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COMMENTARY

Real-world complexity of food security and biodiversity conservation

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Abstract Feeding the booming human population and at the same time conserving biodiversity is a global challenge. Yet, it is particularly acute in developing countries where biodiversity is high and food-security low. There is an ongoing debate whether land for nature and for agriculture should be segregated (land sparing) or integrated (land sharing). While these strategies still need unambiguous empirical validation, we here

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illustrate the real-word complexity of this issue by focusing on the case of Kenya, hosting one of the fastest growing populations in the world. We discuss historical effects and those arising from recent demographic pressure, and integrate these with biotic and abiotic constraints (soil fertility and climate) that additionally challenge land sparing and sharing strategies for biodiversity conservation. Generically, our contribution stresses the importance of recognising the specific context in which land-use strategies are to be applied, and underline the need of a deeper understanding of local conditions. This work goes beyond the current theoretical and highly abstract land-use debate that has been published in high impact journals but which may be less efficient on solving local conflicts.

Keywords Climate change · Colonial and cultural legacy · Soil fertility · Demographic pressure · Post-harvest

Introduction

The ongoing debate among scientists and policy makers on how to reconcile food security and biodiversity conservation, and hence, to produce food in a more biodiversity-friendly way, has resulted in two main alternative strategies (Godfray et al. 2010; Garnett et al. 2013). The first approach argues that the already existing cultivated land has to be used more intensively (but nevertheless sustainably). Authors in favour of this strategy argue that the demand for more food can be met by an increase in productivity in terms of improved use of light, water, nutrients, and mechanization, without a need for more agricultural land (Garnett et al. 2013). This approach is most commonly termed the “sustainable intensification” (Godfray et al. 2010), “land sparing” or “intensive agriculture” strategies (Garnett et al. 2013), as areas for food production are physically separated from areas which are of high conservation value. A second approach, however, assumes that biodiversity at the landscape level is pivotal to sustain both agricultural production and the provision of ecosystem services, and therefore advocates extensive rather than intensive production i.e. by applying eco-agricultural techniques and organic farming. This approach has been termed “land sharing”, “wildlife friendly farming” (Tscharntke et al. 2012), or “eco-agriculture strategies” (Brussaard et al. 2010), and states that food production can be reconciled with the conservation of biodiversity (Tscharntke et al. 2012). Note that a comparable discussion was already held on “segregation” versus “integration” about two decades ago (cf. Primdahl 1990). Pros and cons of both strategies have often been discussed in a very theoretical and often fairly simplistic way (Godfray et al. 2010; Phalan et al. 2011; Garnett et al. 2013), with very few critical notes so far (Habel et al. 2013; Loos et al. 2014). In particular, discussions often seem to ignore local complexities related to historical events, societal life and traditions, or environmental constraints.

Here we analyse real world complexity of food security (including access to food, see Loos et al. 2014) and biodiversity conservation by focusing on the case of Kenya. We thereby highlight the impacts of (i) cultural and colonialist legacy, (ii) past and current demographic pressure, (iii) soil depletion and climate change, (iv) locally-adapted agricultural techniques and varieties, and (v) effective storage techniques to fight against food shortage. By integrating these drivers, we reflect on the relevance of the land-sparing versus land-sharing debate for grassroots conservation in developing countries.

Colonial and post-colonial imprints

Since the colonialism period two centuries ago, prime agricultural land in Kenya has been used for cash crop farming with products mainly being exported to the world market. Examples thereof are the coffee plantations in the Kiambu and Muranga districts of the Central Province, tea plantations in the Kericho district of the Rift Valley, and the wheat-, barley- and maize farms on the high altitude plateaus of Laikipia and Uasin Gishu that were all established under the east African Protectorate in 1902 (Laube 1986). These areas were originally populated by various East African ethnic groups that were subsequently translocated to semi-arid and arid areas of Kenya by the Crown Lands Ordinance between 1904 and 1920, e.g. Masai in southern Kenya, Nandi in western Kenya, and Kikuyu in central Kenya (Kipkorir 1978, 1980; Thurston 1987). When Kenya became independent in 1963, these large-scale human translocations have only been marginally re-adjusted and corrected, and prime agricultural highland regions remain in use for cash crop production until today (Klopp 2000). As a result, a high proportion of the Kenyan human population lives in semi-arid lowlands today, characterised by low soil fertility and strong climatic fluctuations, and thus of low suitability for food crop production (DFID/EC/UNDP/The World Bank 2002; Jaetzold et al. 2006c). This colonial legacy has resulted in the cultivation of large areas of land that are rapidly depleted by nutrients and biodiversity.

Cultural legacy

Negative impacts of settlement in areas unfavourable for high-yield agriculture have become further aggravated by strong (past and present) demographic pressure. The Kenyan population increased by 251 % over the past 30 years, from 16.3 million people in 1980 to 40.9 million in 2010 (FAOSTAT 2014), while during the same period a stagnation of maize yields can be observed (FAOSTAT 2014) (Fig. 1). This increasing human population and the inherited traditions in Kenya has led to the ancestral land splitting dilemma which causes a strong decrease of land available per person (e.g. family); Farm sizes have diminished by more than 50 % between 1977 and 2004 (Jaetzold and Schmidt 1982–1983; Jaetzold et al. 2006a, b, c, 2009, 2010, 2011, 2012). As a consequence, farmers have been forced to switch from crop rotation to permanent crop cultivation, resulting in increased leaching of nutrients in soil, decreased yields, and a further increase in demand for

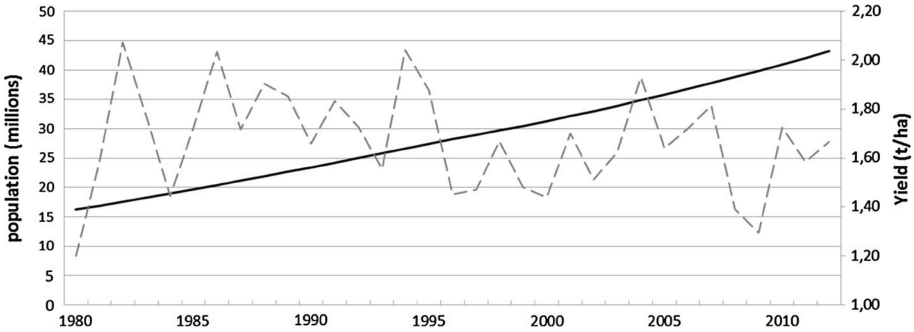

Fig. 1 Increase in the Kenyan human population from 1980 to 2012 in millions (*solid line*) and stagnation of maize yields in tonnes ha^{-1} (*dashed line*)

agricultural land. Apart from the area of cultivable land, yield also depends on the appropriateness of agricultural practices in view of local environmental constraints. For instance, excessive stocking of goats and cows, or the cultivation of inappropriate crops or inappropriate crop rotations, have lowered the resilience of highly sensitive ecosystems throughout Kenya and eventually turned them into semi-deserts (Tittonell et al. 2005). Increased usage of land (and thus loss of biodiversity) due to such poverty-environment interactions (see Gray and Moseley 2005) have become further aggravated by private landowners responding to market opportunities for mechanized agriculture (Homewood et al. 2001).

Soil fertility

Recent negative trends in crop yield across Kenya have been mainly due to soil depletion following over-cropping (Muriuki and Qureshi 2001). For instance, maize yields decreased by 40–60 % over the last 30 years in the densely populated rural areas of humid western Kenya, despite the widely used application of mineral fertilisers (macronutrients N–P–K) (Hornetz and Jaetzold 2006). Reduced pH-levels, resulting from the exhaustion of calcium, magnesium and other micronutrients, and the application of macronutrients turned out to be the major causes for the depletion of micronutrients (*agromining* sensu Jaetzold et al. 2010). Similar stagnations or decreases in crop yields have been observed in many African countries during the past decades, resulting in current per capita food production rates comparable to those in 1961 (Conway 1997; Evenson and Gollin 2003; McIntyre et al. 2011). The use of fertilizer in Kenya increased only marginally between the 1960s and the 1990s, while in India it increased from 10 up to 110 kg ha^{-1}, and in China even up to 240 kg ha^{-1}, during the 1990s (FAOSTAT 2009). Examples from Kenya however indicate that efficient use of fertilizer may have positive effects on crop yields (at least for a certain

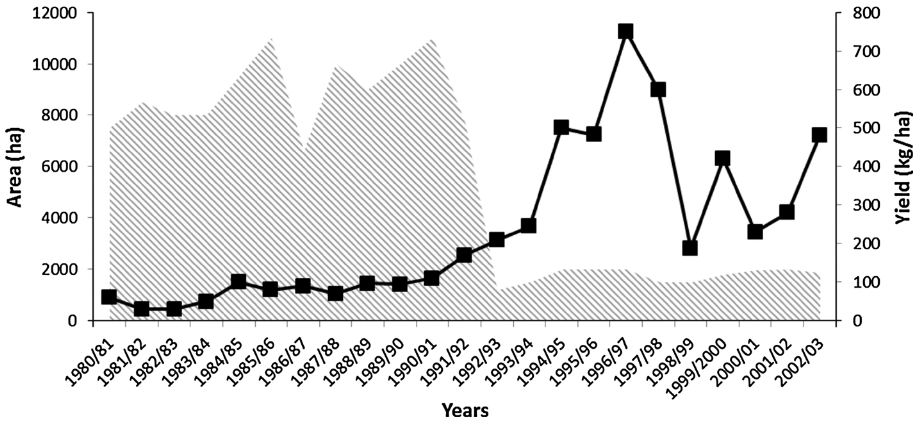

Fig. 2 Area and cotton-yield in Kitui-district, a semi-arid area in east Kenya. While the area needed for the production of cotton strongly decreased (*hatched shape*), the yield increased within the same time window (*solid line*), mainly by the application of subsidised fertilizer. After an initial raise, yields dropped as rare nutrients of low fertile soils became increasingly depleted due to the withdrawal of governmental support for input supply. World marked prices decreased due to the sector liberalisation in 1991 which caused a strong reduction in cotton production in Kenya (Monroy et al. 2012). Data taken from Jaetzold et al. (2012)

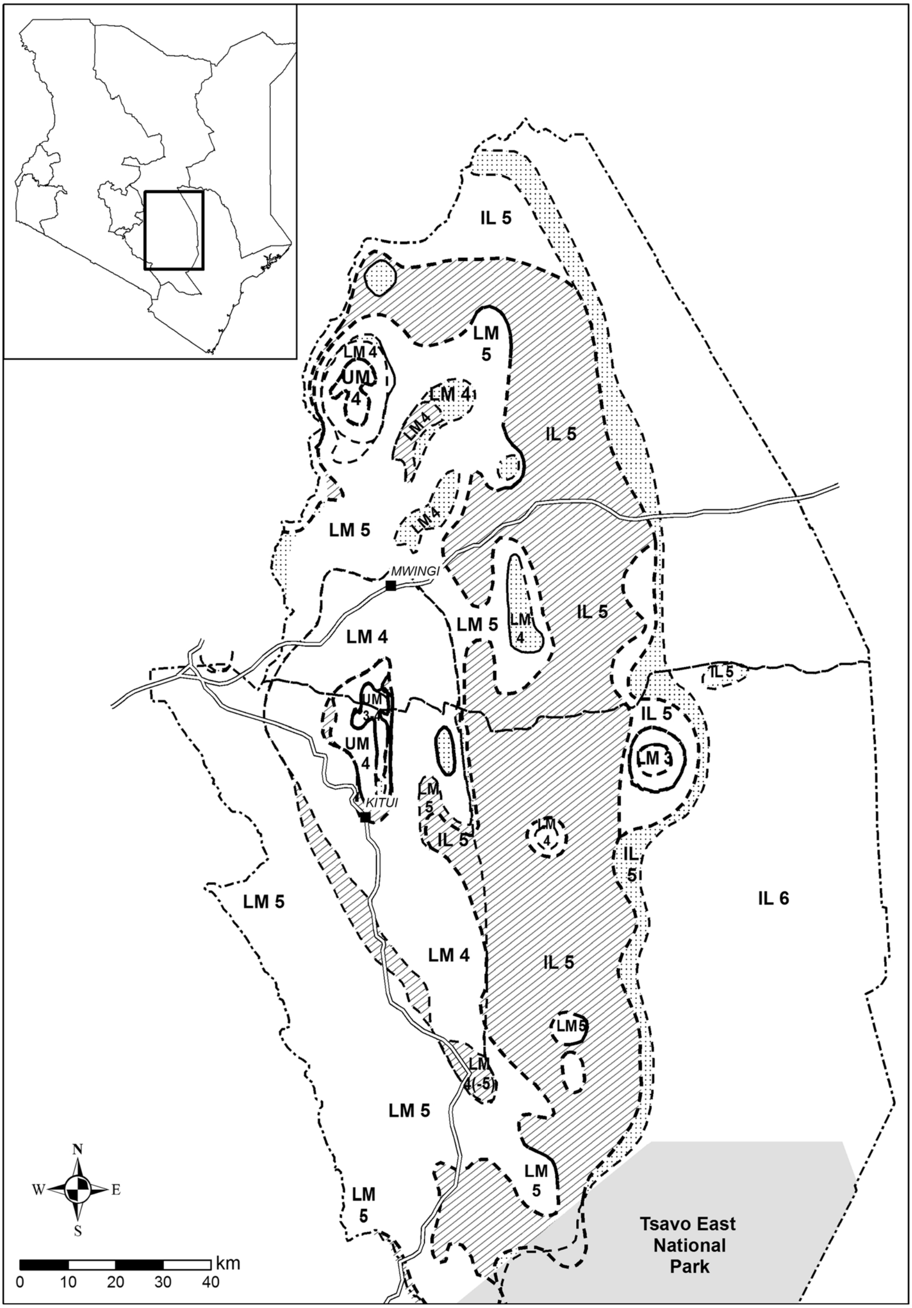

Fig. 3 Changes in climatic conditions and subsequent altitudinal shifts in agricultural use between 1980 and 2007 in Eastern Kitui County. The total area of suitable agricultural land (lower midland LM) decreased by 20 %, the area of less suitable zones of agro-ecological potential (especially the agro ecological zone inner Lowland IL 5 & 6) increased by 20 % since 1980. Increased aridity = *shaded areas*, decreased aridity = *dotted areas*. Data taken from Jaetzold et al. (2006c)

period) (Fig. 2), provided that local soil and climatic conditions, crop varieties, crop combinations, growing season and complementary use of manure are all adequately taken into account (Muriuki and Qureshi 2001; Vanlauwe 2004; Jaetzold et al. 2006a, b, c, 2009, 2010, 2011, 2012).

In contrast to the use of expensive fertilizers, various low-budget practices might safeguard food production and maintain ecosystem functions in fragile ecosystems. For instance, locally adapted crop varieties or low input practices, such as improved fallows using legumes in rotations or intercrops, or intercropping with coppicing legumes may restore soil nutrients, reduce reliance on fertilizer by 50 %, and result in favourable yields (Sileshi et al. 2008; Garrity et al. 2010; Carsan et al. 2014).

Climate

Yields of particular crops, such as sorghum, millet and groundnut, are highly dependent on ambient climatic conditions (Mueller et al. 2012), and climate change predictions indicate that agricultural yield will get negatively affected in the drier parts of Africa in particular (IPCC 2012). In the semi-arid Kitui county of south east Kenya, temperature has consistently increased, and precipitation decreased, during the past decades (Fig. 3), directly resulting in loss of agricultural lands and increased pressure on remnant biodiversity-rich areas. Hence, climate change can be expected to further intensify the conflict between food security and biodiversity conservation, and eventually, disturb various ecosystem services provided (Kirchner et al. 2015). Predicted climate effects on agricultural yield can partly be attenuated by using more resilient crops or crop varieties (Jaetzold et al. 2010). For instance, the Kenyan Agriculture Research Institute (KARI) developed more than 220 maize varieties adapted to particular soil and climate conditions (KEPHIS 2014).

Food storage

Whereas in developed countries food waste is mainly household restricted, developing countries primarily waste food on farms, during transportation, processing and/or storing (Godfray et al. 2010). Post-harvest losses increased during the past decades and are currently estimated to range between 20 and 30 % of the produced food worldwide; For instance, one out of every five kilos of grain produced in Sub-Sahara Africa is lost to pests or decay; This lost food might feed 48 million people for 12 months, and is valued at around 4 billion US$, or half of the annual grain import to Africa (Kimatu et al. 2012). Food waste problems can be locally solved by introducing new storage and preserving techniques, such as small-scale metal silos for single households or local communities. Besides improved food-security, this may also generate extra income by retaining harvest for longer periods as to respond better to price fluctuations.

The delicate balance between yield and biodiversity conservation

Eighty percent of the food-deprived human population lives in developing countries, where demographic pressure and biodiversity are highest (Cincotta et al. 2000). As a consequence, human-biodiversity conflicts in such areas are amply, as exemplified in the Kenyan Taita Hills, Kakamega Forest, and various National Parks (Thaxton 2007; UNEP 2009;

Habel et al. 2013). However, protection of biodiversity per se is hard to justify when people are starving and are unaware of the causal relationship between biodiversity loss and food shortage.

As shown for the Kenyan case, conflicts between food security and biodiversity are multi-facetted and driven by past and current factors such as colonial and cultural legacies, demographic pressure, soil conditions, ambient climatic conditions, non-adapted farming practices and the lack of adequate logistics. The choice between land sparing, biodiversity-friendly farming, or mixed sparing–sharing strategies is highly abstract and theoretical, and therefore not always straightforward at grassroot level. Our study aimed to highlight the importance of fully recognising the local context in which land-use strategies are to be applied as well as local trade-offs between biodiversity conservation and yield improvement (cf. Phalan et al. 2011; Tscharntke et al. 2012). Likely, none of the afore-mentioned strategies will offer a ready solution, especially in areas where people are highly dependent on subsistence cultivation and local markets, rather than on access to the world market (Tscharntke et al. 2012; Habel et al. 2013). There is an urgent need to reconcile traditional farmer knowledge with current ecological insights, both at local and regional levels (cf. Vandermeer and Perfecto 2012). Indeed, biodiversity conservation can be expected to fail if only considered a by-product of other policies, such as on sustainable intensification. Instead, society needs to integrate explicit conservation targets into local, regional and international food policies. This might allow better insights into the interplay between natural and agricultural patterns and processes, urgently required.

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