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Geographic distribution and environmental characterization of livestock production systems in Eastern Africa

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ABSTRACT

The central role played by livestock in the livelihoods of rural households in the developing world is seldom fully appreciated by policy makers, development agencies and donors. Knowledge gaps in the geographic distribution and environmental determinants of farming systems, especially if viewed through the livestock lens, compound this problem. We have produced a map of pastoral, agro-pastoral and mixed farming systems across Eastern Africa, by analysing datasets collected in the framework of livelihood analysis. Input data were gathered between 2000 and 2007 by various emergency and development agencies for Djibouti, Eritrea, Kenya, Somalia, Uganda and parts of Ethiopia and Sudan. A quantitative definition of the production systems is adopted, based on the ratio of livestock- to crop-derived income. The resulting livelihood-based map of livestock production systems was compared through correspondence analysis to an alternative livestock production systems map, produced independently from environmental data. Convergence between the two mapping approaches was evident. The geographic distribution of the livestock production systems was also modelled using multivariate analysis of remotely sensed and other geospatial datasets. Models show high statistical accuracy, and were thus used to fill the gaps in the observed distribution of livestock production systems. Finally, selected environmental factors underpinning the systems (agro-climatology, human and livestock populations and land cover) were analysed in detail, enabling the livestock production systems to be characterized in terms of them. The regional scope of the map, as well as its direct link with a vast amount of livelihood information, render it a valuable tool for a range of development and research applications, including those related to global change.

Abbreviations: CIESIN, Center for International Earth Science Information Network, Columbia University; CIAT, Centro Internacional de Agricultura Tropical; DPPA, Disaster Prevention and Preparedness Agency, Ethiopia; EWU-MAAIF, Early Warning Unit/Ministry of Agriculture, Animal Industries and Fisheries of Uganda; EC, European Commission; ECHO, European Commission's Humanitarian Aid Department; ESA, European Space Agency; FEG, Food Economy Group; FEWS-NET, Famine Early Warning System Network; FAO, Food and Agriculture Organization of the United Nations; FSAU, Food Security Analysis Unit, Somalia; GIS, geographic information system; GLC2000, Global Land Cover 2000; GRUMP, Global Rural–Urban Mapping Project; GLW, Gridded Livestock of the World; HEA, Household Economy Approach; IGAD, Intergovernmental Authority on Development; IPFRI, International Food Policy Research Institute; IFAD, International Fund for Agricultural Development; ILRI, International Livestock Research Institute; IC, Italian Cooperation; KFSM, Kenya Food Security Meeting; LCCS, Land Cover Classification System; LGP, length of growing period; LID, Livestock in Development; LPI, Livestock Policy Initiative; MERIS, medium resolution imaging spectrometer; NFIS, National Food Information System of Eritrea; NGO, non-governmental organization; PAAT, Programme against African Trypanosomiasis; SPOT, Satellite Pour l'Observation de la Terre; SC-UK, Save the Children-United Kingdom; SNNPR, Southern Nations, Nationalities, and Peoples' Region, Ethiopia; SSCCSE, Southern Sudan Centre for Census, Statistics and Evaluation; SIDA, Swedish International Development Cooperation Agency; *C*, total household income deriving from crops; *L*, total household income deriving from livestock; TLU, tropical livestock units; UDDM, Ugandan Department of Disaster Management; UN, United Nations; UNOCHA, United Nations Office for the Coordination of Humanitarian Affairs; USAID, United States Agency for International Development; WB, World Bank; WFP, World Food Programme.

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1. Introduction

It is estimated that livestock contributes to the livelihoods of at least 70% of rural poor (LID, 1999). Despite the importance of livestock to the diets and incomes of poor farmers in Eastern Africa (Sandford and Ashley, 2008) there is relatively little spatially explicit information on the level to which rural households rely on them.

This paper presents a regional map of livestock-oriented production systems that has been derived from livelihood analysis. The study area covers the member states of the Intergovernmental Authority on Development (IGAD) – a regional economic community in Eastern Africa comprising Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda. The work was a collaborative effort by the IGAD Livestock Policy Initiative (LPI) and the Programme against African Trypanosomiasis (PAAT). IGAD-LPI is a project that aims to enhance the contribution of the livestock sector to sustainable food security and poverty reduction in the IGAD region. PAAT is an alliance of international organizations assisting African countries to promote rural development in areas affected by tsetse-transmitted trypanosomiasis. Detailed information on the role of livestock in livelihoods is needed by both initiatives for a range of policy and technical applications.

One of the recent attempts to map livestock production systems was by the International Livestock Research Institute (ILRI) (Thornton et al., 2002; Kruska et al., 2003). They used geospatial datasets on human population density, land cover, length of growing period (LGP), temperature and irrigation to estimate the distribution of livestock production systems in the developing world. The resulting map depicted areas that are environmentally suitable for a given type of system, though it did not specifically incorporate livestock distributions nor the socio-cultural, political and economic factors that also influence livelihood strategies and the use of natural resources.

This study proposes an alternative mapping approach based on data collected for livelihood analysis, most notably in the framework of the Household Economy Approach (HEA) (Seaman et al., 2000; FEG Consulting and Save the Children, 2008). Livelihood analysis was developed to account for the diversity of coping strategies utilized in developing countries, especially by the rural poor. In livelihood studies, information on sources of food and cash income forms a key component of baseline assessments, and income data are linked to well-defined, mappable areas.

The first objective of this study was to use livelihood information to map the geographic distribution of livestock production systems in Eastern Africa. Since livelihood analysis relies predominantly on socio-economic data, the results of the mapping approach developed here can be considered, within the limits of accuracy and spatial resolution we discuss, a depiction of the reality on the ground.

Secondly, we explored the relationship between the environment, populations and the distribution of livestock production systems, thus providing a link between the systems and those factors that are likely to change in future years. The need for this analysis stems from the recognition that global change will affect many of the environmental factors underpinning livestock production systems in Eastern Africa. Demographers foresee the human population doubling to some 700 million over the next 40 years (UN, 2007). Rural population is expected to grow more slowly than urban population, and is forecast to stabilize over this period at a value 40% higher than the present (UN, 2008). This demographic transition is likely to take place in a context of climate warming, with scenarios for median temperature increase (multi-model dataset, A1B scenario, Christensen et al., 2007) lying between 3 and 4 °C for this century in all Saharan and sub-Saharan regions. This temperature increase, combined with changes in annual mean rainfall, is expected to affect profoundly the agricultural production potential (Fischer et al., 2002a).

Three approaches were used to explore the relationship between environmental factors and the distribution of livestock production systems in Eastern Africa. Firstly, the livelihood-based map described here was compared, through correspondence analysis, to a widely used livestock production systems map based on environmental data (Thornton et al., 2002; Kruska et al., 2003). Secondly, the geographic distribution of the livestock production systems in areas where the livelihood data were available was modelled using multivariate analysis of remotely sensed and other geospatial datasets, and these models were used to extend the systems classification into areas of the IGAD region where the livelihood data were unavailable. Finally, the livelihood-based livestock production systems were analysed in relation to agro-climatology (LGP), human and livestock population densities and land cover. These are important environmental factors associated with livestock production systems which hold potential for environmentally based, large scale mapping (Thornton et al., 2002).

2. Materials and methods

2.1. Livelihood maps: concepts, data formats and data availability in Eastern Africa

Livelihood analysis has become increasingly popular with development practitioners, as livelihoods appear to express the complexity of survival in low-income settings in a more complete manner than terms such as "subsistence" or "income" (Ellis, 2000). This has led to the development of various conceptual frameworks, including the sustainable livelihood framework (Scoones, 1998; Carney, 2003) and the HEA (Seaman et al., 2000). The HEA, which has been extensively used in Eastern Africa, was developed in the early 1990s by Save the Children-United Kingdom (SC-UK) with the initial goal of improving the ability to predict short-term changes in access to food. It is a framework for analysing the way people obtain the assets and resources they need, and it aims to help improve emergency response, disaster mitigation and long-term development.

A 'livelihood' can be characterized as the sum of activities and resources through which households fulfil their needs. Areas within which people share broadly the same pattern of livelihood – including aspects such as farming practices, consumption patterns, expenditure, trade and exchange – are defined as 'livelihood zones', depicted in 'livelihood maps'. Though spatial delineation of these zones should ideally be based on geography, production and markets, zone limits are frequently defined by administrative boundaries, as decisions on resource allocation and service provision are often made at this level.

One objective of livelihood analysis is to estimate the impact of various hazards or shocks on livelihoods. Outcomes are measured against a baseline, which includes estimates of the average access to food and cash income in a reference year (often split among three or four wealth groups). Crucial information can be derived from these baseline assessments that relate to production systems. In particular, the contribution of crops and livestock to the food basket and to cash income is clearly identified and can be used to rank or classify livelihood zones by their degree of reliance on livestock and livestock products.

Baseline data on production, expenditure, hazards and response strategies are normally gathered through rapid rural appraisal methods – mainly semi-structured interviewing of focus groups. These data are compiled and used to define 'livelihood profiles'. Profiles generated by different studies may differ in precise format and level of spatial detail, but they all contain information on how

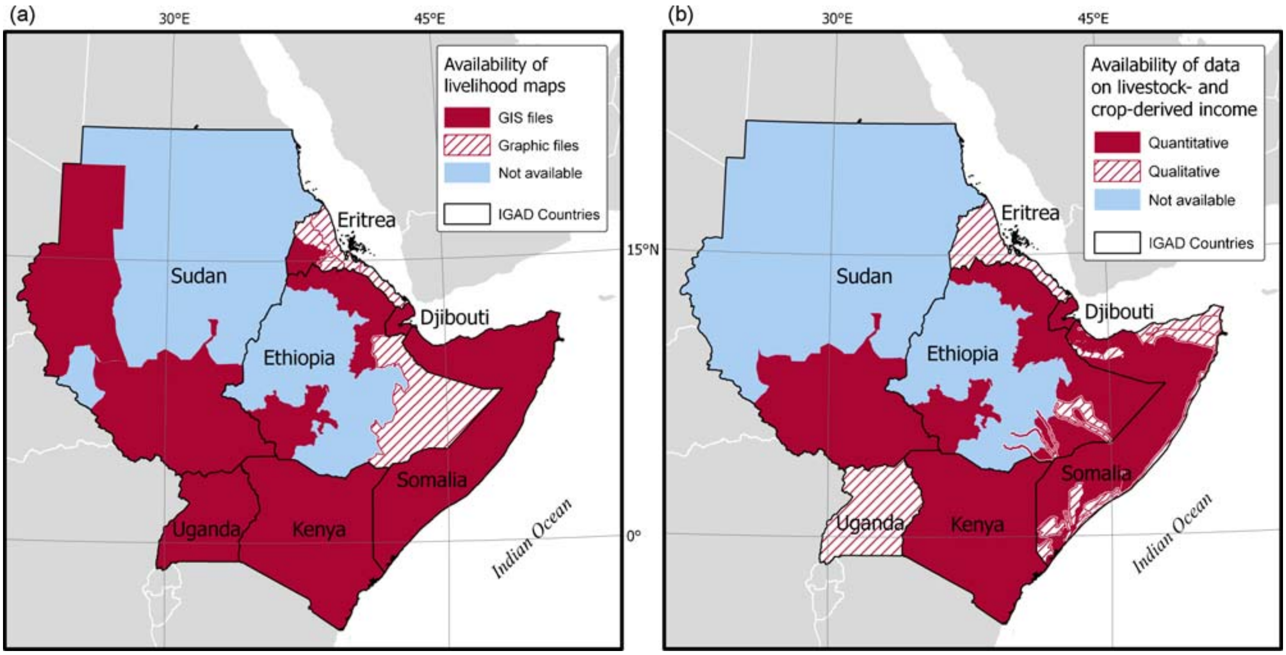

Fig. 1. Availability of (a) livelihood maps and (b) the related data on livestock- and crop-derived income in the IGAD region. Data sources: FEWS-NET, 2004, 2006–2007, 2006a, 2006b; FSAU and SC-UK, 2000–2001–2002; KFSM, 2006; NFIS, 2006; SC-UK and DPPA, 2001–2002–2004–2005; SSCCSE and SC-UK, 2005; UDSS et al., 2005 (see Abbreviations).

livestock contribute to livelihoods. Importantly, the majority of livelihood studies generate livelihood maps in geographic information system (GIS) format, and are thus amenable to spatial analysis (for this study, where GIS files were unavailable the graphic files depicting livelihood zones were georeferenced and digitized).

Livelihood analyses have been conducted for all or parts of some 30 countries worldwide, among which the majority are African and IGAD member states are well-represented (FEWS-NET, 2004, 2006–2007, 2006a, 2006b; FSAU and SC-UK, 2000–2001–2002, KFSM, 2006; NFIS, 2006; SC-UK and DPPA, 2001–2002–2004–2005; SSCCSE and SC-UK, 2005; UDSS et al., 2005, see Abbreviations). Fig. 1 shows the availability of data in the Horn of Africa, as used in the analysis described here.

Table 1 shows the number of livelihood zones defined in the various studies, and their average sizes. Substantial differences among countries are evident: average livelihood zones in Kenya cover about 2200 km^2, while those in Sudan average a much larger, 59,400 km^2.

2.2. Livestock production systems: definitions and mapping

Livestock production systems have previously been classified according to a number of criteria, including integration with cropping, animal–land relationships, agro-ecological zones, intensity of production, and type of product (Otte and Chilonda, 2002). A farming system approach, wherein a system is defined as a group of farms showing similar structure and function (Ruthenberg, 1980), has been widely used to classify livestock production systems (Jahnke, 1982; Wilson, 1995).

In the present analysis, the dominant livestock production system has been defined within each livelihood zone according to the relative dependency on livestock at the household level. If L is defined as the total household income derived from livestock and C as the total household income derived from crops, considering 'total income' as the sum of the value of the marketed production plus the estimated value of subsistence production (as was done by Otte and Chilonda, 2002), then the ratio L/C can be used to define three systems as follows:

- pastoral production systems: where $L/C \geq 4$;
- agro-pastoral production systems: where $1 < L/C < 4$; and
- mixed farming production systems: where $L/C \leq 1$.

These L/C thresholds were chosen to reflect the customary usage of the terms 'pastoral', 'agro-pastoral' and 'mixed farming' in the context of livelihood analysis. If, for example, a household relies entirely on livestock and crops as sources of food and cash income, an agro-pastoral system would be one in which livestock account for between 50% and 80% of the total income, while a pastoral system would have livestock accounting for over 80%.

L/C can be estimated for all households, or groups thereof, including those for which waged labour, remittances or commerce represent an important component of income. However, the relevance of terms such as 'pastoral' or 'mixed farming' is limited where crop and livestock agriculture makes only a marginal contribution to the household revenue. This is normally the case in urban areas, but may also occur where tourism, trade or fishing are the mainstay of the local economy. An 'urban and other areas' category was consequently introduced, which includes areas where the sum of livestock- and crop-derived income is less than 10% of the total income. A fifth class of 'protected areas' accounts for national parks and other reserves.

Where quantitative information was unavailable (most notably in Uganda and Eritrea, Fig. 1b), production systems were assigned according to the livelihood profiles and the descriptions of production systems therein. These normally include explicit, if qualitative, reference to the dominance of either pastoral, agro-pastoral or mixed farming systems. Livelihood information in these areas was complemented by expert opinion (see Acknowledgments).

The combined use of quantitative and qualitative information thus enabled the derivation of a map of livestock production systems in all areas of Eastern Africa where livelihood analysis has

Table 1
Number and average size of livelihood zones in Eastern Africa (by country or by first sub-national administrative unit).

Country	Region	Livelihood zones (number)	Average size of livelihood zones (km^2)	Approximate reporting period (year)
Djibouti		6	3,616	2003–2004
Eritrea		31	3,760	2003–2006
Ethiopia	Afar	7	13,607	2006
	SNNPR[a]	39	2,725	2005
	Somali	17	18,527	2001–2005
	Tigray	16	3,412	2006–2007
Kenya		261	2,223	2003–2005
Somalia		32	19,787	2004–2005
Sudan	South Sudan	7	59,473	2000–2004
Uganda		59	3,433	2003–2005

[a] Southern Nations, Nationalities, and Peoples' Region.

been conducted. A detailed, country-specific description of the input data used in the analysis, as well as the methods to estimate the dominant livestock production system, is beyond the scope of this paper but it is available from the corresponding author upon request (for more information see also Supplementary information (Table A1), which is available in the online version of this paper).

2.3. Correspondence analysis between the livelihood-based map of livestock production systems and a map based on environmental data

As opposed to the livelihood-based method proposed in this study, an alternative approach to mapping livestock production systems combines environmental datasets that include human population density, land cover, LGP, temperature and irrigation (Thornton et al., 2002; Kruska et al., 2003). The use of geospatial layers independent of socio-economic data makes the map by Thornton et al. (2002) suitable for comparison with the livelihood-based systems described here. The environmental approach was based on livestock systems defined by Seré and Steinfeld (1996) as follows:

- "solely livestock systems": those in which more than 90% of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds and less than 10% of the total value of production comes from non-livestock farming activities.
- "mixed farming systems": those in which more than 10% of the dry matter fed to animals comes from crop by-products, stubble or more than 10% of the total value of production comes from non-livestock farming activities.

In an attempt to render Seré and Steinfeld (1996) systems geographically, Thornton et al. (2002) combined digital maps within a decision tree to identify three main systems: (i) livestock only, rangeland-based systems; (ii) mixed rain-fed systems; and (iii) mixed irrigated systems, each of which was further disaggregated to account for agro-climatic conditions – distinguishing among arid/semi-arid; humid/sub-humid; and temperate/tropical highland areas.

For the correspondence analysis with the livelihood-based map, the map by Thornton et al. (2002) was updated using the most recent available GIS datasets. As opposed to the original, this new environmentally based map further distinguishes hyper-arid areas (where LGP is equal to zero days) from the arid/semi-arid areas (where $0 < \text{LGP} < 180$ days). Since irrigated systems are not widespread in Eastern Africa the distinction between irrigated and rain-fed agriculture was dropped for the comparison through correspondence analysis, and the respective mixed farming classes aggregated.

Correspondence analysis (Benzecri, 1973; Greenacre, 1984) is a way of comparing variables based on some measure of correspondence between them, usually frequency. Correspondence analysis plots enable visual inspection of the relationship between the variables and their categories, in that similar categories appear close to each other in the plot. We used rural population as a measure of correspondence between the two classifications because the dominant livestock production system within a given livelihood zone is that associated with the majority of the rural population in that zone, not the one covering the largest area. Rural population numbers were extracted from the Global Rural–Urban Mapping Project (GRUMP) database (CIESIN et al., 2004).

2.4. Modelling the distribution of livestock production systems

Livelihood data are not yet available for large areas of Ethiopia and Sudan. One way to fill the gaps in the observed distribution of the livelihood-based livestock production systems, and thus provide complete coverage for Eastern Africa, is to use stochastic spatial modelling techniques based on logistic regression. These techniques have been widely used to model a range of agro-ecological and epidemiological parameters that are likely to be related to climate, topography, and other environmental variables (Wint et al., 2002; Gilbert et al., 2005). For this study, we used them to model the presence or absence of each of the three livestock production systems.

Logistic regression models were generated using data extracted for each of a regular lattice of sample points spaced approximately 15 km apart. For each point, the presence or absence of a livestock production system was extracted, together with values for a wide range of potential predictor variables (see Table 2).

Separate models were constructed for each of the three defined livestock production systems. As logistic regression is very sensitive to the relative proportions of presence and absence values in the training data, points were sub-sampled to ensure that the numbers of positive and negative training points were equal. Sub-sampling of absence cases (the majority) was carried out by choosing cases at regular intervals within the database (such as every 10th case) when sorted by location coordinates (x and y). This ensured an even geographical spread of absence cases, and avoided any selection bias in terms of any of the predictor criteria. The regression relationships were then applied back to the selected predictor datasets to provide 1 km resolution images giving the predicted probability of presence for each of the three livestock production systems. Each pixel was then assigned the system with the highest predicted probability of presence.

There is a danger of using statistical models to extrapolate into areas that are very different, environmentally, to those from which the models were generated (i.e. into locations where the predictor values are outside the ranges occurring within the known distributions). The risk of this has been reduced by applying a mask defining areas that are unsuitable for ruminant livestock,

Table 2
Candidate predictors used for modelling the geographic distribution of livestock production systems. Spatial modelling was based on logistic regression.

Layers	Sources and references
Temporal Fourier processed MODIS satellite imagery (1 km resolution)[a]: Normalized difference vegetation index; Enhanced vegetation index; Daytime land surface temperature; Nighttime land surface temperature; Channel 3 temperature	Scharlemann et al., 2008
Temporal Fourier processed MODIS satellite imagery (5 km resolution)[a]: Potential evapotranspiration	
Monthly precipitation 1961–2000	Worlclim datasets URL: http://www.worldclim.org
Elevation	Derived from NASA Shuttle Radar Topography Mission data layer URL: http://eros.usgs.gov/products/elevation/
Slope	Derived from GLOBE Digital Elevation Map URL: http://www.ngdc.noaa.gov/mgg/topo/globe.html
Human population density	Gridded Population of the World (GRUMP) URL: http://beta.sedac.ciesin.columbia.edu/gpw/global.js
Distance to towns	Derived from Gridded Population of the World (GRUMP) urban extents URL: http://beta.sedac.ciesin.columbia.edu/gpw/global.js
Access to markets	Accessibility map (Nelson, 2008) URL: http://gem.jrc.ec.europa.eu/gam/index.htm.
Modelled poverty	Welfare Index Map of the Horn of Africa[b]
Distance to populated places	Derived from a gazetteer produced by National Center for Geographic Information and Analysis (NCGIA) URL: http://www.ncgia.ucsb.edu/
Agricultural parameters: cattle, sheep, goat, pig, chicken density, cultivation percentage, length of growing period (1 km resolution)	Produced by FAO IGAD Livestock Poverty Initiative, using methods described in Wint and Robinson (2007).
Distance to roads	Derived from Landscan 2000 Road dataset URL: http://www.ornl.gov/landscan
Rivers and lakes	Derived from MODIS imagery NDVI
Distance to rivers and water	Derived from rivers and lakes layers
Distance to wetland	Derived from International Water Management Institute wetlands layer URL: http://www.iwmi.cgiar.org/

[a] Variables subjected to Fourier processing to produce a series of additional data layers: mean, amplitude 1, amplitude 2, amplitude 3, phase 1, phase 2, phase 3, variance of mean, variance 1 (it refers to the percentage of variance in the total signal accounted for by Fourier component 1), variance 2, variance 3, variance all, minimum, maximum, range.

[b] Rogers, D.J., Alexander, N., Wint, G.R.W., 2008. Welfare Index Mapping in the Horn of Africa. Produced by Spatial Ecology and Epidemiology Group, Oxford University and ERGO Ltd. for the Pro-Poor Livestock Policy Initiative, FAO, Rome.

which is based on a series of eco-climatic, topographic and agricultural thresholds (Wint and Robinson, 2007).

2.5. Environmental characterization of the livestock production systems

GIS layers of human and livestock populations, length of growing period and land cover were combined with the livelihood-based map of livestock production systems to provide an environmental characterization of these systems in the IGAD region. In order to avoid circularity potentially ensuing from the use of the modelled distributions, these analyses were conducted using only the observed distributions of the systems, as depicted in Fig. 2. Gaps in the observed distributions have only been filled through modelling for calculating the human and livestock populations by country and by production system, in order to provide complete estimates for each country and for Eastern Africa as a whole.

2.5.1. Human population density

The relationship between livestock production systems and human population density was analysed by means of the GRUMP dataset (CIESIN et al., 2004), which estimates population numbers for the year 2000 on a 30 arc-second resolution grid (approximately 1 km at the equator), distinguishing urban and rural populations. Rural population growth rates, as estimated by the United Nations (UN, 2008), were applied to the GRUMP data (evenly across each country) to generate a rural population surface for the year 2005, which better corresponded to the time from which most of the livelihood data were collected (see Table 1). The average rural population density was calculated for each of the 410 zones, which were then ranked (by rural population density) and binned into deciles, each containing 41 zones. For each decile the proportion of the livelihood zones classified as each livestock production system was estimated and plotted by using the central value of each decile.

In addition to the analysis of human population density, the total rural population was estimated by country and livestock production system.

2.5.2. Livestock

Livestock production systems can also be characterized by the different combinations of livestock species they support. Livestock population estimates were taken from a series of 1 km resolution digital maps for the IGAD region, created within the framework of the IGAD-LPI using the methods described in Wint and Robinson (2007). Livestock population estimates generated by IGAD-LPI are based on the most recent national statistics available for the period 2000–2005. For the purpose of comparison, livestock populations can be expressed as tropical livestock units (TLUs), where one TLU is equivalent to 250 kg of biomass. The conversion factors used for the different species are: 1 for camels, 0.15 for sheep and goats, 0.7 for cattle, 0.02 for chicken and 0.5 for pigs (Jahnke, 1982).

As with the analysis of rural population, the livestock production systems map was also used to estimate livestock numbers by species, by livestock production system and by country.

2.5.3. Length of growing period

LGP is the number of days when both water availability and prevailing temperatures permit crop growth (Fischer et al., 2002b)

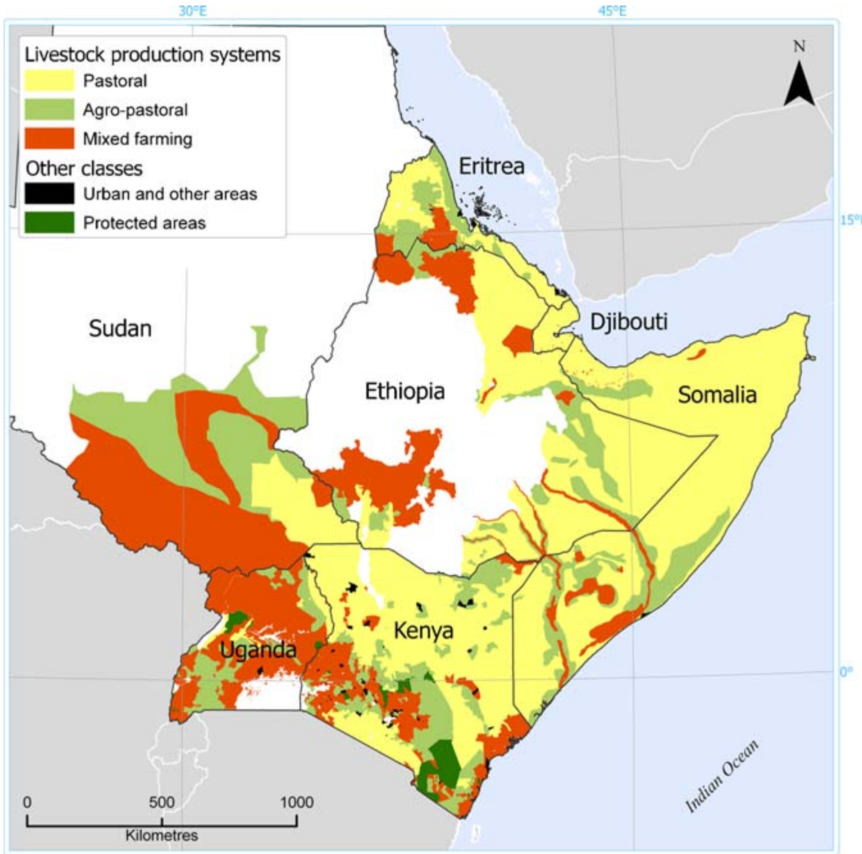

Fig. 2. Livestock production systems in the IGAD region. The systems are defined as a function of the ratio L/C, where L is the total household income derived from livestock and C is the total household income derived from crops. Total income is considered to be the sum of the value of the marketed production plus the estimated value of subsistence production (Otte and Chilonda, 2002). $L/C \geq 4$: pastoral; $1 < L/C < 4$: agro-pastoral; $L/C \leq 1$: mixed farming (the list of all livelihood zones and derived livestock production systems is available in Supplementary information (Table A1), see online version of this paper).

and can be calculated as a function of diurnal temperature range, precipitation and average daily temperature. LGP provides an environmental characterization particularly relevant to agricultural assessments, and has also been used to define and map livestock production systems. Seré and Steinfeld (1996), for example, used LGP to discriminate between production systems in arid, semi-arid, sub-humid and humid areas, and Thornton et al. (2002) subsequently used LGP to map the Seré and Steinfeld (1996) systems.

The livelihood-based map of livestock production systems was analysed with respect to LGP data derived from the WorldCLIM dataset (Hijmans et al., 2005), as described by Thornton et al. (2006). Values of LGP and production systems were extracted for each pixel, and extracted values ranked by LGP. These were binned using 18 equally spaced LGP classes and the proportions of each production system evaluated within each bin.

2.5.4. Land cover

Changes in land cover (i.e. the biophysical attributes of the earth's surface (Lambin et al., 2001)) readily signal human intervention, and can affect the ability of biological systems to sustain human needs (Vitousek et al., 1997), including the ability to support agricultural systems (Kruska et al., 2003). In order to clarify the relationship between land cover and livestock production systems in Eastern Africa, three datasets were explored: (i) Africover (http://africover.org/); (ii) Global Land Cover 2000 (GLC2000, Mayaux et al., 2004); and (iii) Globcover (Bicheron et al., 2006). All of these are based on the Land Cover Classification System (LCCS) (Di Gregorio, 2005).

The analysis of GLC2000[1] and Globcover[2] (version 2.2) is not discussed further in this paper, as the results confirmed the difficulty of mapping crops in Africa using medium resolution satellite imagery (Mayaux et al., 2004). By contrast, the higher resolution and the different mapping methodology of the Africover maps render them suitable to describe the land cover patterns within livestock production systems of Eastern Africa despite their earlier production date.[3]

The FAO Africover project produced national maps for 10 countries in Eastern Africa, including five IGAD member states (Eritrea, Kenya, Somalia, Sudan and Uganda). Africover maps rely on visual interpretation of medium-high resolution imagery acquired by Landsat satellites, followed by ground-truthing. Spatial resolution of the sensors on board the Landsat satellites used by Africover ranges from 15 to 30 m, resulting in land cover maps at scales of between 1:100,000 and 1:200,000. For the present study, a simplified map based on 10 land cover classes was derived from thematic aggregation of over 500 classes that are described in the full resolution, multipurpose Africover databases (the table of class aggregation is available in Supplementary

[1] GLC2000 is mainly based on daily data collected by the "vegetation" sensor on the "Satellite Pour l'Observation de la Terre" (SPOT) 4 satellite, acquired between 1 November 1999 and 31 December 2000.

[2] Satellite imagery for Globcover land cover was acquired between January 2005 and June 2006 by the medium resolution imaging spectrometer (MERIS), on-board the European Space Agency (ESA)'s Envisat platform.

[3] Satellite images used by the Africover project were acquired mainly in the year 2000–2001 for Uganda, 1999 for Eritrea and Kenya, 1995–1998 for Somalia, 1994–1999 for Sudan.

Table 3
Total land area by livestock production system, as derived from available livelihood maps.

Country	Region	Pastoral (km^2)	Agro-pastoral (km^2)	Mixed farming (km^2)
Djibouti		21,539	–	157
Eritrea		59,770	40,794	17,695
Ethiopia	SNNPR[a]	15,391	10,786	80,088
	Afar	84,848	472	9,930
	Tigray	–	12,881	41,714
	Somali	240,228	58,500	16,235
Kenya		336,367	112,081	97,881
Somalia		501,905	95,375	35,397
Sudan	South Sudan	67,845	190,315	285,340
Uganda		13,313	48,782	138,233

[a]Southern Nations, Nationalities, and Peoples' Region.

information (Table A2), see online version of this paper). Thematic aggregation was carried out in compliance with LCCS rules.

3. Results

Fig. 2 shows the distribution of livestock production systems in Eastern Africa as derived from livelihood data. Allowing for the exclusion of protected areas and zones where less than 10% of the total income is derived from agriculture (i.e. 'Urban and other areas'), near complete coverage was achieved in areas where livelihood studies were undertaken (the list of all livelihood zones and derived livestock production systems, upon which this map is based, is available in Supplementary information (Table A1), see online version of this paper).

Approximately three quarters (72%) of the study area is characterized by the dominance of livestock rearing over crop agriculture (i.e. pastoral or agro-pastoral production systems). This is further illustrated in the national and sub-national breakdowns given in Table 3.

3.1. Correspondence analysis between the livelihood-based map of livestock production systems and a map based on environmental data

Results of the correspondence analysis (Table 4; Fig. 3) reveal a good agreement between the mapping approach based on livelihood data and that based on environmental data. Table 4 shows, for each livelihood-based production system, the proportional distribution of the rural population among the environmentally based systems.

Approximately two thirds of rural people living in pastoral livelihood zones are found in the class "livestock only, arid/semi-arid", while over 80% of rural people in mixed farming zones are found in temperate/tropical highland and humid/sub-humid mixed areas. Populations living in agro-pastoral livelihood zones tend to be concentrated in arid/semi-arid areas (both "mixed farming" and "livestock only"). Hyper-arid areas are only marginally represented in the study region.

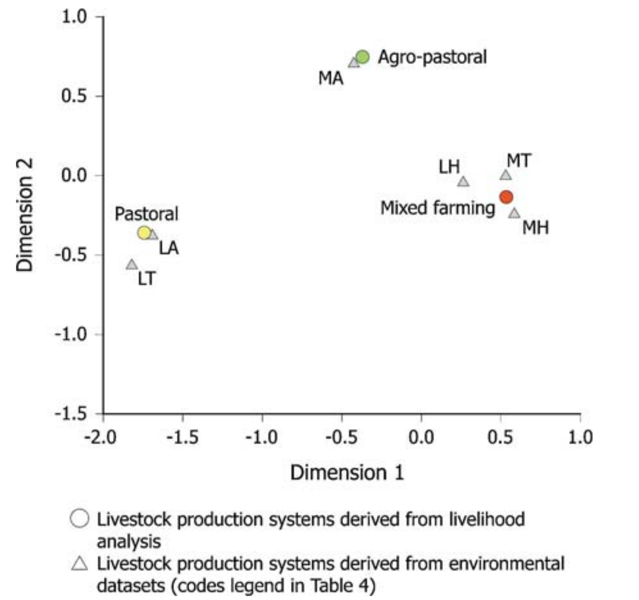

Fig. 3. Correspondence analysis plot between livelihood-derived and environmentally derived maps of livestock production systems. The livelihood-derived distribution is that shown in Fig. 2; the environmentally derived map is an updated version of that produced by Thornton et al. (2002). In the latter map, the distinction between irrigated and rain-fed systems has been dropped. For the present analysis, rural population is used as a measure of correspondence (symmetrical normalization).

Fig. 3 shows the correspondence analysis plot between the outputs of the two different approaches to mapping livestock production systems.

With the exception of the category "livestock only, humid/sub-humid" (LH), all combinations in Fig. 3 are easily interpreted: livestock only, both arid/semi-arid (LA) and temperate/tropical highland (LT), are strongly associated with pastoral livelihood zones; "mixed arid/semi-arid" (MA) is associated with agro-pastoral zones, and "mixed temperate/tropical highland" (MT) and humid/sub-humid (MH) correspond to mixed farming livelihood zones. The anomalous position of the LH category may be explained (a) by its limited presence in the study region (see Table 4) and (b) since in Eastern Africa these LH areas are intermixed with MH areas within the boundaries of zones in which livelihoods depend predominantly on crops. Thus, the association

Table 4
Correspondence analysis between livelihood-derived and environmentally derived maps of livestock production systems (column profile based on the correspondence table). Rural population is used as measure of correspondence.

Environmentally derived livestock production systems (name and code)	Livelihood-derived livestock production systems rural population		
	Pastoral (%)	Agro-pastoral (%)	Mixed farming (%)
Livestock only, hyper-arid (LY)	0.4	0.0	0.0
Livestock only, arid/semi-arid (LA)	63.8	21.1	2.3
Livestock only, temperate/tropical highland (LT)	1.4	0.4	0.0
Livestock only, humid/sub-humid (LH)	0.6	0.9	1.1
Mixed hyper-arid (MY)	0.0	0.0	0.0
Mixed arid/semi-arid (MA)	29.2	33.1	13.3
Mixed temperate/tropical highland (MT)	2.4	25.6	41.1
Mixed humid/sub-humid (MH)	2.1	18.9	42.1
Total	100	100	100

Table 5
Accuracy metrics for the models of livestock production systems (confusion matrixes).

Value	Pastoral			Agro-pastoral			Mixed farming		
	0	1	% Correct	0	1	% Correct	0	1	% Correct
0	5,543	751	88.1	1,861	523	78.1	2,697	369	88.0
1	391	5,199	93.0	446	1,887	80.9	349	2,601	88.2
All			90.4			79.5			88.1

between LH and mixed farming zones appears to be an artefact of limited coverage and spatial resolution, rather than a functional association.

3.2. Modelled distribution of livestock production systems

Results of the correspondence analysis presented in the previous section illustrate the link between livelihoods and the environmental datasets used by Thornton et al. (2002) to generate maps of livestock production systems for the developing world. Results of the statistical modelling of livelihood-based production systems confirm the strong link with environmental parameters. In Table 5, the accuracy metrics for the models are given. They show the models for pastoral and mixed farming zones to be nearly 90% correct and that for the agro-pastoral zones to be about 80% correct.

Fig. 4 shows the modelled distribution of pastoral, agro-pastoral and mixed farming systems in the IGAD member states. Areas unsuitable for livestock – including high elevation areas, urban centres, water bodies, forests and protected areas – have been masked out. A second mask depicts desert areas where environmental conditions are not suitable for rearing ruminant livestock.

The statistical accuracy of the models provides good grounds for using them to fill the gaps in the livelihood-based map of livestock production systems shown in Fig. 2.

3.3. Environmental characterization of the livestock production systems

3.3.1. Human population density

The pattern of association between the livelihood-based livestock production systems and rural population density is shown in Fig. 5, with population density (*x*-axis) plotted on a logarithmic scale.

Pastoral systems predominate for densities of 20 people km^{-2} or less and they decrease in frequency as population density increases. Mixed farming systems are the most widespread for densities in excess of 35 people km^{-2}, while the proportion of agro-pastoral systems peaks at approximately 30 people km^{-2}. While the broad trends of the relationship between production systems and population density are clear – the proportion of pastoral systems steadily decreases as population density increases; mixed farming systems display the opposite trend

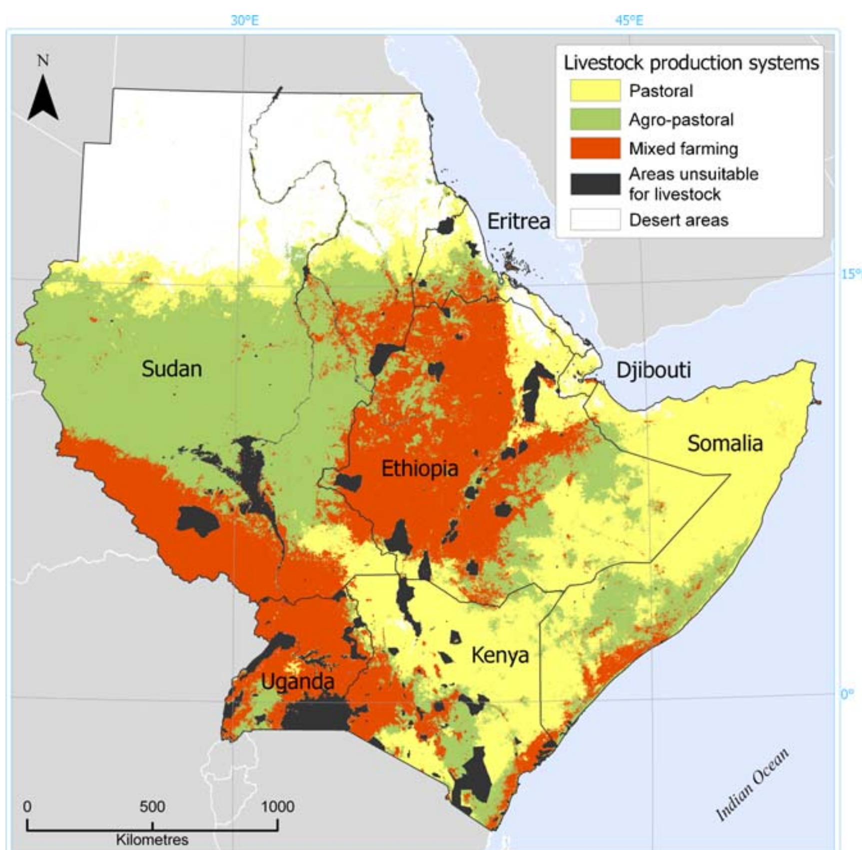

Fig. 4. Modelled distribution of livestock production systems in the IGAD region. The models are based on logistic regression of the observed distribution of the systems (as depicted in Fig. 2) against a range of remotely sensed and other geospatial datasets (Table 2). Deserts as well as other areas unsuitable for livestock (including high elevation areas, urban centres, water bodies, forests and protected areas) have been masked out.

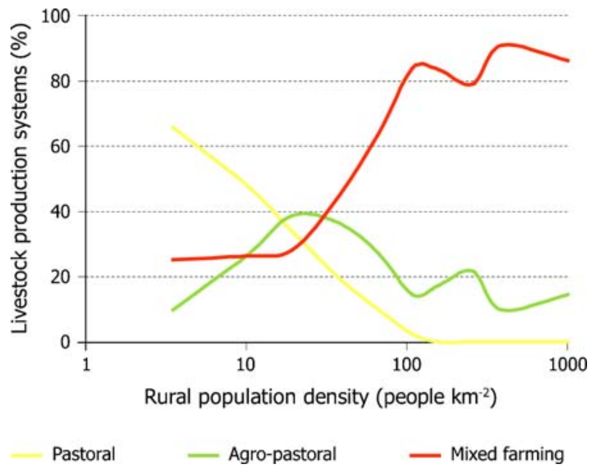

Fig. 5. Proportion of the three livestock production systems as a function of rural population density in 2005 (people km^{-2}). Rural population density is based on the GRUMP dataset for the year 2000 (CIESIN et al., 2004), which was adjusted to 2005 by using rural population growth rates as estimated by the United Nations (UN, 2008). The average rural population density was calculated for each of the 410 zones, which were then ranked (by rural population density) and binned into deciles, each containing 41 zones. For each decile the proportion of the livelihood zones classified as each livestock production system was estimated and plotted on a logarithmic scale by using the central value of each decile.

and agro-pastoral systems peak at intermediate density values – it is difficult to interpret some of the details in the graph: the irregular, undulating shape of the curves at densities greater that 100 people km^{-2}, for example. Several factors related to the collection methods and formats of livelihood data may be responsible for these irregular pattern. One problem, for example, may be the diversity in the sizes of livelihood zones, which serve as denominators in density calculations.

Global GIS layers of human population density were also used to estimate the rural population by country and livestock production system (using a complete regional map of the systems, with gaps filled with modelled data). The estimates presented in Table 6 have been rounded to the nearest thousand in consideration of the uncertainties in the calculations and the natural fluctuations of the quantities described, which are very likely to occur also at small time scales.

In the IGAD region as a whole, approximately 50 million rural people (over a third) are estimated to live in pastoral and agro-pastoral areas, in which livestock make the predominant contribution to livelihoods.

3.3.2. Livestock

Fig. 6 shows the proportions of different livestock species that occur within the different livestock production systems.

Cattle are the most represented species in all three systems, accounting for approximately 30%, 60% and 72% of the whole stock for the pastoral, agro-pastoral and mixed farming systems respectively. However, we note that in pastoral zones, cattle's share is equalled by camels', and even surpassed by small ruminants', as sheep and goats combined account for over 40%.

Table 6
Rural population by country and livestock production systems in the IGAD region (numbers given in thousands).

Country	Rural population			Total
	Pastoral	Agro-pastoral	Mixed farming	
Djibouti	135	–	1	136
Eritrea	766	1,249	1,558	3,573
Ethiopia	4,585	6,722	50,090	61,397
Kenya	2,048	6,392	16,972	25,412
Somalia	4,947	1,372	1,150	7,469
Sudan	3,263	14,926	3,689	21,878
Uganda	282	3,696	19,437	23,415
IGAD region	16,026	34,357	92,898	143,281

In Table 7 livestock numbers by species and by livestock production system are provided for each IGAD member state and for the study region as a whole. As done in Table 6, and for similar reasons, the figures in Table 7 have been rounded to the nearest thousand.

3.3.3. Length of growing period and land cover

The proportions of pastoral, agro-pastoral and mixed farming systems as they relate to LGP are shown in Fig. 7.

Fig. 7a shows how the relative dependence on livestock and crops of rural households is correlated with agro-ecology: areas with low LGP values are dominated by pastoral systems, areas with high values by mixed farming and, in a narrow intermediate range (130–170 days), agro-pastoral systems predominate. Alternative perspectives are shown in Fig. 7b, where agro-pastoral and mixed farming systems have been combined, revealing an LGP threshold for truly pastoral systems of <110 days, and in Fig. 7c, where the pastoral and agro-pastoral systems have been combined, revealing an LGP threshold for truly mixed systems of >180 days.

Finally, the patterns of association between land cover classes and the three livestock production systems is shown in Fig. 8.

As concerns natural vegetation, the proportion of the class "forests and woodlands" decreases markedly from mixed farming areas, through agro-pastoral to pastoral areas. Conversely, the proportions of "shrubland", "savannah", "grassland", "sparse vegetation" and "bare soil" increase.

It is also interesting to note that the proportions of "cultivated areas" in the three systems, i.e. approximately 18%, 9% and 1% in the mixed farming, agro-pastoral and pastoral systems respectively, are coherent with the systems' definitions based on crop- and livestock-derived income, in that cropping indeed appear to be marginal in pastoral areas, while it occupies a sizable, but clearly distinguishable surface in the agro-pastoral and mixed farming zones.

4. Discussion on potential pitfalls and sources of error

Assembling and harmonizing heterogeneous livelihood datasets over such large and diverse a region as Eastern Africa is fraught with difficulties, biases and uncertainties, which can affect various processing steps.

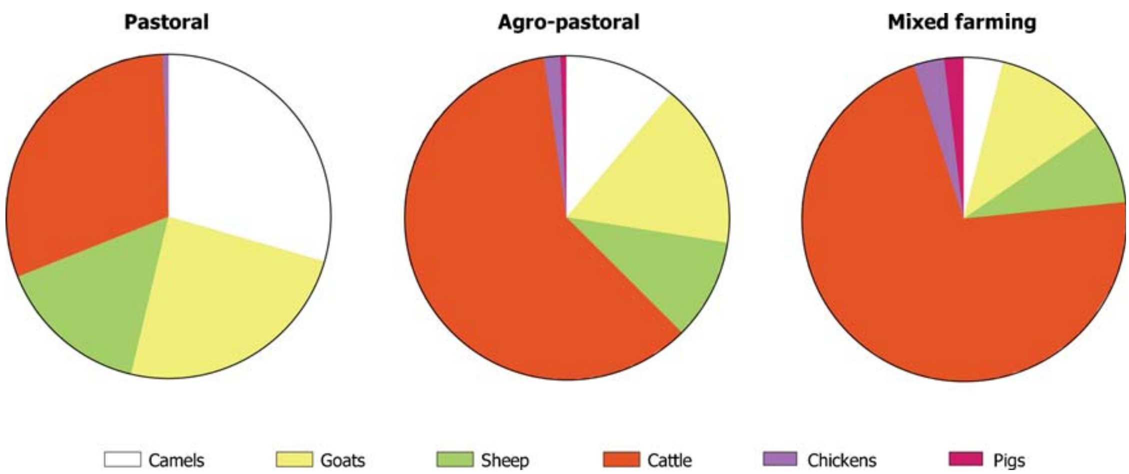

Fig. 6. Proportions of camels, goats, sheep, cattle, chickens and pigs within each livestock production systems in the IGAD region. All species are measured in terms of tropical livestock units (TLUs). The conversion factors used for the different species are: 1 for camels, 0.15 for sheep and goats, 0.7 for cattle, 0.02 for chicken and 0.5 for pigs (Jahnke, 1982).

One major source of uncertainty is due to the inherent accuracy of the quantitative livelihood data from which the map of livestock production systems was derived. The reported statistics normally provide average household incomes derived from livestock and crops within each study unit (livelihood zone), but these are not accompanied by estimates of variability, so it is not possible to assess precision. It would be even more difficult to evaluate the reliability of the livestock production systems map for those livelihood zones where quantitative information was lacking (e.g. in Uganda and Eritrea) and the dominant livestock production system was determined from qualitative, descriptive information combined with expert opinion. The simplicity of the three-class livestock production systems classification adopted here, while capturing significant geographic and environmental patterns, substantially reduces problems arising from such errors. More detailed classifications would have been impossible to implement

Table 7
Livestock populations in the IGAD region by country and livestock production system (numbers given in thousands). The column 'Totals' is calculated by converting all species numbers into tropical livestock units (TLUs); conversion factors are: 1 for camels, 0.15 for sheep and goats, 0.7 for cattle, 0.02 for chicken and 0.5 for pigs (Jahnke, 1982).

Country	Production systems	Camels	Goats	Sheep	Cattle	Chickens	Pigs	Totals (TLUs)
Djibouti	Pastoral	72	630	554	284	2,045	–	489
	Agro-pastoral	–	–	–	–	–	–	–
	Mixed farming	1	19	20	5	114	–	12
	Sub-total Djibouti	73	649	574	289	2,159	–	502
Eritrea	Pastoral	144	2,023	701	625	964	–	1,010
	Agro-pastoral	113	1,364	539	540	1,341	–	803
	Mixed farming	39	948	734	619	1,320	–	751
	Sub-total Eritrea	295	4,335	1,974	1,784	3,626	–	2,563
Ethiopia	Pastoral	1,672	9,066	7,307	3,707	469	2	6,733
	Agro-pastoral	281	3,357	2,272	5,536	5,602	3	5,114
	Mixed farming	402	10,877	13,806	35,501	38,341	23	29,734
	Sub-total Ethiopia	2,355	23,300	23,386	44,744	44,412	28	41,581
Kenya	Pastoral	648	6,009	4,478	2,538	1,316	9	4,028
	Agro-pastoral	139	3,176	2,137	2,742	6,255	54	3,008
	Mixed farming	75	2,800	2,143	4,903	11,252	174	4,561
	Sub-total Kenya	861	11,985	8,758	10,183	18,823	238	11,596
Somalia	Pastoral	5,428	24,939	13,441	3,471	1,947	–	13,654
	Agro-pastoral	1,334	4,057	1,283	1,391	630	–	3,121
	Mixed farming	596	1,009	298	590	531	–	1,216
	Sub-total Somalia	7,359	30,004	15,022	5,452	3,108	–	17,991
Sudan	Pastoral	1,052	3,294	3,122	863	8,247	–	2,784
	Agro-pastoral	1,958	28,079	33,482	28,829	20,809	–	31,788
	Mixed farming	214	7,698	8,842	6,862	5,254	–	7,604
	Sub-total Sudan	3,224	39,071	45,445	36,554	34,310	–	42,175
Uganda	Pastoral	–	373	257	718	236	11	608
	Agro-pastoral	1	1,379	743	2,510	1,985	101	2,166
	Mixed farming	2	3,580	837	3,104	9,184	658	3,350
	Sub-total Uganda	3	5,376	1,854	6,391	11,518	785	6,184
IGAD region	Pastoral	9,016	46,335	29,859	12,206	15,225	22	29,305
	Agro-pastoral	3,825	41,412	40,457	41,548	36,622	158	46
	Mixed farming	1,329	26,931	26,680	51,583	65,996	856	47,227
	Grand total	14,170	114,678	96,996	105,337	117,842	1,036	122,532

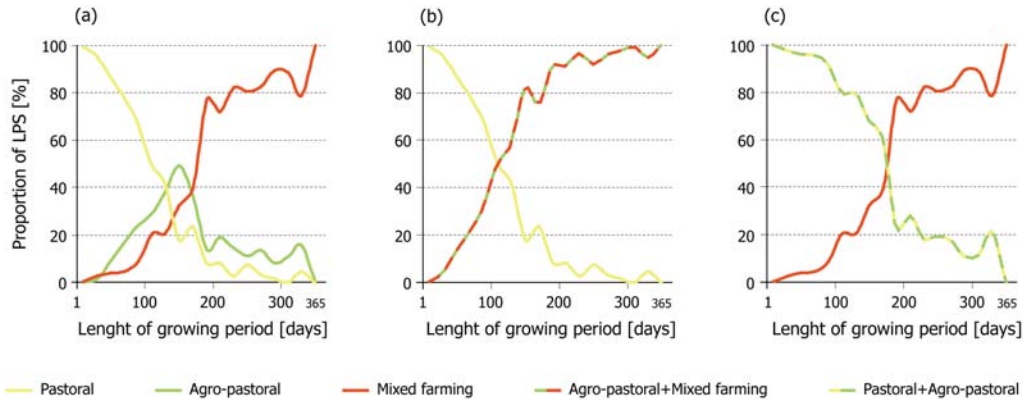

Fig. 7. Livestock production systems and length of growing period (LGP). LGP data were derived from the WorldCLIM 1 km climate grid (Hijmans et al., 2005), as described by Thornton et al. (2006). Values of LGP and production systems were extracted pixel by pixel, subsequently ranked by LGP, and binned by using 18 equally spaced LGP classes before calculating the proportion of each production system in each bin. In (b) agro-pastoral systems were combined with mixed farming systems; in (c) they were combined with pastoral systems (dashed lines).

at the regional level, though they may be feasible for some countries.

A further source of error, in this case inconsistency, is caused by the significant size differences among livelihood zones. Large livelihood zones, for example those delineated for South Sudan, may hide a mosaic of diverse livestock production systems that would only be captured at higher spatial resolutions. That said, livelihood analysis demarcates zones to be relatively homogeneous in terms of production, consumption and risk patterns. The potential bias introduced by the size factor in the mapping of livestock production systems is, therefore, likely not to be great.

Lastly, there are diverse ways in which different livelihood approaches collect and disseminate livelihood data. For example,

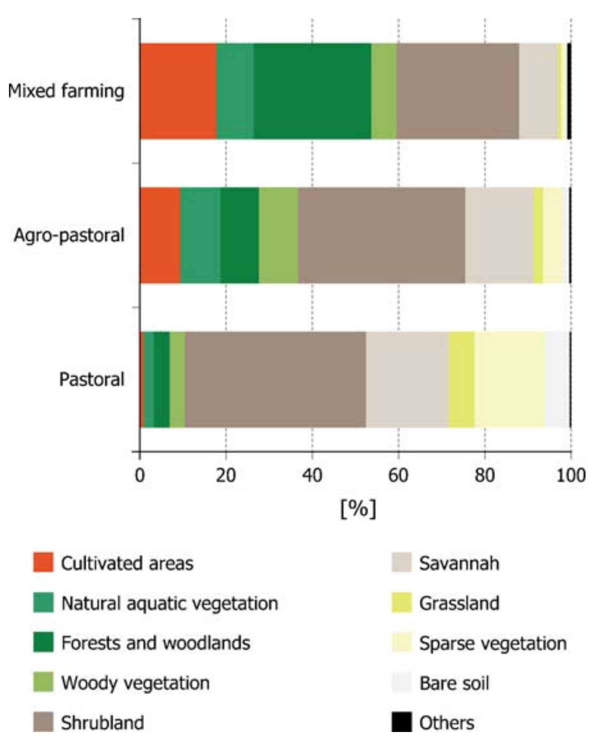

Fig. 8. Land cover (Africover) in livestock production systems for Eritrea, Kenya, Somalia, South Sudan and Uganda. A simplified land cover map based on ten classes was derived from thematic aggregation of over 500 classes originally described in the full resolution, multipurpose Africover databases (the table of class aggregation is available in Supplementary information (Table A2), see online version of this paper).

different wealth groups within the livelihood zone are studied separately only by certain approaches, while other frameworks provide information for the average household only. This and other differences are part of the challenges of carrying out a regional study and they are also likely to have an impact on the accuracy of the results.

5. Conclusions

Data generated through livelihood analysis have been used to incorporate socio-economic and livestock related information into the mapping of livestock production systems in Eastern Africa and to examine the relationships between these systems and the environment. Recognizing that demographic dynamics and environmental and climatic modifications will pose exceptional challenges to the livelihoods and the welfare of poor farmers in future years (FAO, 2008; Schneider et al., 2007), the attention here has been focussed on those factors that are likely to most affect agricultural production.

As an example, the spatial pattern of change in agro-ecology in Eastern Africa, measured in terms of LGP, is expected to be complex, with some areas increasing while other fall (Thornton et al., 2002). If, as this study suggests, LGP is a major determinant of livestock production systems, then these changes are likely to alter peoples' livelihoods within the region, thus potentially posing further challenges to the ability of poor farmers to cope with future climatic vagaries (Boko et al., 2007).

The analysis presented here has demonstrated that livelihood maps can help improve our knowledge of the geographic distribution of livestock production systems. It has also highlighted gaps; suggesting that better availability of livelihood data (especially the raw data collected in baseline assessments) and better harmonization across the different livelihood analysis frameworks would facilitate quantitative analysis at the regional level.

The map of livestock production systems for the IGAD region elucidates some of the environmental correlates of livelihood strategies. The ways in which rural people access food and cash income appear to be strongly linked with the environment: sufficiently so to allow statistical modelling of these systems using environmental predictors. Furthermore, future studies could benefit from the correlations identified between livestock production systems and environmental parameters such as LGP and rural population density. A better understanding of these relationships will help predict how the systems may evolve in space and time (Jagtap and Amissah-Arthur, 1999; Kristjanson et al., 2003), driven by both environmental dynamics (Thornton et al., 2004) and intensification processes (Bouwman et al., 2005).

Incorporating socio-economic and livestock related information into the systems' definition may also help to make the mapping of agricultural systems more useful, in that maps can be linked to more aspects of the rural livelihoods than has hitherto been the case. The fact that livelihood analyses are widely used within the development community, and are being produced in more and more countries, also indicates that data will be available to extend the approach presented here to much of the developing world.

The map of livestock production systems may also contribute to raising the awareness of the central role played by livestock in farmers' livelihoods in the developing world (Anderson, 2003; Randolph et al., 2000; Moll, 2005). It is estimated here that nearly 40% of all livestock in the IGAD region are kept in mixed farming areas, where they contribute to rural livelihoods in diverse ways, not least by enhancing crop production through manure and draught power and by providing additional indirect inputs to livelihoods that are seldom properly accounted for. Moreover, an estimated 50 million rural people in Eastern Africa – over a third of the rural population – live in areas where livestock predominate over crops as a source of income. Investment statistics would suggest that this fact often fails to be appreciated fully by governments, donors and policy makers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agee.2009.08.011.

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