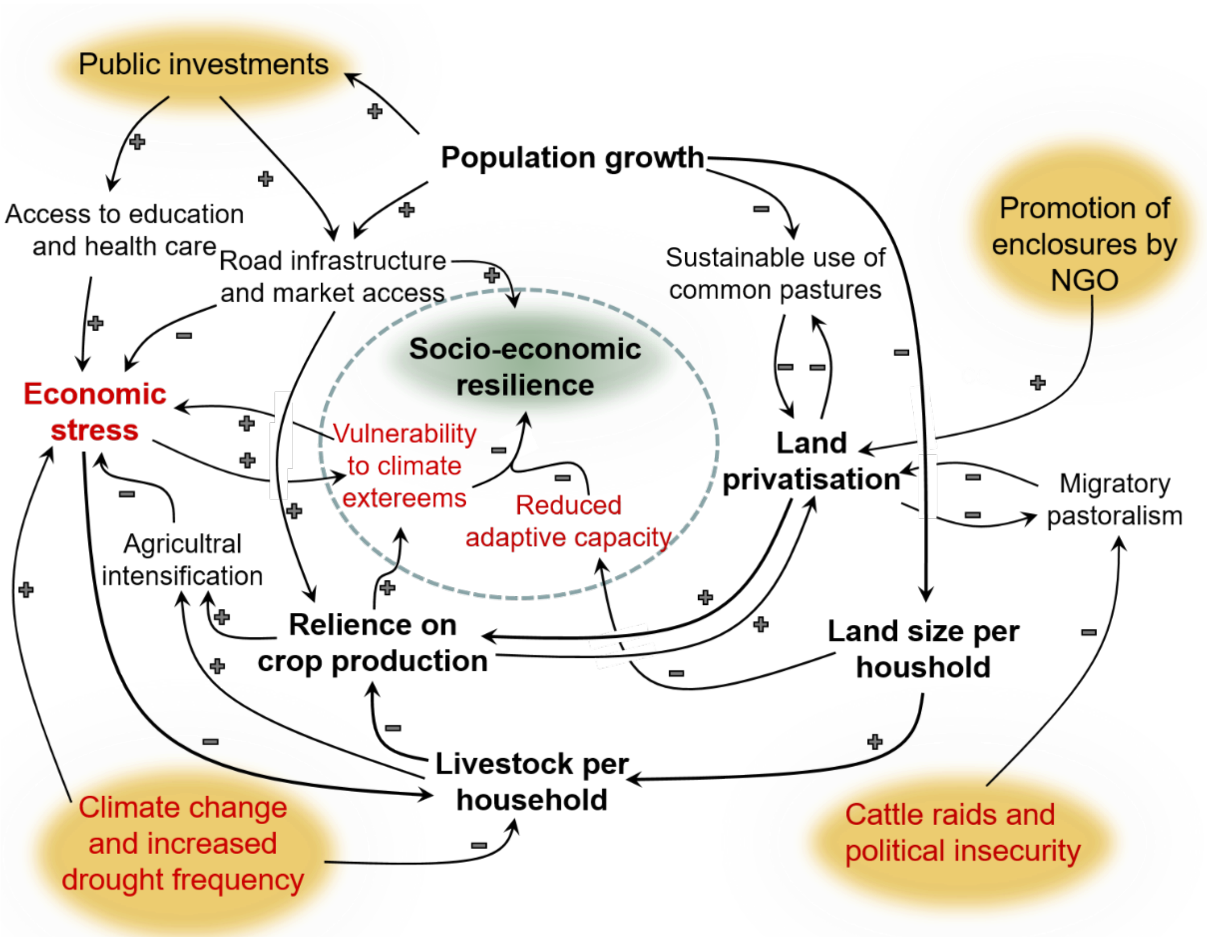

Fig. 5 Causal loop diagram providing a conceptual overview on population growth and its effects on internal system dynamics in Pserum during the last 30 years. Links outside the dashed inner circle summarise focus-group and interview data, links inside the circle were added to relate system dynamics to household resilience. External factors are highlighted in **yellow**, stressors are printed in **red**. Arrows indicate the direction and **plus** and **minus** signs the stimulating or inhibiting nature of interactions. E.g. land size and livestock are positively related, resulting in a negative effect of lower land sizes on livestock densities household^{-1}.

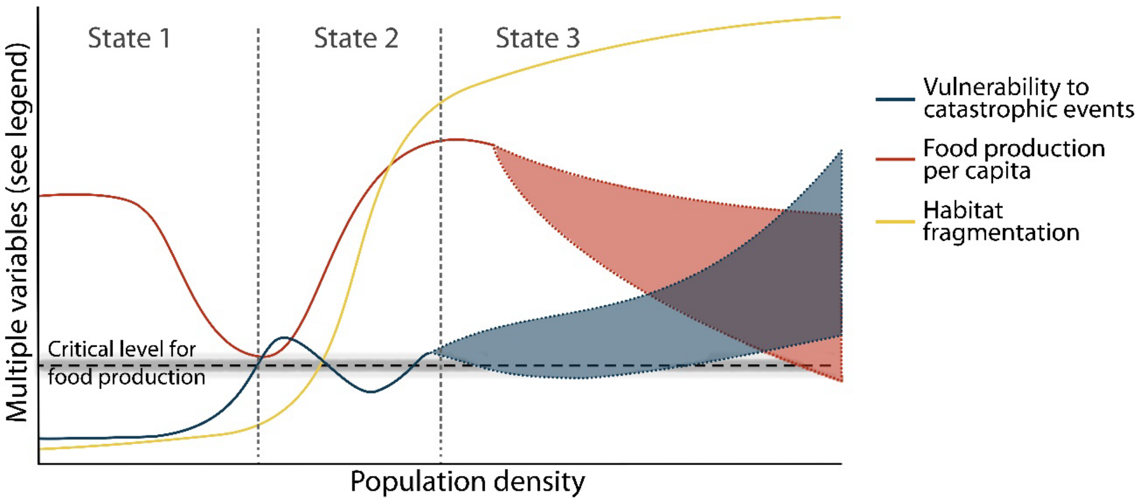

Fig. 6: Conceptual relationship between population density, food production per capita, land fragmentation and the vulnerability to catastrophic events in Sub-Saharan drylands. Three states were defined. **State 1** is characterised by migratory pastoralism and community land tenure. Once all arable land is utilised, further population growth increases the risk of overgrazing and decreases food production per capita. **State 2** represents a transitional state. Multiple drivers, among them food insecurity, trigger a switch from community to private land tenure, which is linked to habitat fragmentation and a switch from migratory pastoralism to sedentary agro-pastoralism. Agricultural intensification facilitates the increase of food production per capita. **In state 3**, all land has been privatised. Habitat fragmentation nevertheless continues as population growth leads to subdivision of plots. There is a tendency towards increased drought vulnerability and a lower per-capita food production with further population growth. However, the development of these factors strongly depends as indicated by shaded areas on internal dynamics and management strategies.