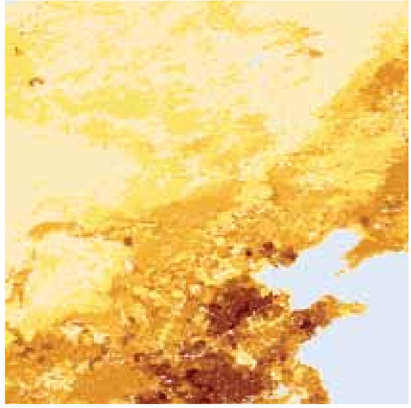

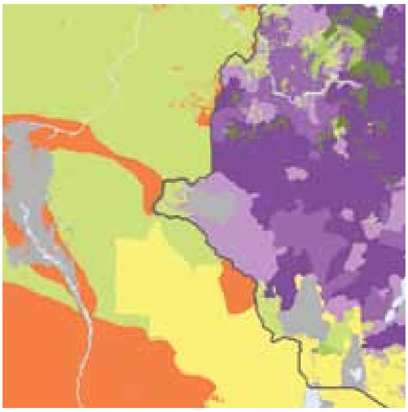

Global livestock production systems

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

Pro-Poor Livestock Policy Initiative
A Living from Livestock

FIAT PANIS

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Global livestock production systems

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Contents

Abbreviations and acronyms

AAT	African Animal Trypanosomosis
ADF	African Development Fund
AEZ	Agro-Ecological Zone
AGA	Animal Production and Health Division of the Food and Agriculture Organization
AVHRR	Advanced Very High Resolution Radiometer
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIESIN	Centre for International Earth Science Information Network
CSA	Central and South America
CWANA	Central and West Asia and North Africa
EA	East Asia
EAP	East Asia and the Pacific
EECA	Eastern Europe and Central Asia
ERGO	Environmental Research Group Oxford
ESAP	East and South Asia and the Pacific
FAO	Food and Agriculture Organisation of the United Nations
FPU	Food Producing Unit
GAUL	Global Administrative Unit Layers
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GLC	Global Land Cover
GLIMS	Global Livestock Impact Mapping System
GLiPHA	Global Livestock Production and Health Atlas
GLW	Gridded Livestock of the World
GPW	Gridded Population of the World
GRUMP	Global Rural-Urban Mapping Project
HIC	High Income Countries
IAASTD	International Assessment of Agricultural Science and Technology for Development
IFPRI	International Food Policy Research Institute

IGAD	Intergovernmental Authority for Development
IGBP	International Global Biosphere Project
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
ISCBD	Interim Secretariat for the Convention on Biological Diversity
LAC	Latin America and the Caribbean
LCCS	Land Cover Classification System
LDPS-2	Livestock Development Planning System, Version 2
LGP	Length of Growing Period
LID	Livestock in Development
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries (Uganda)
MEA	Millennium Ecosystem Assessment
MENA	Middle East and North Africa
MERIS	Medium Resolution Imaging Spectrometer
MLCCA	MODIS Land Cover Classification Algorithm
MODIS	Moderate Resolution Imaging Spectroradiometer
NAE	North America and Europe
NCGIA	National Center for Geographic Information and Analysis (USA)
NEMA	National Environment Management Agency (Uganda)
NPA	National Planning Authority (Uganda)
NRP	National Rural Poverty line
OIE	World Organization for Animal Health
PLK	Poor Livestock Keeper
PNN	Probabilistic Neural Network
PPLPI	Pro-Poor Livestock Policy Initiative
SA	South Asia
SC-UK	Save the Children-United Kingdom
SEA	Southeast Asia
SIDA	Swedish International Development Cooperation Agency
SPAM	Spatial Production Allocation Model
SPOT	Système Pour l'Observation de la Terre
SSA	Sub-Saharan Africa
SSCCSE	Southern Sudan Centre for Census, Statistics and Evaluation
TLU	Tropical Livestock Unit

UBOS	Uganda Bureau of Statistics
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USA	United States of America
USGS	United States Geological Survey
VHLSS	Vietnam Household Living Standards Survey
WANA	West Asia and North Africa
WRI	World Resources Institute

Compound abbreviations for livestock production systems

L	Livestock only production system
M	Mixed, crop-livestock production system
C	Crop only production system
G	Grassland-based
L	Landless
R	Rainfed
I	Irrigated
HYP	Hyper-arid
A	Arid and semi-arid tropics and subtropics
H	Humid and sub-humid tropics and subtropics
T	Temperate and tropical highlands

e.g. LGA = Livestock only, grassland-based, arid and semi-arid tropics and subtropics

Foreword

The global livestock sector is rapidly changing in response to globalization and growing demand for animal-source foods, driven by population growth and increasing wealth in much of the developing world. The rapid rate of urbanization seen in many countries is not only linked to growing affluence but also gives rise to changes in people's food preferences; usually tending towards greater convenience and higher standards of safety. As well as the many benefits and opportunities associated with rapid sector transformation and growth, they are also associated with social, environmental and public health risks. Moreover, there is a growing appreciation that the livestock sector needs to operate in a carbon-constrained economy, resulting in increasing competition for land and water resources, and growing pressure for the sector to be managed cleanly, safely and sustainably. But there are huge differences in the ways in which livestock are kept in different places and what their roles are. We need to develop a good understanding of the differences among production systems if we are to be able to help poor livestock keepers take advantage of the rising demand for animal-source foods, help livestock keepers adapt to a changing and more volatile climate; minimize the risk of disease emergence and spread, not only among livestock but also in people; and to help all livestock keepers mitigate greenhouse gas emissions via a wide range of options.

This book has grown out of a long-standing collaboration between the Food and Agriculture Organization of the United Nations (FAO), and the International Livestock Research Institute (ILRI). It emerged from a meeting of international organizations held at the Earth Institute at Columbia University in 2004, at which FAO and the Consultative Group in International Agricultural Research were charged with closing a gap in our understanding of the distribution of agricultural production systems. The book took further shape following a workshop convened by FAO in Bangkok in 2006, during which the custodians of many of the key datasets needed to produce maps of global livestock production systems were brought together with experts and researchers in agricultural production systems. It brings together the results of several years' of activity by FAO and ILRI, along with colleagues from the International Food Policy Research Institute, the International Institute for Applied Systems Analysis and many other organisations not explicitly linked to the production of the book.

The book provides a stock-take of where we are with livestock system classification. It presents the most up to date maps of global livestock production systems and provides revised estimates of the number of poor livestock keepers, globally, within the different production systems. It proposes alternative approaches to mapping production systems that are explicitly linked to livelihoods, and reviews the ways in which intensive production can be accounted for. Several examples are presented of how systems' information can be of value. It also underscores the areas that need further development. The FAO and ILRI continue to work jointly on several of these.

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Summary

One of the datasets that is becoming increasingly important for priority-setting and targeting by organisations with a mandate for agriculture and agricultural research for development is a spatial agricultural systems classification that provides not only detailed information on the distribution of crops and livestock in different places, but also information on how they are produced and how the various elements interact.

There is considerable spatial heterogeneity in the determinants of rural poverty, and development interventions increasingly need to be targeted at relatively small groups of people, calling for a finer grain in the definition of intervention domains than has been available in the past. Despite the continued development of sophisticated spatial analysis methods and tools, and improving availability of global, spatial datasets, there are still considerable constraints to the development of high-resolution data on livestock, crops, population, climate, land cover and land use to develop useful systems maps that can meet the requirements of a wide variety of potential users.

A short historical review is given of some of the global agricultural systems classifications that have been proposed. A systems classification based on three levels of increasing complexity is presented, and this is used as an organising framework throughout the book. Level one in the classification describes potential livestock production systems and relies on a simple set of global datasets that is continually being updated. Despite its simplicity, this classification system, like many others, relies on land cover data. Problems of uncertainty in all the land cover products currently available persist, although there are several on-going efforts to address these. Level two moves from potential to actual livestock production systems, and attempts to account for other livelihood options in addition to the specific combinations of crops and livestock that people depend on. Level three addresses issues relating to the intensity and scale of production, to incorporate information on management practices, moving from what is done to how it is done.

The relationships between livestock production systems, rural livelihoods and poverty are investigated using case studies at country and regional levels for Uganda, Vietnam and the Horn of Africa, using statistical clustering, artificial neural networks, and livelihood zone analysis.

Four examples of the application of livestock production system classification schemes and maps are then presented: allocating projected livestock production data by system and region for global integrated assessment modelling; mapping methane emissions from livestock in Africa now, and in the future; evaluating the benefits arising from control of African animal trypanosomosis, a serious disease of cattle transmitted by the tsetse fly, in East Africa; and estimating the numbers and distribution of poor livestock keepers, globally.

Further advancements in systems classification and mapping are sorely needed, particularly in relation to level three and the higher-input systems, for these are the areas where changes are occurring most rapidly and where most information is needed on the implications that intensifying systems may have for livelihoods, poverty alleviation, animal

diseases, public health and environmental outcomes. Validation of systems mapping products remains a critical constraint, although meta-analyses and expert evaluation, such as the use of geo-wiki systems, may well provide relatively easy and affordable solutions for global validation in the future. There are considerable challenges ahead, if the global population is to be fed sustainably and healthily in 2050 and beyond. Classifying and mapping global agricultural production systems is not an end in itself but a necessity if we are efficiently to evaluate different technology and policy options and effectively to target where they may be applicable.

1 Introduction

Many organizations are involved in assembling and disseminating global spatial datasets that can be used for a wide variety of purposes. Such datasets are becoming increasingly important for priority setting and targeting by organizations with a global mandate for agriculture and agricultural research for development, such as the United Nations (UN) Food and Agriculture Organization (FAO), the international centres of the Consultative Group on International Agricultural Research (CGIAR), regional and subregional research organizations, and donors who need to target their investments and measure their impacts on beneficiaries. The world in which we live is extremely dynamic, and this is reflected in the ways in which the world feeds itself and people meet their livelihood requirements. There can be considerable heterogeneity in the determinants of rural poverty (Snel and Henninger, 2002; Kristjanson *et al.*, 2005). An implication of this is that poverty alleviation efforts increasingly need to be targeted at relatively small groups of people, and this calls for a finer grain in the definition of intervention domains than has perhaps been considered in the past.

Currently, one of the biggest gaps in the availability of global datasets is a spatial agricultural systems classification that provides appropriate detail on the distribution of crops and livestock in different places. This publication addresses this gap by bringing together some recent developments in agricultural production system mapping and highlighting some of the difficult problems involved. The book also identifies further work that is required to develop a dynamic global agricultural production systems classification that can be mapped, ground-truthed, and refined through time. The work builds on considerable efforts that have been made in the past decade and draws upon some case study systems classifications, from which general lessons may be learned for application on a global scale. The outputs described here should find immediate application among development organizations, donors and research institutes, in targeting investment and technology or policy interventions that are effective in promoting sustainable livelihoods of the poor in developing countries.

WHY MAP LIVESTOCK PRODUCTION SYSTEMS?

Farming of crops and livestock cannot be considered independently of one another nor should they be considered in isolation. Established links between livestock numbers, cultivation levels and human populations suggest that greater attention should be paid to quantifying and mapping these associations (Bourn and Wint, 1994). The interdependence of crops and livestock in mixed farms and the different contributions made to livelihoods (Powell *et al.*, 1995) suggest that these two aspects of farming should be considered together. The nature of such interactions is heavily shaped by environmental factors and, increasingly, by economic forces.

A detailed knowledge of the distribution of livestock resources finds many applications, for example, in estimating production and off-take, the impacts of livestock on the environment, livestock disease risk and impact, and the role that livestock plays in people's livelihoods (Robinson *et al.*, 2007; FAO, 2007a). But livestock is not all equal. In different contexts it serves quite different functions, plays different roles in people's livelihoods, varies in herd structure and breed composition, and is fed and managed in different ways. For most applications some sort of practical stratification is needed: milk yields are not the same from cows reared in extensive, low-input pastoral systems as they are from specifically-bred dairy cows raised intensively. In the same way, the risks posed by livestock diseases vary considerably depending on whether animals are kept in high-density housing or grazed over large areas of rangeland, for example. At its simplest, combining information on production systems with livestock statistics allows livestock numbers to be disaggregated by production system (see, for example, the appendices in FAO, 2007a). Compared with simple national totals, this gives a more meaningful breakdown of how livestock are distributed across the globe.

Thornton *et al.* (2002; 2003) used a systems classification to delineate and extract a number of socio-economic variables. They produced tables for a series of livestock production systems in developing countries, including estimates of the numbers of poor people and poor livestock keepers involved. Livestock production varies across different livestock production systems, which can provide a stratification by which to parameterize livestock growth and off-take models (FAO, 2002a; 2007a). Following from this, livestock disease impacts can be estimated more accurately if a production system stratification is used. Numbers of livestock at risk from a disease can be disaggregated by production system, as shown for trypanosomosis in the Horn of Africa (FAO, 2007a). Perry *et al.* (2002) used a livestock production system framework to rank different diseases of livestock based on estimates of their impacts on poor livestock keepers. More sophisticated approaches have been developed, which involve the differential parameterization of livestock off-take models, such as the Livestock Development Planning System, Version 2 (LDPS-2) for different production systems, with and without disease (FAO, 1997). An example is the evaluation of the impact of bovine brucellosis on milk and meat off-take from cattle in sub-Saharan Africa (FAO, 2002b). This approach has been further developed by combining herd growth and off-take models with livestock movement models to map the potential benefits of trypanosomosis control interventions in West Africa (Shaw *et al.*, 2006) and East Africa (Shaw *et al.*, in press) over a 20-year period. Production systems are also useful for breaking down environmental analyses. Herrero *et al.* (2008) estimated methane emissions from domestic ruminants in Africa for a range of production systems. A recent FAO report on the global dairy sector estimated that it accounts for around four percent of all global anthropogenic greenhouse gas (GHG) emissions (FAO, 2010). Again, this relied on a detailed livestock production systems classification. Gerber *et al.* (2005) distinguished different levels of intensification of livestock farming in estimating nutrient loading from livestock in Asia, as did Menzi *et al.* (2009) in estimating the potential threat to the environment arising from livestock production. In sum, many such studies have found that the productivity, disease risks and impacts, livelihood benefits, and environmental risks of crop and livestock production vary considerably, not only regionally, but also according to the production system.

As well as providing a simple stratification for impact assessment, a classification of livestock production systems can provide a framework within which to predict how the livestock sector is likely to evolve in response to changing demography and associated quantitative and qualitative changes in demand (for animal-source foods), land use and climate. The livestock production systems of Thornton *et al.* (2002) are defined in terms of population density, land use, and length of growing period (LGP), all of which are projected to change considerably in the coming years. The production system classification can thus be re-evaluated using different scenarios of change into the future. Thornton *et al.* (2006) made a tentative assessment of how these systems might be transformed by human population growth and climate change, giving some clues as to how the distribution of farming systems, and thus livelihood systems, may change over the next 20 to 40 years. Considerably more sophisticated analyses have been undertaken recently: these use various combinations of econometric models of the global agricultural sector and explicit models of land use change into the future, to assess how the nature and distribution of different agricultural production systems may shift in response to sets of socio-economic and demographic stimuli. Rosegrant *et al.* (2009) is one example.

BACKGROUND AND OUTLINE

In September 2004 a meeting to discuss the state of global datasets was jointly convened by the Centre for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University, FAO, the UN Environment Programme (UNEP), the World Health Organization and the CGIAR (de Sherbinin and Chen, 2005). The meeting covered a wide range of topics, including the standardization and harmonization of spatial data and information, integration of biophysical and socio-economic data, identification of users' needs for online data services, and education and capacity building in how to use such services. Stock was taken of global data sets under three broad themes: the environment; food and agriculture; and population, poverty and health. It was concluded that the most significant gap under the food and agriculture theme was our understanding of the distribution of agricultural production systems; FAO and the CGIAR were charged with championing efforts to resolve this shortfall. The work reported here is in direct response to that recommendation. Some of the major limitations of existing system classifications were identified as the following.

- They tend to focus either on crops or on livestock farming, rather than embracing the need to balance the two.
- Some classification systems tend to group the majority of production systems into a single 'mixed farming' category, which in many regions of the world are often highly diverse, with many different combinations of crop and livestock species. From a poverty perspective, these systems are the very ones that we need to understand better, because they contain such large numbers of the rural poor (Thornton *et al.*, 2002; 2003).
- Many existing classification systems can be useful at very broad scales (global or regional), but because they have low spatial resolution and accuracy, they are often of little practical use for priority setting and planning at national level.

These limitations need to be overcome if targeting and planning are to be significantly improved. This will require long-term inputs from a range of stakeholders to build on existing work, in order to define more generally applicable production system classifications that can be updated readily to reflect the rapidly evolving global livestock sector, and to identify and fill gaps in global coverage of the input data that are needed to delineate them. With the continued development of sophisticated spatial analysis – available in many geographic information systems (GIS) – and improving availability of global spatial data sets, the prospects are very good of being able to use relatively high-resolution raster data on livestock, crops, population, climate, land cover and land use to develop useful systems maps that can meet the requirements of a wide variety of potential users.

This book describes some initial steps in this longer-term process. It summarizes past work, describes work in progress and makes some proposals for future work. Section 2 contains a short historical review of some of the global agricultural systems classifications that have been proposed over the last 40 years or so. This section also outlines a three-level systems classification that is used as an organizing framework for the remainder of the book. These three levels are of increasing complexity.

Section 3 describes a livestock classification scheme that was proposed in 1996 and has since been mapped and used in various ways. This first level in the classification describes potential livestock production systems and relies on a simple set of global datasets that are continually being updated. The classification itself has also been somewhat modified and the maps have been updated regularly. These modifications and updates are described here, together with a brief evaluation of the classification scheme. The final subsection in Section 3 addresses the key issue of uncertainty in land cover products and current efforts to improve them, because these are critical inputs into any agricultural systems classification.

Section 4 takes a closer look at the types and combinations of crops and livestock species that are prevalent in different places. It also includes a discussion on those whose livelihoods are significantly dependent on sectors other than crops and livestock, such as forestry and aquaculture. This second level moves from potential to actual livestock production systems.

Section 5 explores issues relating to the intensity and scale of production, addressing the question, where are the highly intensive and large-scale production systems located? This third level in the classification scheme addresses management practices, moving from *what* is done towards *how* it is done.

Section 6 explores the relationships between livestock production systems, rural livelihoods and poverty, through three case studies that delve into the nature of livestock systems at the country and regional levels. Case studies are presented and discussed for Uganda, Viet Nam and the Horn of Africa, using various sources of data and different techniques (statistical clustering, artificial neural networks, and livelihood zone analysis).

Section 7 presents case studies of the application of livestock production system classification schemes and maps. The examples are drawn from a wide range of possibilities and have been selected to cover the main global public goods associated with the livestock sector: livestock production now and in the future; livestock and the environment; public health and animal diseases; and livestock and livelihoods. Specifically, the examples are: allocating projected livestock production data by system and region; mapping methane emissions from livestock in Africa; mapping the benefits from trypanosomosis control in East Africa; and estimating the numbers and distribution of poor livestock keepers, globally. Tables providing the current estimates of the numbers of poor livestock keepers, by country and production systems – updated from Thornton *et al*. (2002) – are provided in Appendices B through to F.

In Section 8, some conclusions are drawn, and possible future developments are outlined in relation to refining the methods presented.

2 Agricultural systems classifications

The classification of agricultural systems has a long history, but there is no generic system that is truly comprehensive and can serve all purposes (Spedding, 1975). Existing classifications are based on a wide variety of factors and differ markedly in their utility, comprehensiveness, and ability to be mapped. This section provides a historical overview of some of the main global agricultural systems classifications that have been developed, briefly reviewing and comparing them, and covering in greater detail those that are more relevant to the global mapping of livestock production systems. A three-level systems classification is proposed, and a discussion presented on the compromises that must be made in moving from a theoretical approach to agricultural production systems classifications towards the practicalities of mapping these in a useful and consistent way.

A BRIEF REVIEW OF SOME CLASSIFICATION SYSTEMS

Ruthenberg (1980) distinguished between collection, cultivation, and grassland utilization. At the global level, collection probably does not need to be dealt with because of its minor economic significance. Cultivation classifications may be based on the following:

- According to type of rotation: natural fallow, ley system, field system, system with perennial crops.
- According to the intensity of rotation: specified by *R*, the proportion of the area under cultivation in relation to the total area available for arable farming (*R* = 10 for a shifting system with two years of cropping and 18 of fallow; *R* = 300 for a system where three crops are grown per year).
- According to water supply: irrigated versus rainfed farming, bearing in mind that much cropping may take place in valley bottoms where water is impounded naturally, as opposed to 'upland' farming (truly dry farming).
- According to cropping patterns and animal activities: grouping households together by their major activities.
- According to the degree of commercialization: subsistence, partly commercialized farming (if > 50 percent of the value of produce is for home consumption), and commercialized farming (if > 50 percent of produce is for sale).

For grassland utilization, there is a continuum from total nomadism through to stationary animal husbandry via transhumance:

- Total nomadism: no permanent place of residence, no regular cultivation.
- Semi-nomadism: a permanent place of residence exists, supplementary cultivation is practised, but for long periods of time animal owners travel to distant grazing areas.
- Transhumance: a permanent place of residence exists, their herds are sent to distant grazing areas, usually on seasonal cycles.
- Partial nomadism: characterized by farmers who live continuously in permanent settlements and have herds at their disposal that graze in the vicinity.
- Stationary animal husbandry: animals remain on the holding or in the village throughout the year.

Ruthenberg (1980) addressed the following systems: shifting cultivation systems, fallow systems, systems with regulated ley farming, systems with permanent upland cultivation, systems with arable irrigation farming, systems with perennial crops, nomadic grassland use, and ranching. Other forms of grassland use are folded into the appropriate cultivation systems, using a classification from

FAO and SIDA (1974), into permanent cultivation systems ($R > 66$), ley systems, and natural fallow systems – further divided into shifting systems ($R < 33$) and fallow systems ($33 < R < 66$).

Grigg (1972) discussed classification based on the work of Whittlesey (1936), who proposed that there are five criteria by which characteristic types of agriculture can be recognized:

- The crop and livestock association.
- The methods used to grow crops and produce the stock.
- The intensity of application to the land of labour, capital and organization, and the out-turn of product that results.
- The disposal of the products for consumption.
- The ensemble of structures used to house and facilitate the farming operations.

However, it is not clear how these criteria are used to arrive at the set of systems that Grigg (1972) identifies: shifting agriculture, wet-rice cultivation in Asia, pastoral nomadism, Mediterranean agriculture, mixed farming in western Europe and North America, dairying, the plantation system, ranching, and large-scale grain production. This is a highly pragmatic approach to classification.

The Dixon *et al.* (2001) approach produced a classification based broadly on whether production was rainfed or irrigated, agro-ecology, and location (urban/coastal), and did not involve livestock in any detail. They distinguished the following systems, although it is not explicitly stated how these were selected:

- Irrigated farming systems, embracing a broad range of food and cash crops.
- Wetland rice based farming systems, dependent on monsoonal rains supplemented by irrigation.
- Rainfed farming systems in humid high potential areas, with systems dominated by a crop activity (notably root crops, cereals, industrial tree crops – both small-scale and plantation – and commercial horticulture) and mixed crop–livestock systems.
- Rainfed farming systems in steep and highland areas, often mixed crop–livestock systems.
- Rainfed farming systems in dry or cold low potential areas, with mixed crop–livestock and pastoral systems; these grade into sparse and often dispersed systems with very low current productivity or potential because of extreme aridity or cold.
- Dualistic mixed large-scale commercial and smallholder farming systems, across a variety of ecologies and with diverse production patterns.
- Coastal, artisanal fishing, often in mixed farming systems.
- Urban-based farming systems, typically focused on horticultural and animal production.

Dixon *et al.* (2001) described 72 farming systems for the developing world, with an average agricultural population of about 40 million inhabitants; there are some 15 of these in sub-Saharan Africa, for example.

A more explicitly livestock-orientated classification was developed by Seré and Steinfeld (FAO, 1996). There are two parts to the classification. At a first level, solely livestock systems are distinguished from mixed farming systems. Solely livestock systems are those in which more than 90 percent of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds, and less than 10 percent of the total value of production comes from non-livestock farming activities. Mixed farming systems are those in which either more than 10 percent of the dry matter fed to animals comes from crop by-products or stubble, or more than 10 percent of the total value of production comes from non-livestock farming activities.

Subsequently, solely livestock systems are split into two. First are the grassland-based systems (LG), in which more than 10 percent of the dry matter fed to animals is produced on the farm, and in which annual average stocking rates are less than 10 temperate livestock units per hectare of agricultural land. Second are the landless livestock production systems (LL), in which less than 10 percent of the dry matter fed to animals is produced on the farm, and in which annual average stocking rates are above 10 temperate livestock units per hectare of agricultural land. The landless systems are further split into two categories: first, landless monogastric systems, in which the value of production of the monogastric enterprises (pig or poultry) is higher than that of the ruminant enterprises (cattle, buffalos, sheep, goats, etc.); second, landless ruminant systems, in which the value of production of the ruminant enterprises is higher than that of the monogastric enterprises.

The mixed systems are also broken down into the following two categories:

- Rainfed mixed farming systems, in which more than 90 percent of the value of non-livestock farm production comes from rainfed land use.
- Irrigated mixed farming systems, in which more than 10 percent of the value of non-livestock farm production comes from irrigated land use.

The livestock-only and mixed farming systems defined above are further characterized in agro-climatic terms, based on temperature and LGP: essentially, the number of days per year during which crop growth is possible. The agroclimatic categories were defined as:

- Arid and semi-arid: LGP ≤ 180 days.
- Humid and sub-humid: LGP > 180 days.
- Tropical highlands or temperate. Temperate regions are defined as those with one month or more of monthly mean temperature below 5 °C, corrected to sea level. Tropical highlands are defined as those areas with a daily mean temperature during the growing period of 5–20 °C.

This classification system of Seré and Steinfeld thus includes eleven system types: livestock only, grassland based (LG), which may be arid/semi-arid (LGA), humid/sub-humid (LGH), or tropical highland/temperate (LGT); landless monogastric-based (LLM), and landless ruminant-based (LLR); mixed, rainfed systems (MR) by the three agro-ecological zones, and mixed, irrigated systems (MI), also by the three agro-ecological zones.

Both the Dixon *et al.* (2001) and the Seré and Steinfeld (FAO, 1996) systems include elements of agro-ecology, but these approaches are quite different from those based on agro-ecological zonation *per se*. Agro-ecological zone (AEZ) approaches are now quite sophisticated – see Fisher *et al.* (2002), for example. In essence, AEZ methods involve matching the demands of specific crops with specific land characteristics, to assess whether (and how) the ecological, climatic and soil characteristics of any piece of land are suitable to the production of specific crops, and if they are, what levels of productivity may be expected for given inputs and technology. Analyses based on AEZs avoid entirely the problem of farming system definition, but such analyses indicate not where production actually occurs, but where it may occur from a systems classification perspective; this speaks more to the notion of potential systems than actual systems. In addition, such analyses have little to say regarding the future and the potential impacts of change on sustainable livelihoods at the household level.

One other type of classification system should be mentioned here: those based on statistical methods. Relatively simple statistical classifications have been investigated (Wint *et al.*, 1997), which involve a clustering of spatial units based on their values *vis-à-vis* cattle densities, human population densities, cultivation intensity, and elevation. Whereas these classifications have the advantage of providing data-driven definitions of 'farming systems' and can delineate areas where these parameters have similar numerical values, statistical groupings are entirely arbitrary: they are sensitive

TABLE 2.1 A COMPARISON OF SOME EXISTING FARMING SYSTEM CLASSIFICATIONS AND METHODS*

Classification	How are crops dealt with?	How are livestock dealt with?	How many categories?	Pros, cons, and can it be mapped?
Ruthenberg (1980)	1. Degree of cultivation (R) 2. Forest, bush, savanna, grass 3. Crop type 4. Irrigated vs rainfed	Degree of movement/ permanence	8 major	Categories too broad and incomplete
Grigg (1972) after Whittlesey (1936)	1. Crop type 2. Commercialisation 3. Location/agro-ecology	Degree of movement/ permanence	9 major	System incomplete and somewhat selective
Dixon *et al.* (2001)	1. Crop type 2. Commercialization 3. Location/agro-ecology	Degree of movement/ permanence	8 major 72 globally (type by region)	Derivation not explicit, may be difficult to map using existing global data sets
Seré and Steinfeld (1996)	1. Are there crops or not? 2. Rainfed vs irrigated 3. Agro-ecology	1. Landless or rangeland based 2. Agro-ecology	11 major	Livestock based, so no categorization of crop systems Can be mapped approximately using appropriate proxies
Explicit AEZ methods, e.g. Fischer *et al.* (2002)	Match land suitability to crop requirements for given inputs and technology	Not dealt with, though probably could be included	As required	Easily mapped Assesses what may be, rather than what actually is
Statistical classifications, e.g. Wint *et al.* (1997)	Cluster spatial units based on crop densities, intensities	Cluster spatial units based on livestock densities	As required	Easily mapped Arbitrary, data sensitive, and non-replicable

* Numbers in the columns showing how crops and livestock are dealt with, broadly indicate the stages in the classification.

both to geographical region and value range, and classifications cannot be replicated systematically in time or space.

These six classification systems and classification methods are summarized and compared in Table 2.1. Pragmatically, we can attempt to develop some system as a refinement or development of existing classifications. Currently, we can map broad systems and zones based on available data sets, but we are still quite far from making these relevant to livelihood options – issues related to crop distribution, livestock distribution, and heterogeneity of systems, for example. Indeed, there are disadvantages to all of the schemes and methods summarized in Table 2.1. The methods that lend themselves to being represented spatially, as digital maps, have significant problems in relation to how readily they may be generalized and being able to describe accurately what exists on the ground, while other systems may be incomplete or based on largely arbitrary methods. The Seré and Steinfeld (FAO, 1996) livestock production system classification tends to amalgamate similar systems; no distinction is possible within the 'mixed system' category, and it does not capture important differences in livestock husbandry practices within categories – for example, grassland-based systems combine pastoralists and ranchers, but these are clearly not equivalent.

A quest for a generic system that is truly comprehensive and can serve all purposes is probably destined to fail. Our focus here is on poverty and livelihoods, and this is likely to continue to present mapping problems: consistent global poverty data sets do not exist, and there are fundamental issues associated with trying to represent essentially non-spatial factors in spatial terms – not all aspects of poverty are of a spatial nature. Furthermore, the drivers of change in agricultural systems will often not be easy to represent spatially (and are thus outside the scope of spatial data sets); this makes representing the dynamics of systems and poverty particularly challenging.

MAPPING GLOBAL AGRICULTURAL PRODUCTION SYSTEMS: BETWEEN THEORY AND PRACTICE

The examples in the previous section illustrate the complexity of classifying the agricultural production systems of the world, and reflect the diversity of interests in how the Earth's agricultural resources are used. Classification approaches are often biased towards particular subsectors and are therefore difficult to compare and reconcile. Most classifications lack clear, quantitative boundaries between systems, which hinders comparisons between different mapped outputs and complicates updates and multitemporal analyses. It comes as no surprise, therefore, that the need for better harmonization and standardization is felt in the field of agricultural production systems classification.

While the focus of this book is to provide practical, analytical tools for decision-making, it seems useful to discuss here some theoretical aspects that have a bearing on present and future prospects for agricultural production systems classification and mapping.

It could be argued that an ideal classification scheme should be:

- Flexible. The scheme should not provide a predefined set of production systems, rather it should set up a framework for users to define the systems they are interested in, in a coherent and comparable manner.
- Consistent. The criteria for defining the systems should be quantitative and measurable, and therefore objective.
- Mappable. In order for the classification system to be effective, it should be possible to demarcate the defined production systems spatially.
- Hierarchical. The systems would ideally be hierarchical, so as to enable different levels of detail to be captured while maintaining consistency.

A classification scheme that incorporated these factors could be developed by building on the concepts of land cover units, land use units and land use systems. Land cover can be defined as the observed physical cover of the Earth's surface, while land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type, to produce, change, or maintain it (FAO, 1998; FAO, 2005). Following this line, land use systems could be defined as associations of different land use units that are interconnected through spatial and functional relationships. Parker *et al.* (2008) consider land use systems in this way, suggesting that they are characterized by complex interactions between human decision-makers and their biophysical environment, with the effects of these interactions reflected over space, time and scale. Agricultural production systems, which include both cropping and livestock keeping activities, can be regarded as just a special case of the more general category of land use systems. In the light of these considerations, standardization of approaches to classifying land cover and land use would logically provide a solid foundation for classifying agricultural production systems.

Recent years have witnessed significant progress in the development of a standardized system for land cover classification. The land cover classification system (LCCS) developed by FAO and UNEP (FAO, 1998; FAO, 2005) is a hierarchical, modular system that allows land cover classes to be defined regardless of mapping scale, data collection method or geographic location. The LCCS has already been adopted for land cover mapping exercises at the regional level, e.g. Africover, and at the global level, e.g. Global Land Cover (GLC) 2000 (Mayaux *et al.*, 2004; Bartholomé and Belward, 2005) and GlobCover (Bicheron *et al.*, 2008), but a high degree of complexity still hinders its widespread utilization.

While procedures are underway to have the LCCS adopted as an International Organization for Standardization standard for land cover mapping, a land use classification system that builds on the same solid foundation may still be a long way off. A standardized land use classification system should encompass, among other things, the use of resources, inputs and outputs (including energy, nutrients, water, crop and livestock production, for example), management practices (e.g. level of mechanization), ownership, and the authority responsible for management. The multidisciplinary nature of land use makes the development of a standardized and comprehensive land use classification system particularly challenging, so it may be some time before satisfactory solutions are found to the semantic, conceptual, technical and – possibly most importantly of all – data issues that affect the development of a land use classification system and its use in agricultural systems mapping.

In the absence of adequate tools for a more systematic approach to land use systems classification, there is a need to explore practical avenues for classifying and mapping global agricultural production systems that also address the key role that livestock plays in many of these systems. The following sections provide a framework that allows global maps of livestock production systems to be produced and updated regularly. The proposed scheme draws on a number of global, geospatial datasets which, when combined, are believed to best represent the real systems on the ground. The classification scheme developed here therefore provides a pragmatic solution to the problems imposed by data availability constraints and gaps in theory.

TOWARDS A STEPWISE METHODOLOGY FOR CLASSIFYING AND MAPPING LIVESTOCK PRODUCTION SYSTEMS

As part of the process of moving forward the mapping of production systems, a meeting was convened in Bangkok in April 2006 by FAO and the International Livestock Research Institute (ILRI) (FAO, 2006a), which brought together a number of practitioners involved in agricultural systems mapping and various case studies, and the producers and custodians of various relevant global datasets. The major objectives of the meeting were to begin to develop a classification framework and a detailed plan of work to allow it to be mapped. The aim was to use existing global data sets, with sufficient detail that the outputs would be of use at national level. Various operational requirements were identified as being important for such a framework, including the following:

- The scheme should account adequately for livestock systems and deal with issues of convergence versus independence of livestock-cropping systems – in other words, support situations where a particular cropping system may be associated with a number of livestock systems and a particular livestock system may be associated with a number of different cropping systems.
- The classification should be dynamic, to allow investigation of the likely developments of farming systems in the future and how they might evolve, in response to global drivers such as population pressure, changes in demand for livestock and crop products and climate change.
- The classification should place emphasis on the poor, in terms of being able to identify relatively small populations of poor agriculturalists, but should ultimately have global coverage, enabling an understanding of the dynamics among the developed and developing regions of the world and analysis of the evolution of production systems.

One proposal from the meeting, based on a case study of Uganda, was to attempt to develop a stepwise approach to production system mapping, involving a sequence of steps that result in increasing levels of detail concerning the systems identified. Input data for each level of the stepwise mapping system are summarized in Table 2.2.

In an attempt to map the classification system of Seré and Steinfeld (FAO, 1996), the first level of the stepwise mapping approach could be based on globally available geospatial datasets that are able to provide information on broad systems characteristics. This approach, outlined in some detail in

TABLE 2.2 A THREE-LEVEL AGRICULTURAL PRODUCTION SYSTEMS MAPPING SCHEME

Level	Input data
Level 1	Length of growing period (days per year) Human population density Land cover Irrigated areas Temperature Elevation
Level 2	Modelled crop distributions Modelled livestock distributions Aquaculture, fishing, forest crops
Level 3	Level of intensification

Source: adapted from FAO (2006a).

the next section, broadly follows the datasets and methods used in Thornton *et al.* (2002), Kruska *et al.* (2003) and Kruska (2006).

It should be noted that, for several reasons, the systems as defined by Seré and Steinfeld (FAO, 1996) cannot be mapped directly. First, the classification occurs essentially at the farm level, while the spatial unit of global geospatial datasets is the pixel. Second, definitions used in the Seré and Steinfeld classification include such elements as 'the amount of farm-produced dry matter fed to animals'; these are simply not available spatially, let alone at the global scale. Accordingly, appropriate proxies need to be identified for which global data do exist, and that are still able to represent the spirit of the classification, if not its exact nature. Despite its limitations (some of which are discussed in the next section), the Seré and Steinfeld classification (FAO, 1996) was felt to be the most appropriate starting point: it provides a relevant stratification through which to describe, visualize and explore livestock and livestock-related issues, and constitutes a useful baseline that can be refined, improved upon, and adapted through time. The datasets used to translate the Seré and Steinfeld classification into global maps could include the best available estimates of land cover, human population densities, LGP, irrigated areas, elevation, and temperatures, with thresholds informed by comparisons with other datasets and by case studies (for example, in distinguishing the hyper-arid areas). Input data for such variables are all available globally at a fairly consistent level of detail.

It was proposed that a second level could include more specific data on particular crop and livestock combinations and on other livelihood options, such as aquaculture. While it should be possible to obtain global coverage at this level, there may be considerable differences in the level of detail from country to country. A third level of system characterization would attempt to distinguish intensive (high input) systems from more extensive systems. Data pertaining to intensification, such as production efficiency, market orientation, management practices and cultural practices, may however vary considerably in detail from country to country.

The proposed scheme loosely follows the 'ideal' classification approach based on land cover units, land use units and land use systems. Level 1 ultimately hinges on land cover maps for discriminating livestock-only from potentially mixed farming systems. At this level, additional geospatial layers serve the two purposes of 1) redressing shortcomings in global land cover maps and 2) providing an agroclimatic characterization of the production systems. At level 2, elements more explicitly linked to land use are brought in, e.g. by including information on the actual distribution of crop and livestock species. At level 3, emphasis is placed on livestock management practices, with particular reference to the distinction of intensive from extensive systems, wherein the functional and spatial relationships between land use units (as describable in land use systems) plays a central role.

These steps are described in the following sections.

3 Mapping global livestock production systems

The classification system of Seré and Steinfeld (FAO, 1996) was outlined in the previous section. To recap, if we disregard the agroclimatic characterization, this scheme classifies livestock systems into four types: 1) landless livestock production systems (LL, which may be monogastric or ruminant); 2) grassland based system (LG, in which crop-based agriculture is minimal); 3) mixed rainfed systems (MR, mostly rainfed cropping combined with livestock); and 4) mixed irrigated systems (MI, in which a significant proportion of cropping uses irrigation and is interspersed with livestock). Seré and Steinfeld (FAO, 1996) used their classification to disaggregate a large number of resource variables (e.g. population, arable land and livestock numbers), production variables (e.g. meat, milk and egg production) and productivity variables (e.g. meat and milk yields per animal). National data from FAOSTAT (or Agrostat as it was then known) were assigned to one or more of ten AEZs using 'prorating factors'. Exactly how the very detailed, farm-level classification was overlaid on these broad AEZs to assign the data to the defined livestock production systems is not clear, however. A more robust method would be to map the systems at relatively high spatial resolution and to overlay them on the variables in question.

METHODOLOGY, DEVELOPMENTS AND CURRENT STATUS

A method was devised to map an approximation to the Seré and Steinfeld classification in the developing world based on land cover, human population density, LGP, temperature and elevation (Thornton *et al.*, 2002; Kruska *et al.*, 2003). This classification has since been used to stratify many analyses (some described in FAO, 2007a). Because climatic and population variables are used as input data, this has enabled the classification to be re-evaluated in response to different scenarios of climate and population change in the future (Thornton *et al.*, 2006). In this section the original mapping of the classification scheme is described, as are the various updates carried out since then, and a brief evaluation of the classification is presented in terms of its uses and limitations. The section concludes with a discussion of one of the key uncertainties associated with mapping this (or indeed any other) classification scheme: identifying crop extent.

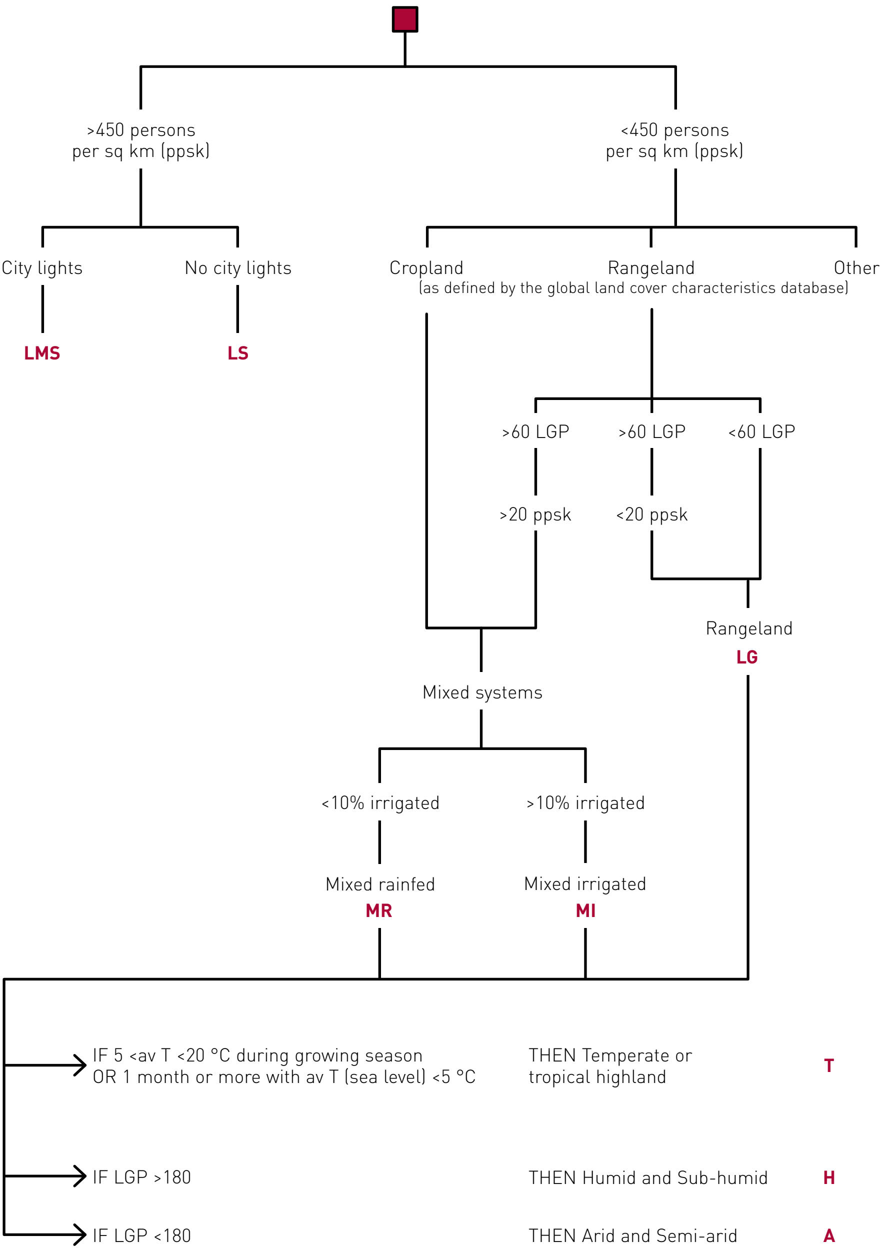
Input data and methods

As discussed previously, mapping of the Seré and Steinfeld (FAO, 1996) classification using all the same criteria that were used in its derivation is not possible because of the unavailability of some key data at the global scale, or indeed for anywhere other than perhaps small areas where detailed studies have taken place. This situation is not likely to change in the foreseeable future. Accordingly, proxies have been identified for which global data exist, and that are at the same time able to represent the spirit of the classification.

Ten systems were mapped for the developing world using the decision tree shown in Figure 3.1. The first distinction was made between landless and land-based livestock production systems. A threshold of 450 people per km^2 was used to identify areas within which landless livestock production occurs, generally highly intensive systems involving ruminants or monogastrics, which can be either large-scale or small-scale operations.

The next branch in the tree required that the mixed systems be differentiated from the grassland-based systems. While cropland extent can be derived from various land cover products, there is wide variation in their estimates (see the end of this section for a discussion of this

3.1 DECISION TREE FOR MAPPING LIVESTOCK PRODUCTION SYSTEMS



Source: adapted from Thornton *et al.* (2002).

problem). Largely as a result of the problems of underestimating cropland extent, the original mapping scheme used LGP and human population to reallocate part of the 'rangelands' (the term generally used by Thornton *et al.* (2002) instead of 'grasslands') to the mixed system category. In particular, the rangelands were divided into 'cultivatable' and 'non-cultivatable', using an LGP threshold of 60 days. (This is quite severe: cropping is extremely marginal in areas with less than 60 growing days, even for drought-resistant crops such as millet and sorghum). Human population density was then used to identify additional cropping areas within the cultivatable rangelands category. All cultivatable rangelands with a population density greater than 20 people per km^2 were added to the cropland category to define the mixed production system category. The remaining area under the rangelands category corresponds to the 'livestock-only' systems as defined by Seré and Steinfeld. The threshold density of 20 people per km^2 was based on comparisons of population data with higher resolution land cover maps for Latin America, West Africa and East Africa, and on expert opinion (Kruska *et al.*, 2003). Human population has been shown to be strongly related to the amount of land cultivated (Bourn and Wint, 1994; Reid *et al.*, 2000), and it was estimated that the threshold of 20 people per km^2 is generally equivalent to 15–25 percent of the land cultivated.

At the next decision point in the tree (Figure 3.1), the mixed systems were classified as either rainfed or irrigated. Seré and Steinfeld (FAO, 1996) defined mixed irrigated systems as those in which more than 10 percent of the value of non-livestock farm production came from irrigated land use. Following this, the original mapping classification used a threshold of 10 percent of area irrigated for each grid cell, above which a pixel was assigned mixed irrigated. The remaining mixed systems pixels were then classified as rainfed.

The mixed rainfed, mixed irrigated and rangeland system categories as defined above were then subdivided based on agro-ecology, strictly according to the Seré and Steinfeld definitions (FAO, 1996). The original datasets used to map the classification are shown in the second column of Table 3.1; Version 1.

Recent updates

The global livestock production systems map has been updated in various ways since it was devised. The basic model has been expanded by making additions to the original LGP breakdown to include hyper-arid regions, defined as areas with zero growing days. This was done because livestock can be found in some of these regions (e.g. Turkana, northern Kenya) during wetter years when the LGP is greater than zero, despite long-term LGP being at or close to zero days per year.

Most of the updating of the systems maps for Version 3 (an intermediate Version 2 is not included in the discussion here) was associated with the use of new datasets. In the GLC 2000 data layer[1] (Mayaux *et al.*, 2004; Bartholomé and Belward, 2005) irrigated areas were included for Africa. Kruska (2006) used this instead of the irrigated areas database of Döll and Siebert (2000); however, this database continued to be used for Asia and South America. For human population, the 1 km Global Rural-Urban Mapping Project (GRUMP) data were used (CIESIN, 2005). Length of growing period data were developed from the WorldClim 1 km data for the year 2000 (Hijmans *et al.*, 2005), together with a new 'highlands' layer for the same year based on the same dataset (methods are outlined in detail in Thornton *et al.*, 2006). Cropland and rangeland were defined from the GLC 2000 and areas classified as rock or sand were included as part of rangelands. As before, areas in the GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2, as well as an LGP greater than 60 days (which can occasionally allow cropping), were included in the mixed system categories. Urban areas were defined by the GLC 2000. The landless systems remained problematic and were not included in this version of the classification.

[1] http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

TABLE 3.1 DATA INPUTS USED FOR THE DIFFERENT VERSIONS OF THE MAPPED GLOBAL LIVESTOCK PRODUCTION SYSTEMS*

Data inputs	Version 1, 2001 (Thornton *et al.*, 2002; Kruska *et al.*, 2003)	Version 3, 2006 (Kruska, 2006)	Version 4, 2007 ILRI/FAO GLW web site	Version 5, 2011 This publication
Land cover	USGS Global Land Cover Characterization (1 km)	GLC 2000 Global Land Cover (1 km) (Mayaux *et al.*, 2004; Bartholomé and Belward, 2005)	GLC 2000 except now using GRUMP urban extents to supplement the GLC 2000 'urban' category + Africover	Same
Length of growing period (LGP)	LGP 2000 (55 km) (Fischer *et al.*, 2002)	LGP 2000 (5 km) (Jones and Thornton, 2005), based on WorldClim (Hijmans *et al.*, 2005)	Same LGP data, but re-modelled to 1 km resolution by ERGO (Wint, 2007)	LGP 2000 (1 km) (Thornton and Jones, 2010), based on WorldClim (Hijmans *et al.*, 2005)
Highland and temperate areas	Highland and temperate regions 2000 (55 km) (Jones and Thornton, 1999)	Highland and temperate regions 2000 (5 km) (Jones and Thornton 2005), based on WorldClim (Hijmans *et al.*, 2005)	Same highland and temperate regions, but re-modelled to 1 km resolution by ERGO (Wint, 2007)	Highland and temperate regions 2000 (1 km) (Thornton and Jones, 2010), based on WorldClim (Hijmans *et al.*, 2005)
Human population	Population density 1990 (5.6 km) (Deichmann, 1996a; 1996b); 2000 for Latin America (Hyman *et al.*, 2000)	GRUMP population density 2000 (1 km) (CIESIN, 2005)	Same	Same
Irrigated areas	Global Irrigation Database (Aquastat) Version 1.0 (5.6 km) (Döll and Siebert, 2000)	Aquastat Version 3.0 (5.6 km) (Eliasson *et al.*, 2003) (Aquastat Version 1.0 continued to be used for Asia and Latin America)	Aquastat Version 4.0.1 (public product at 10 km) (Siebert *et al.*, 2007)	Aquastat Version 4.0.1 (source data at 1 km) (Siebert *et al.*, 2007)

* Nominal spatial resolutions provided refer to those at the equator.

A further-updated fourth version was produced under a collaborative agreement between ILRI and FAO. Version 4 provided global coverage: urban areas were defined by a combination of the GRUMP dataset (CIESIN, 2005) and the GLC 2000 urban class; irrigated areas were based on the FAO Aquastat map Version 4.0.1. (Siebert *et al.*, 2007).

Again, produced jointly between ILRI and FAO, Version 5 of the global livestock production systems map is now available for download from the Gridded Livestock of the World (GLW) web site[2]. These maps for the developing regions of the world are included in Appendices B to F of this book. In this version the GLC 2000 land cover base map has been replaced by the much more detailed and accurate Africover data sets[3] for countries in Eastern Africa where these are available (Burundi, Democratic Republic of Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda)[4]. Urban areas are defined by the GRUMP dataset (CIESIN, 2005). LGP and highland and temperate areas have been remodelled to 1 km spatial resolution (Thornton and Jones, 2010). The source of human population data remains the same (CIESIN, 2005) and for irrigated areas the same resource has been used (Siebert *et al.*, 2007) though the original 1 km data, which are not publicly available, have been incorporated to specify areas with more than 10 percent of irrigated area (these data are described in Siebert *et al.*, 2005).

[2] http://www.fao.org/AG/AGAInfo/resources/en/glw/home.html
[3] http://www.africover.org

[4] In-house exercises have been made to integrate other regional land cover products that were developed with a methodology similar to Africover data, e.g. with the aggregate land cover of the Himalaya region developed under the Global Land Cover Network, www.glcn.org

The major versions of the classification, and the evolution of the datasets used to map it, are shown in Table 3.1.

Uses and limitations

The mapped global livestock production systems classification, in its various incarnations, has been used quite widely since it was first assembled. It was first applied in a global livestock and poverty mapping study designed to assist in targeting livestock research and development activities (Thornton *et al.*, 2002; 2003). In these studies, estimates of the numbers of poor livestock keepers by production system and region were derived and mapped. This information was then used by Perry *et al.* (2002), to identify priority research opportunities that could improve the livelihoods of the poor through better control of animal diseases in Africa and Asia. Possible changes in livestock systems and their implications have been assessed for West Africa (Kristjanson *et al.*, 2004). Given that the mapping scheme is based on data for which changes (climate, population and land cover) can be estimated with varying degrees of confidence, it has been possible to predict how the production systems may change in the future. In this context the methods have been used in studies to map climate vulnerability and poverty in sub-Saharan Africa in relation to projected climate change (Thornton *et al.*, 2006), to assess the spatial distribution of methane emissions from African domestic ruminants to 2030 (Herrero *et al.*, 2008), to investigate the role of agricultural science and technology on economic growth and poverty alleviation to the middle of the current century (Rosegrant *et al.*, 2009), and to assess the potential impact of changes in crop–livestock systems on agro-ecosystem services and human well-being (Herrero *et al.*, 2009). Some of these applications are described in more detail as case studies in the applications section below.

Even while the global livestock production systems maps have been used extensively, it is acknowledged that there are various uncertainties and weaknesses associated with them (e.g. Rosegrant *et al.*, 2009). By far the most problematic of these are the vagaries concerning land cover data, particularly related to cropland extent. Other major weaknesses include that the mixed systems categories are too general for many practical applications, and indeed the treatment of crops in the system is weak. In addition, the widespread 'other' class clearly reflects a limitation in interpreting unambiguously all land cover classes for their capacity to support livestock; the annexes in FAO (2007a) show that many livestock fall into this class. Only limited independent evaluation of the maps has been undertaken (one example is Cecchi *et al.*, 2010) and more work needs to be carried out to improve them. Even qualitative expert assessment, particularly for parts of Asia, Latin America and the developed world, would be useful.

For many purposes, maps based on the Seré and Steinfeld classification scheme may be either too complicated or not wholly appropriate. For example, both FAO and ILRI have made efforts to make distinctions between the different ways poor people might be able to benefit from agricultural or livestock development. In terms of understanding how livestock systems may evolve in the future in response to market forces and other drivers of change, as well as the opportunities afforded by the natural resource base, some discussions at ILRI have been framed in relation to a different set of systems. An example is in Perry *et al.* (2002), in which animal health researchable issues are assessed in relation to three pathways out of poverty for livestock keepers: securing the assets on which they depend, reducing constraints to productivity enhancement, and improving market opportunities. Another example is Thornton *et al.* (2007), in identifying three types of livestock system associated with very different issues:

- Agropastoral and pastoral systems in which natural resources are constrained and people and their animals adopt adaptation strategies to meet these constraints.

- Smallholder crop–livestock systems in which natural resources can be managed to intensify the productivity of the system.
- Industrial livestock systems, which are highly intensive and tend not to be so tied to the local natural resource base as are the agropastoral and smallholder mixed systems.

Similarly, work done within FAO has been framed in relation to other types of breakdown of potential target beneficiaries. The idea of livestock intervention domains was a central element of the Pro-Poor Livestock Policy Initiative (PPLPI)[5]. The initiative recognized three intervention domains with respect to livestock keepers and the livestock sector, each requiring different types of policy intervention: reducing vulnerability, creating conditions for growth, and coping with growth. Attempts have been made (e.g. Dijkman in FAO, 2006a) to map these domains using factors such as agricultural suitability, market access and economic potential.

Other work ongoing at FAO takes a socio-economic approach to livestock production systems mapping (reviewed below). Rather than using the environmental data that the global livestock production systems classification mapping is based on, this draws on data collected in the context of livelihood analysis (Cecchi *et al.*, 2010). While the Horn of Africa was relatively well represented by these types of survey, global coverage could not be achieved through this approach.

The mapped global livestock production systems classification is a useful starting point and baseline, but there are clear demands for more information or different system cuts (which could be made in many different ways, if more detail were available about the systems being investigated). Issues such as how intensified systems are, whether there is potential for intensification, and what the scale of production of commodities is in particular places, are all examples of valid questions that the classification scheme needs to move towards being able to answer. This is an important justification for increasing the level of detail in the classification system, which is discussed in the sections below.

ACCURACY OF GLOBAL LAND COVER MAPS: IMPLICATIONS FOR MAPPING LIVESTOCK PRODUCTION SYSTEMS

In order to define livestock systems on a global scale, accurate information on the spatial distribution of different land cover types, in particular cropland and grassland, is essential. Global land cover is derived through the classification of satellite images integrated with ground-based data collection. The use of remote sensing technologies for applications such as land cover is desirable for a number of reasons:

- There are low marginal costs involved.
- They provide higher levels of spatial resolution and sampling frequency than alternative approaches.
- They are the only feasible data gathering mechanism in some locations.
- They provide precise, automated repetition of data collection efforts.
- They can be combined with ground-based data to generate value-added products that can be of great value for decision-making in agriculture.

Global land cover maps represent important sources of baseline information to a wide variety of users: the UN Millennium Ecosystem Assessment (MEA, 2005), the Interim Secretariat for the Convention on Biological Diversity (ISCBD, 1994) and the Global Environmental Outlook Project (UNEP, 2002), to name a few. In the area of climate change modelling, global land cover has been used to verify the predictions from global circulation models where a dynamic vegetation component has been added (Foley *et al.*, 1998). Global models of land use also use remotely sensed land cover maps as inputs: for example, to determine how much land is available for the expansion of agriculture, or to evaluate whether 'Reducing Emissions from Deforestation and Forest Degradation in

[5] http://www.fao.org/ag/againfo/programmes/en/pplpi/home.html

Developing Countries' is a more cost-effective mitigation option than carbon capture and sequestration. Accurate spatial information on cropland is particularly important for crop monitoring and food security, and satellite-derived land cover datasets have been widely used for this purpose. However, a detailed comparison of different land cover datasets reveals there to be considerable disagreement between them (Fritz and See, 2005; Giri *et al.*, 2005; Jung *et al.*, 2006). These inconsistencies are particularly high for cultivated land (cropland and managed pasture) compared with other vegetation types such as tree cover (Wood *et al.*, 2000). Because of the lack of consistent and reliable data on the location, area and intensity of cultivation from other sources, global land cover datasets are central to the mapping of livestock production systems. This section outlines the most current global land cover datasets available and the methods that have been used to compare the different products in the cropland domain.

Global land cover datasets

A number of global, remotely-sensed datasets has emerged over the last 20 years. The first sensor from which land cover datasets were produced was the Advanced Very High Resolution Radiometer (AVHRR), with a spatial resolution of around 1 km at the Equator. Data from the AVHRR sensor led to the production of the International Global Biosphere Project (IGBP) land cover dataset (Loveland and Belward, 1997), the Global Land Cover characterization dataset (USGS, 2008) and the University of Maryland global land cover products based on AVHRR (Hansen *et al.*, 2000) and the Moderate Resolution Imaging Spectroradiometer (MODIS) (Hansen *et al.*, 2005). The more recent sensors – with increased geometric accuracy and higher resolution – include the Satellite Pour l'Observation de la Terre (SPOT) vegetation sensor from which the GLC 2000 land cover product was produced, the MODIS sensor from which the MODIS land cover and several other products, such as the Vegetation Continuous Field (Hansen *et al.*, 2003; 2006), have been produced, and the European Medium Resolution Imaging Spectrometer (MERIS) sensor, which has led to the production of GlobCover 2005 and GlobCover 2009 (Bicheron *et al.*, 2008). However, to date there is no single satisfactory global land cover product available, and uncertainty in the cropland domain remains high. The most recent products are discussed briefly below.

GLC 2000

The GLC 2000 was developed by the Joint Research Centre for the baseline year 2000, which is a reference year for environmental assessment. The product was created using 14 months of pre-processed daily global data at a spatial resolution of 1 km, acquired by the VEGETATION instrument on board the SPOT 4 satellite. A bottom-up approach to product development was undertaken in which more than 30 research teams around the world contributed to 19 regional windows (Bartholomé and Belward, 2005). The regional legends were derived from the LCCS as a common framework to produce 22 global classes (FAO, 1998; 2005).

MODIS

The MODIS land cover product was created by Boston University using the MODIS instrument on the National Aeronautics and Space Administration Terra Platform using data from the year 2005. Several different products have been created from this sensor, including land cover, a radiation budget and ecosystem variables (Morisette *et al.*, 2002). The land cover product (MOD12Q1) was produced at a resolution of 500 metres and uses information from a number of other MODIS products. The MODIS land cover data set uses all 17 classes of the IGBP legend (Loveland and Belward, 1997) and was created using a global classification approach. The MODIS land cover classification algorithm (MLCCA) uses a supervised classification methodology based on a globally distributed set of training sites. One of the key features of the MLCCA algorithm is a technique known as 'boosting', which allows robust assignments of pixel probabilities (Friedl *et al.*, 2010). Version 5 of the MODIS land cover data set (MOD12Q1 V005) is now available, where the classification algorithm has continued to be developed and improved since 2005.

GlobCover 2005 and 2009

GlobCover is a European Space Agency initiative to develop a service to produce a global land cover map for 2005/6, using 300 metre resolution data acquired by the MERIS sensor on board the ENVISAT satellite (Bicheron *et al.*, 2008). This new product is intended to update and to complement the other existing comparable global products – GLC 2000 in particular – and to improve on their spatial resolution. GlobCover 2009 was released in December 2010.

Comparison of global land cover datasets

In order to compare two global land cover datasets, their respective legends and the specific definitions associated with each legend class must first be reconciled. Various approaches have been developed to achieve this. Fritz and See (2005) created a look-up table to indicate any occurrence of overlap in the definition of two classes in two different land cover data sets. This overlap was treated as 100 percent agreement when these two classes occurred for a given pixel. The remaining combinations of legend classes in the look-up table were considered as disagreement. To determine the degree of disagreement ranging from 0 to 1.0, experts were asked to indicate on a scale of 1 to 5 concerning how important it is to be able to distinguish between each pair of land cover classes for a given application. This importance matrix was then translated into a disagreement fuzzy set that was used to map the degree of disagreement spatially. Experts from different application areas were chosen (e.g. forestry, biomass and agriculture) in order to illustrate that the amount of disagreement can vary by application.

The approach taken by Fritz and See (2005) was a conservative one, because it assumed that any overlap in legend definition between two land cover products resulted in 100 percent agreement. In Fritz and See (2008), this analysis was modified to take into account differences in legend definitions. For example, for the GLC 2000 class 1 (tree cover, broadleaved, evergreen), the defining features are > 15 percent tree cover and tree height > 3 metres. For MODIS class 2 (evergreen broadleaf forest), the defining features are > 60 percent tree cover and tree height > 2 metres. An uncertainty value was calculated based on the amount of overlap in the definitions, which was then applied in the calculation of disagreement.

The disagreement between land cover types can be characterized in three ways: 1) measures of overall disagreement; 2) maps of spatial disagreement; and 3) comparison with FAO statistics at the national level.

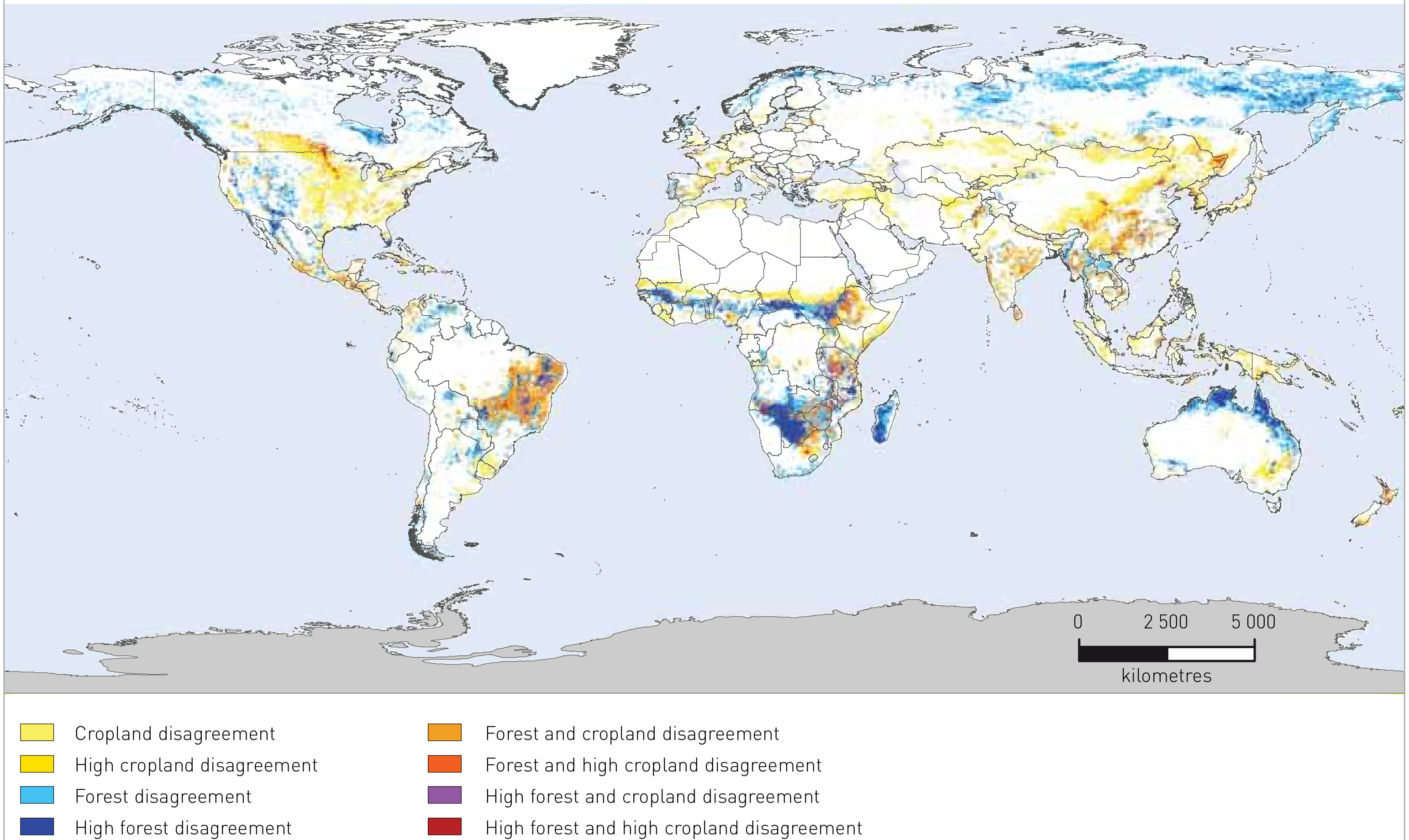
Overall disagreement

The total areas under cropland based on the GLC 2000, GlobCover and MODIS v.5, are 2 057 Mha, 1 642 Mha and 1 711 Mha, respectively. Table 3.2 shows the overall differences in Mha, including as a percentage of the FAO reference figures for 2005 between different pairs of land cover products in the cropland domain. Comparing the two most recent products, GlobCover and MODIS v.5, the disagreement is 506 MHa or 36 percent of the FAO arable land in 2005. These figures clearly illustrate significant differences between the three land cover products. Table 3.2 also shows the considerable disagreement for forest cover among these land cover products. While cropland is important in defining the mixed systems, forest is one of the main contributors to the 'other' class and is also used in suitability masking for livestock mapping; so it, too, has important implications for mapping livestock production systems.

Spatial disagreement

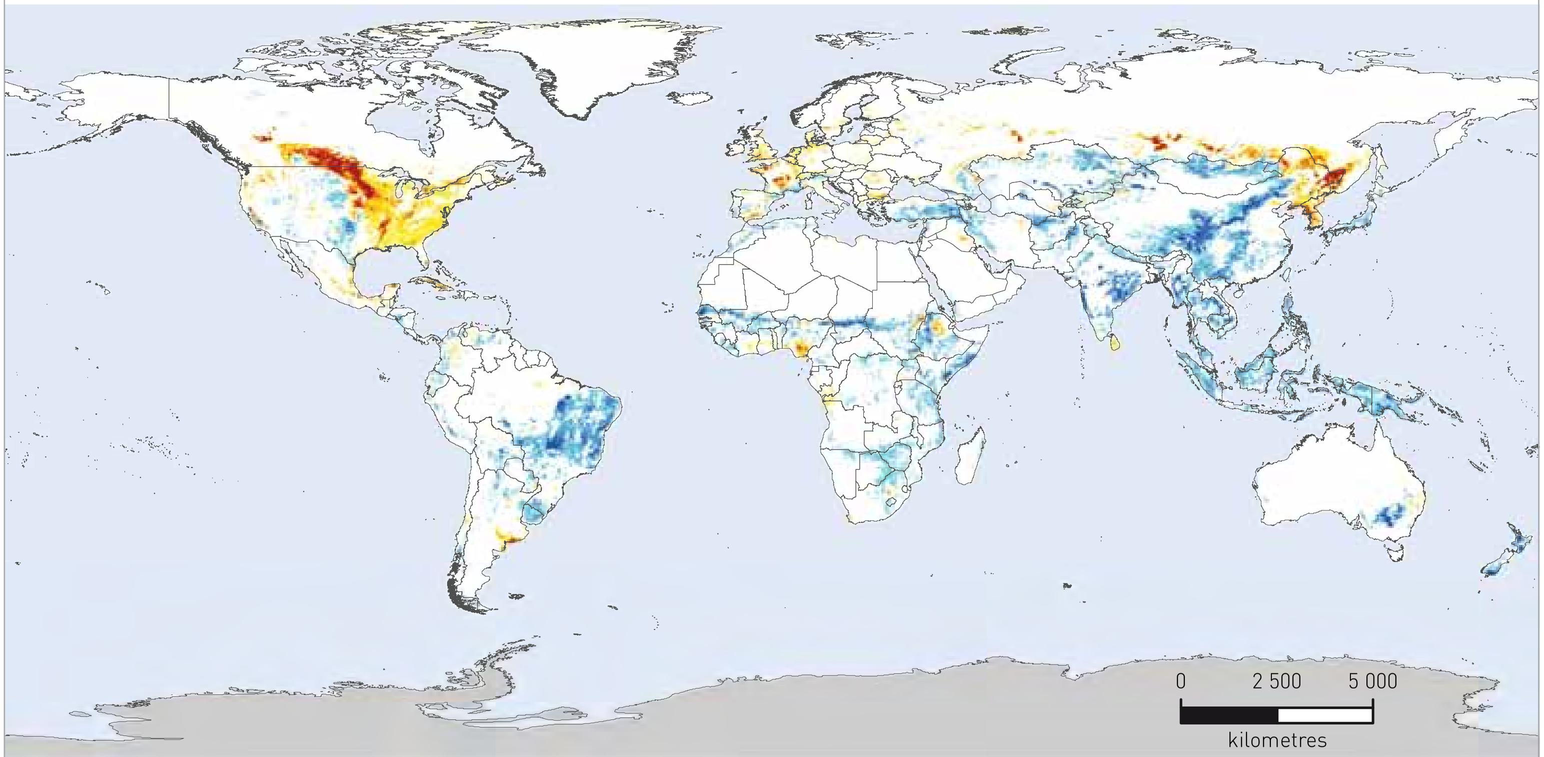
In addition to the global measures of correspondence among the classes, the disagreements can be visualized spatially. Figure 3.2 shows the global distribution of disagreement in the cropland and

3.2 OVERALL DISAGREEMENT AMONG MODIS V.5, GLOBCOVER AND GLC 2000 LAND COVER PRODUCTS IN THE FOREST AND CROPLAND DOMAINS



Source: adapted from http://www.geo-wiki.org.

3.3 GLOBAL DISAGREEMENT IN THE CROPLAND DOMAIN BETWEEN MODIS V.5 AND GLOBCOVER



Percent more cropland in MODIS v.5

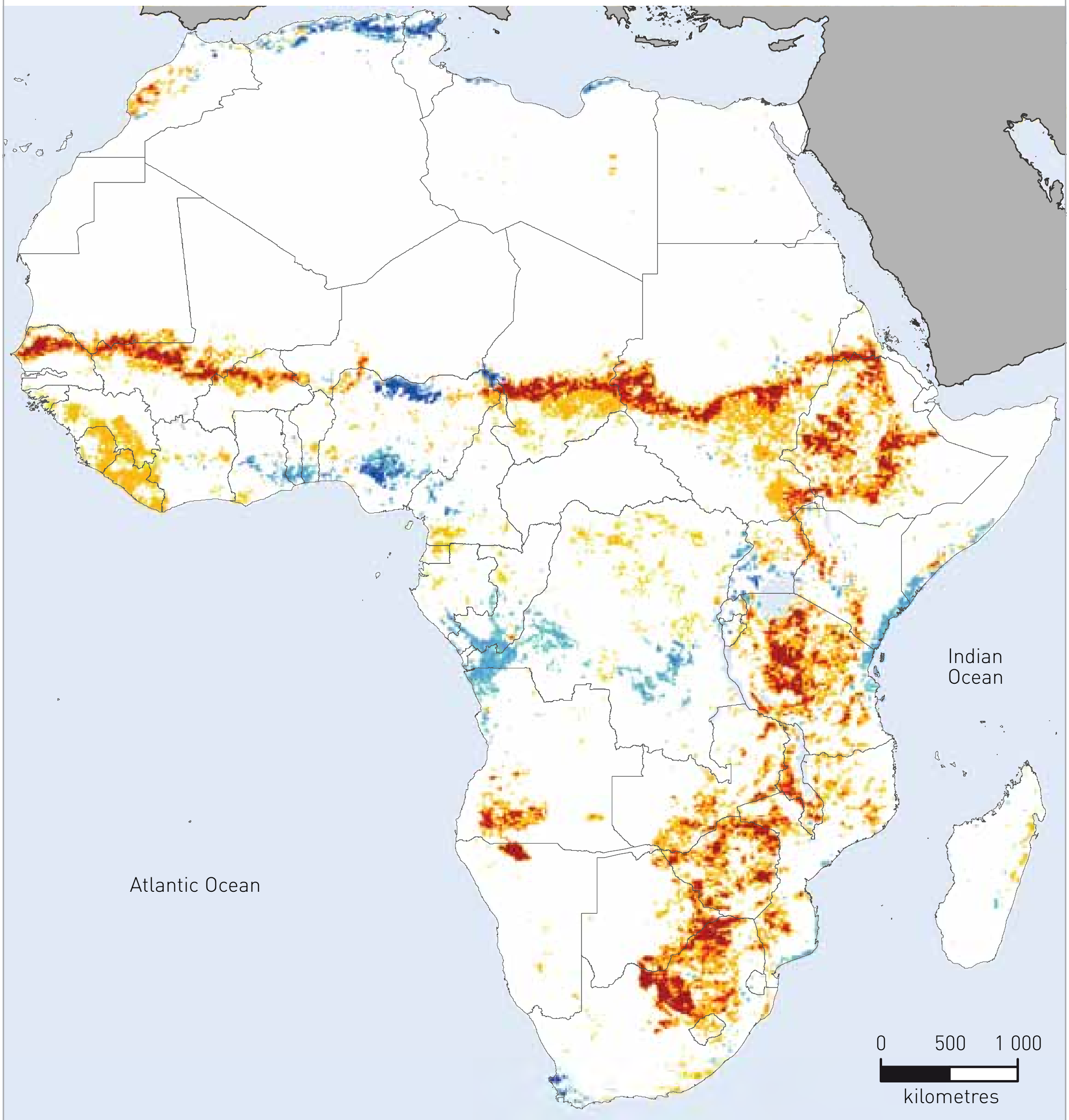
40–60
30–40
20–30
5–20

Percent more cropland in GlobCover 2005

5–20
20–30
30–40
40–70

Source: adapted from http://www.geo-wiki.org.

3.4 DISAGREEMENT IN THE CROPLAND DOMAIN BETWEEN GLC 2000 AND MODIS V.5 IN AFRICA



Percent more cropland in GLC 2000

40–50 | 30–40 | 10–30 | 5–10

Percent more cropland in MODIS v.5

5–10 | 10–20 | 20–30 | 30–60

Source: adapted from http://www.geo-wiki.org.

TABLE 3.2 DISAGREEMENT BETWEEN MOST RECENT LAND COVER PRODUCTS IN THE DOMAINS OF FOREST AND CROPLAND

Disagreement between land cover products	Forest (Mha)	% relative to FAO	Cropland (Mha)	% relative to FAO
Overall disagreement GlobCover vs MODIS v.5	**387.2**	**9.5**	**505.9**	**36.3**
Present in GlobCover Absent in MODIS v.5	285.6	7.0	360.0	25.9
Present in MODIS v.5 Absent in GlobCover	101.7	2.5	145.8	10.5
Overall disagreement GLC 2000 vs GlobCover	**314.3**	**7.7**	**395.2**	**28.4**
Present in GLC 2000 Absent in GlobCover	167.8	4.1	162.3	11.7
Present in GlobCover Absent in GLC 2000	146.5	3.6	232.9	16.7
Overall disagreement GLC 2000 vs MODIS v.5	**730.8**	**18.0**	**325.8**	**23.4**
Present in MODIS v.5 Absent in GLC 2000	517.9	12.8	94.8	6.8
Present in GLC 2000 Absent in MODIS v.5	212.9	5.2	231.1	16.6

Source of FAO reference estimates: FAOSTAT data for 2005.

forest domains as well as their combined disagreement. It is clear that there are large differences in many regions of the world.

Extensive disagreement is particularly evident in northern African countries, at the transition between savannah and desert. These areas of disagreement warrant more detailed examination, but are likely to result partly from the complex landscapes in these areas and the prevalence of small-scale farming, which is difficult to map. Another reason for these discrepancies is the difficulty in distinguishing between cropland and natural or semi-natural grassland in those regions, resulting from the similarity of their spectral and temporal profiles. From the livestock production systems perspective, this represents the transition from pastoral through agropastoral to mixed farming systems; accurate mapping of land cover is therefore absolutely critical in order to delineate these systems accurately.

The full set of maps showing the disagreements between each pair of land cover products, and the combined disagreement for cropland and forest, can be found on the Geo-Wiki web site[6]. Geo-Wiki was developed by Fritz *et al.* (2009) as a way of encouraging public participation in the validation of land cover. Geo-Wiki also allows users to explore inconsistencies between remotely sensed data and FAO statistics, as described below.

Disagreement at the national level

The third method for examining disagreement is at the national level. Countrywide area comparisons for the cropland and forest domains are available on the Geo-Wiki web site. An example is shown in Figure 3.5 for cropland in Mali for the GLC 2000, GlobCover and MODIS v.5 land cover products, based on the minimum and maximum thresholds in their respective legend definitions. It is interest-

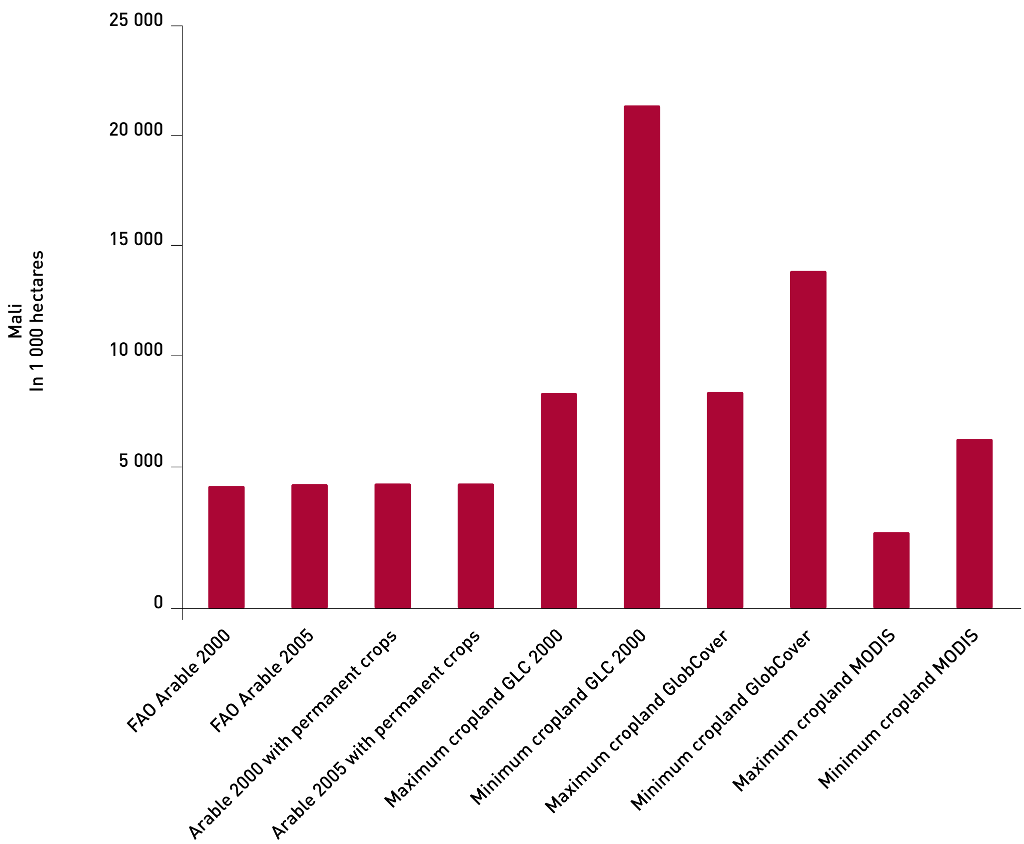
[6] Geo-Wiki: http://www.geo-wiki.org

ing that all land cover products (except the MODIS minimum) record higher cropland extents than those reported by FAO.

Possible future developments and solutions

More research needs to be directed towards finding ways to improve global land cover and to decrease the uncertainty in these datasets. One area for improvement is in the classification algorithms and methodologies used to create these products. The algorithms for creating MODIS products are continually being improved and used to reprocess MODIS data retrospectively. Other initiatives have involved improvements in the resolution of the global land cover products, for example the 300 metre spatial resolution of GlobCover as compared with the 1 km resolution for GLC 2000. However, as shown in Table 3.2, improving spatial resolution alone is clearly not a solution to this problem. This point is absolutely critical, given proposals for the Group on Earth Observations to coordinate the development of a 30 metre global land cover product, announced at the recent geo-ministerial summit in Beijing (US Department of the Interior, 2010). The big issue is to find ways to tackle the lack of sufficient ground data for the calibration and validation of these products. This task is now increasingly discussed by the Committee on Earth

3.5 COMPARISON OF FAO STATISTICS WITH THE GLC 2000, GLOBCOVER AND MODIS V.5 FOR MALI



Source: adapted from http://www.geo-wiki.org.

Observation Satellites, land cover validation and calibration subgroup, which advocates the collection of more 'authorized' hard validation data[7]. On the other hand, the soft validation data collected via crowd-sourcing and web 2.0/3.0 technologies can play a vital role in gathering a vast quantity of validation data quickly and at low cost. Bottom-up initiatives such as Geo-Wiki (Fritz *et al.*, 2009) may provide a short-term solution (Macauley and Sedjo, 2010). This online tool has already resulted in the accumulation of more than 12 000 validation points from around the world, which can be downloaded by any individual or institution for their own calibration/validation purposes. The ultimate goal of Geo-Wiki is the collection of high quality validation data distributed over different ecosystems which can be used in the future for the validation and calibration of products derived from remotely-sensed data, and the production of more accurate, hybrid land cover products. Fritz *et al.* (2011) have shown how five different land cover products can be integrated into a hybrid cropland map for Africa that is more accurate than any of the individual products. More efforts need to be channelled into developing algorithms for creating hybrid products in the future, given the importance of this layer in mapping agricultural production systems.

[7] See details at: http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=75&Itemid=116

4 From potential to actual production systems: accounting for crops, livestock and other livelihood options

The livestock production systems mapped by Thornton *et al.* (2002) may possibly be better referred to as 'potential livestock production systems', since they contain no information whatsoever on the actual distribution, or role, of livestock. The same does not apply completely to crops because – issues of accuracy notwithstanding – the land cover classification of cropland is based on satellite images and therefore should depict the actual distribution of crops, if not the types of crops or combinations thereof found on the ground.

The second level in the scheme proposed in Table 2.1 incorporates more detail on livestock systems – in particular detail related to the distributions and types of crops and livestock species that prevail in different places – and accounts for livelihood options that go beyond crops and livestock. By incorporating empirical data on crops, livestock and other livelihood options, we attempt in this section to move from the 'potential livestock production systems' of Thornton *et al.* (2002) towards a classification that reflects more closely the actual situation on the ground.

INTEGRATING MODELLED LIVESTOCK AND CROP DISTRIBUTIONS

The possibility of integrating detailed spatial data on crop and livestock distributions with the global livestock production systems is explored in this section, with two main objectives. First, to modify the potential livestock production systems of Thornton *et al.* (2002) to reflect the actual distribution of livestock. An area deemed livestock only, based largely on its land cover characteristics, may not support livestock in reality, as indeed many so-called mixed crop–livestock areas may support few or no livestock for a variety of reasons. As discussed earlier, the same is not directly true for crops, since mixed systems are determined by the detection of crops or fields from satellite data. The second objective of including empirical crop and livestock data is to characterize the potential livestock production systems, and in particular, to disaggregate further the mixed crop–livestock systems.

Subnational agricultural statistics are collected regularly by national governments, usually through agricultural censuses conducted every ten or so years; these form the baselines from which the data reported in statistical yearbooks are estimated. Various efforts, described below, are made to compile such subnational data globally, for example Agro-MAPS[8] for crop statistics (George *et al.*, 2009) and the Global Livestock Impact Mapping System (GLIMS) for livestock data (Franceschini *et al.*, 2009). However, the resulting statistics are often patchy and vary considerably in terms of spatial resolution (level and size of administrative units) and reference date. Modelling approaches have been developed to overcome these shortfalls and to produce global, high-resolution estimates of these distributions, offering the possibility of incorporating such data into agricultural systems classifications and maps.

Livestock distributions

FAO has an ongoing programme to collate and disseminate subnational livestock statistics for the globe: the GLIMS (Franceschini *et al.*, 2009). Subnational livestock statistics are collected from a variety of sources and geo-registered to digital administrative area boundaries at the level at which they are reported for the various countries. Subnational boundaries are standardized to the

[8] Agro-MAPS: http://kids.fao.org/agromaps

Global Administrative Unit Layers (GAUL)[9] system where possible. There is a number of products derived from the GLIMS information system. One of these is GLiPHA[10] – the Global Livestock Production and Health Atlas – which provides a coarse spatial resolution view of the data (usually at administrative level 1). Another product is the GLW[11] (Robinson *et al.*, 2007; FAO, 2007a), which provides modelled distribution data in raster format for cattle, buffalos, sheep, goats, pigs, chickens and other poultry. The map values are animal densities (i.e. number of animals per square km), at a resolution of 3 arc minutes (approximately 5 km at the Equator). These maps are updated regularly, more recently at a spatial resolution of *c.* 1 km, using the method summarized below (also described in detail in FAO 2007a).

First, the best available subnational data on livestock populations, at a range of spatial resolutions depending on availability, are collected and standardized. These are converted to densities and adjusted to account for the area of land deemed suitable for livestock production. The suitability adjustments are based on environmental, land cover and land use criteria. For example, livestock are excluded from areas where satellite-derived vegetation indices indicate there is insufficient grazing (for ruminant species) and where topographic features such as elevation and slope would preclude livestock production. They are also excluded where land cover is unsuitable, such as in dense forests and urban areas, and where prevailing land use would not permit livestock to be found, such as in protected areas.

The resulting suitability-adjusted livestock densities are then used to establish robust statistical relationships between livestock densities and an extensive suite of predictor variables, summarized in Table 4.1. Details and references to the data sources are provided in Robinson *et al.* (2007) and FAO (2007a).

TABLE 4.1 GENERIC LIST OF VARIABLES USED IN LIVESTOCK DISTRIBUTION MODELLING

Generic type	Variables
Locational	Longitude, Latitude
Anthropogenic	Distance to roads Distance to city lights
Demographic	Human population
Topographic	Elevation
Land cover	Normalized difference vegetation index
Temperature	Land surface temperature Air temperature Middle-infrared
Water and moisture	Vapour pressure deficit Distance to rivers Cold cloud duration Potential evapotranspiration
General climatic	Modelled length of growing period
Other	Tsetse distributions (for Africa)

Source: adapted from Robinson *et al.* (2007)

Since the best predictors of animal densities are unlikely to be the same from region to region or across different agro-ecological zones, models are developed separately for different regions and for different ecological zones (defined empirically by cluster analysis of remotely-sensed climatic variables). A series of stepwise multiple regression analyses are performed between the livestock densities and the predictor variables. The models are developed at several different spatial scales – continental; subregional; for 50 ecological zones; for each ecological zone within each region – and using a variety of data transformations (no transformation; logarithmic; exponential; and power) to accommodate non-linear relationships. The best relationship for any point (pixel) is selected according to coefficients of determination (R^2). If the statistical relationship for the analysis at the level of ecological zone by region has an R^2 value in excess of 40 percent then it is used; if it is less than 40 percent those equations are discarded and the relationship at the next level up, i.e. the ecological zone, is evaluated. If that relationship has

[9] GAUL (available through Geonetwork): http://www.fao.org/geonetwork/srv/en/main.home
[10] GLIPHA: http://kids.fao.org/glipha
[11] GLW: http://www.fao.org/ag/againfo/resources/en/glw/home.html

an R^2 value of greater than 40 percent it is used; if not then it is discarded and the regional equations evaluated. In the few cases that these still fail to attain R^2 values better than 40 percent, the continental equation is used. Typically, R^2 values range between 50 and 80 percent and all the predictive equations are statistically highly significant ($P < 0.001$).

The selected equations are then applied back to the images of predictor variables to generate a map of modelled density for each species. To avoid spurious predictions the modelled numbers for each administrative unit are adjusted to equal those reported and further products are then generated, adjusting the modelled national totals to match FAO's official national statistics, providing time-standardized datasets (so far for the years 2000 and 2005).

This modelling approach has the major dual advantages of predicting livestock densities in areas with no livestock data, and disaggregating livestock density data that are available originally only at a coarse spatial resolution. Since the original global datasets were produced (FAO, 2007a) work has been ongoing at FAO to develop the GLW methodology further, and to improve and update both the predictor variables used and the quality of the reported, subnational statistics on which the modelled outputs are based. These improvements have been applied initially to poultry distributions in Asia (Prosser *et al.*, 2011; Van Boeckel *et al.*, 2011) and new, global, 1 km resolution datasets for all livestock species are also under construction. Figure 4.1 shows the global modelled livestock distributions for cattle and pigs, standardized to FAOSTAT 2005 national totals.

Crop distributions

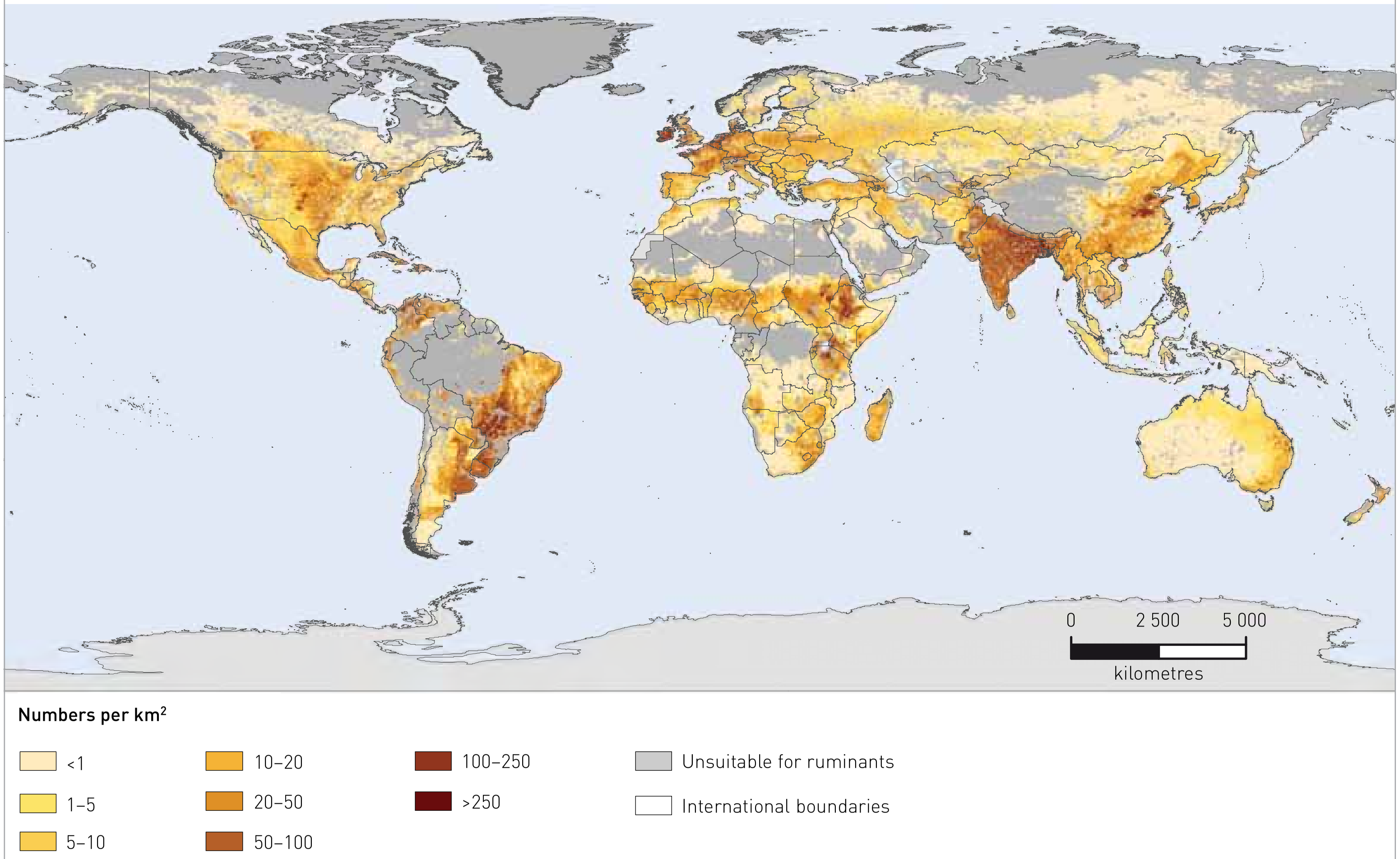
Similarly, though using a different modelling approach, work has been undertaken at the International Food Policy Research Institute (IFPRI) to disaggregate reported crop production statistics (You and Wood, 2004; 2006; You *et al.*, 2006; 2009). Crop production data from large reporting units (usually national or administrative level 1) are allocated spatially to a raster grid at a spatial resolution of 5 arc minutes (approximately 9 km at the Equator). These modelled crop layers are referred to as the Spatial Production Allocation Model (SPAM) dataset, and can be freely downloaded from the MapSPAM web site[12] (the version current at the time of writing was SPAM 2000 Version 3.0.2, produced in April 2010).

The allocation model works by inferring likely production locations from multiple indicators including farming systems, land cover, crop-specific biophysical suitability, commodity prices, and local market access. The model employs a cross-entropy approach (Shannon, 1948) – essentially, a statistical estimation procedure designed to make the most of the informational content of specific data – to manage inputs with different levels of likelihood in indicating the specific locations of agricultural production. No attempt is made in this book to describe in detail the rather complex approach involved; for the interested reader a recent description of the data sources and methodology can be found in You *et al.* (2009). In essence though, crop areas at the national level are first broken down by four different management intensities: 1) irrigated; 2) high-input rainfed; 3) low-input rainfed; and 4) subsistence. Initial, plausible, spatial allocations of each crop are then generated using subnational reported data from a variety of sources, including Agro-MAPS (George *et al.*, 2009) and crop suitability surfaces (Fischer *et al.*, 2001). A cross-entropy approach (Shannon, 1948) is then used to optimize the initial crop allocations with respect to minimizing the cross-entropy distances between different probability distributions of the variables in the analysis, under different spatial constraints. By minimizing cross-entropy, the estimation procedure ensures that uncertainty – information entropy is a metric that measures the uncertainty of expected information – is minimized. Specifically, these constraints are as follows:

- Total agricultural land in a given pixel is estimated by merging the two different

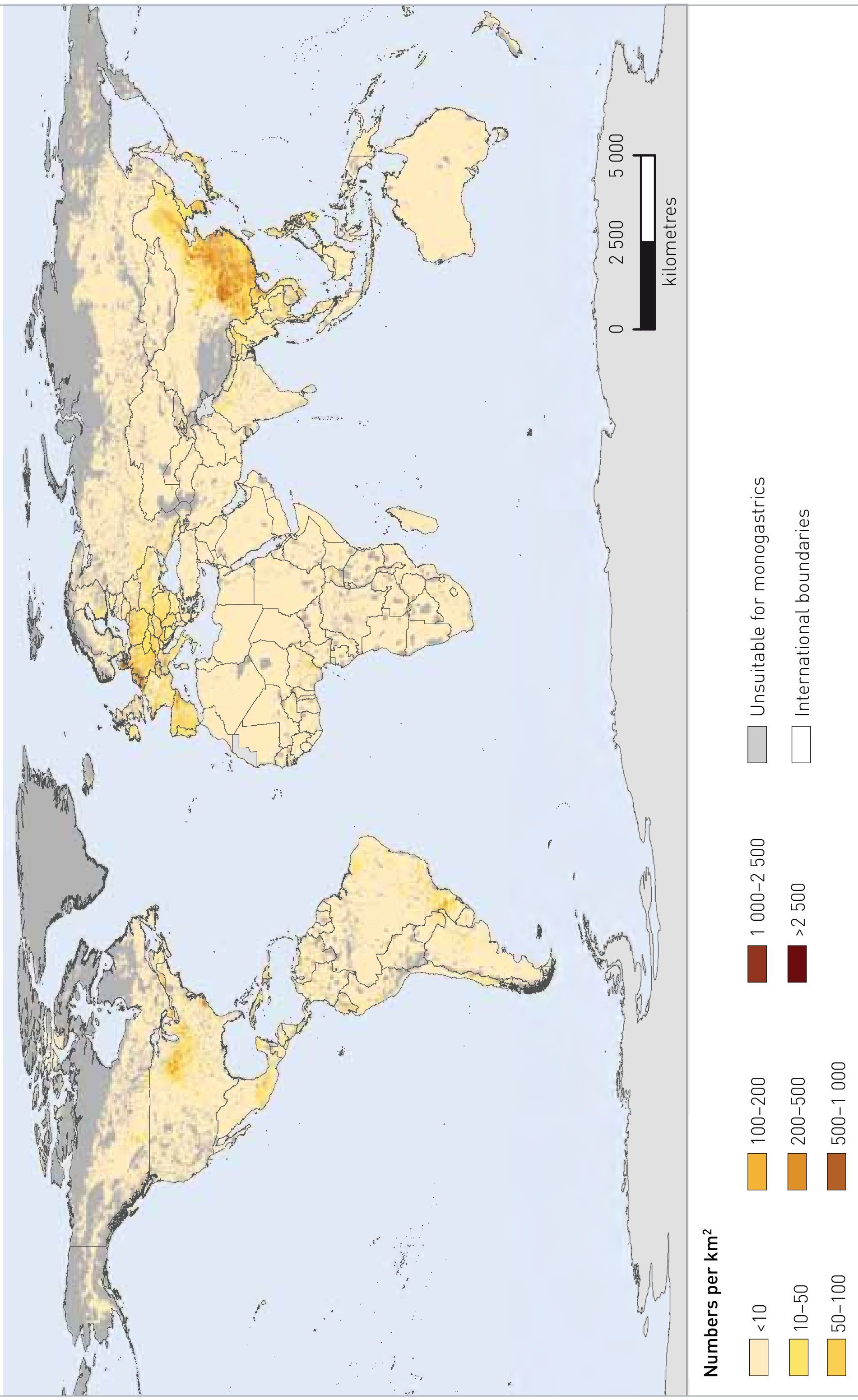
[12] MapSPAM: http://mapspam.info

4.1a ESTIMATED GLOBAL DISTRIBUTIONS OF CATTLE, ADJUSTED TO MATCH TO FAOSTAT 2005 NATIONAL TOTALS



Source: adapted from FAO (2007a).

4.1b ESTIMATED GLOBAL DISTRIBUTIONS OF PIGS, ADJUSTED TO MATCH TO FAOSTAT 2005 NATIONAL TOTALS



Source: adapted from FAO (2007a).

satellite-derived products: Boston University's MODIS-derived land cover product and the GLC 2000 dataset (Ramankutty *et al.*, 2008). In addition to a mean cropland estimate, Ramankutty *et al.* (2008) also calculated 5th percentile and 95th percentile values of the cropland. A consistency index is estimated to account for the uncertainty and inconsistency of cropland estimates.

- Crop suitability is estimated building on an approach initially developed by FAO (1981) that used location-specific data on elevation, temperature, and rainfall to assess agroclimatic suitability for a series of crops under low- and high-input rainfed conditions. The approach has since been extended in many ways and the data used for the crop allocation are the most recent versions of the crop suitability data, available globally at a spatial resolution of 5 arc minutes (Fischer *et al.*, 2001).
- The irrigated area in each pixel is taken from the FAO Aquastat map Version 4.0.1. (Siebert *et al.*, 2007). Aquastat provides a global map of irrigation that shows the amount of area equipped for irrigation as a percentage of the total pixel area, at a spatial resolution of 5 arc minutes.
- Transaction costs and market access are implied by a market access proxy estimated by using a normalized rural population density measure, described in You *et al.* (2009). Population data are taken from the Gridded Population of the World Version 2, which provides global estimates of population counts and population densities (CIESIN *et al.*, 2000). Urban areas, which do not normally produce any crops, are eliminated using the urban mask from the GRUMP dataset (CIESIN *et al.*, 2004). National figures are reconciled with UN population estimates for 1990 and 1995.

The allocated crop areas are finally converted into production by considering both the broader production systems and the spatial variation within the systems. An average potential yield within each spatial allocation unit is estimated for each crop using the allocated areas as a weight. The yield of each crop in each production system is then estimated by multiplying the suitability by the reported yield, and dividing by the potential yield. Production is estimated by multiplying yield by the allocated area and the cropping intensity. A validation of the approach in Brazil has shown that the disaggregated coarse resolution data agree well with available data from smaller reporting units (You and Wood, 2006).

Figure 4.2 shows the resulting crop distribution maps for maize and sorghum. Similar maps have been generated for an additional 18 major crops (see Table 4.2) covering over 90 percent of the world's crop land. In addition to these area distribution maps, the model results include production and harvested area distribution maps, as well as the subcrop type maps split by the four production input levels.

Crop and livestock characteristics of the global livestock production systems

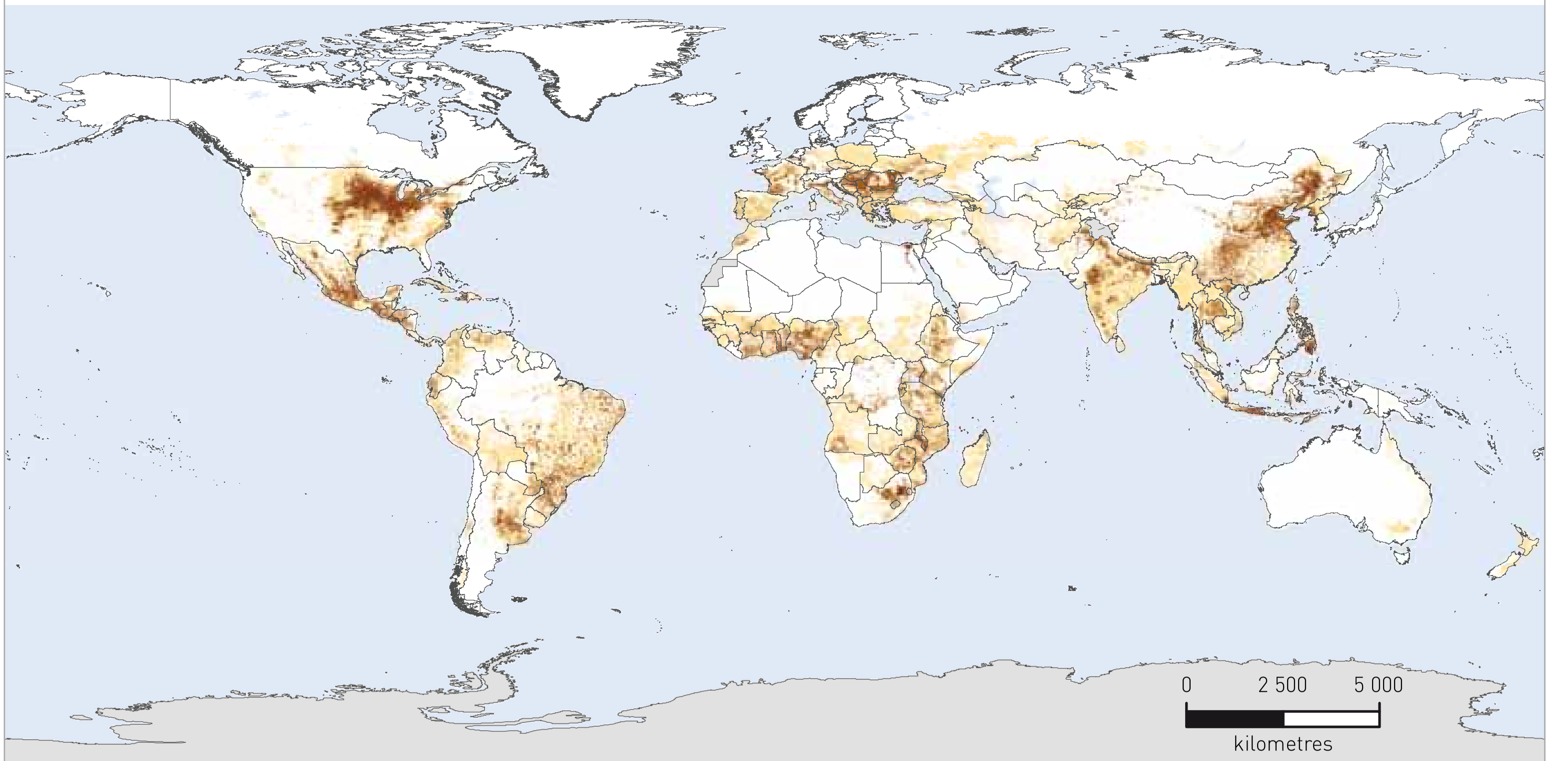
Neither the original Seré and Steinfeld (FAO, 1996) classification, nor any of the subsequent efforts

TABLE 4.2 CROPS WHOSE DISTRIBUTIONS HAVE BEEN MODELLED BY IFPRI

Hierarchy	Input data
Cereals (6)	Wheat, rice, maize, barley, millet, sorghum
Roots and tubers (3)	Potato, sweet potato and yams, cassava
Fruits (1)	Banana and plantain
Pulses (2)	Dry beans, other pulse
Sugar crops (2)	Sugar cane, sugar beets
Fibre crops (2)	Cotton, other fibres
Oil crops (3)	Soybean, groundnuts, other oil crops
Stimulant crops (1)	Coffee

Source: adapted from You *et al.* (2006).

4.2a ESTIMATED CROP DISTRIBUTION MAPS OF THE WORLD: HARVESTED AREA OF MAIZE



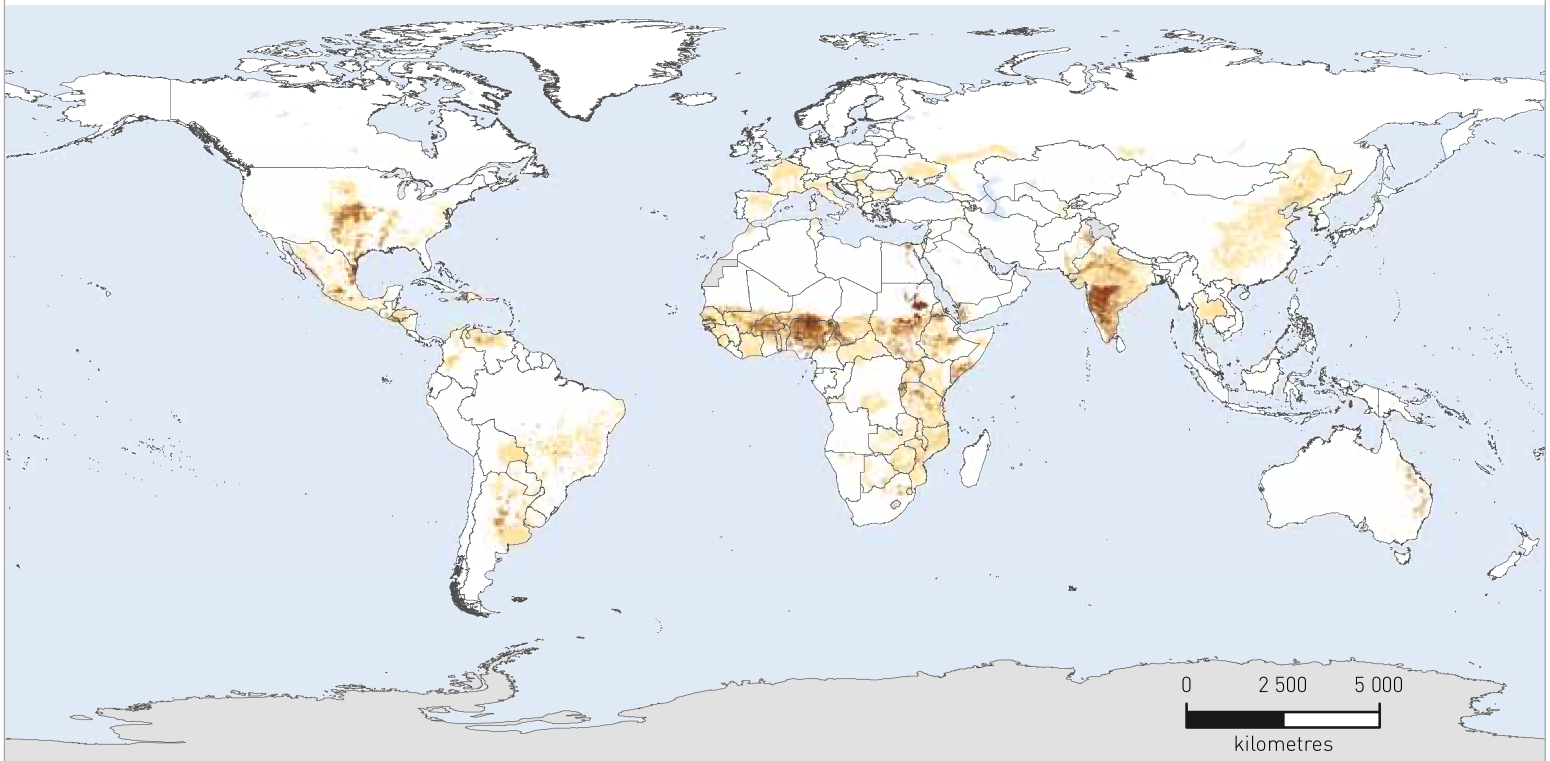
Harvested area (hectares per cell*)

1–100 | 100–200 | 200–400 | 400–800 | 800–1 600 | 1 600–3 200 | >3 200

* Harvested areas of less than 1 hectare per cell are not shown on the map.

Source: drawn from SPAM data (You *et al.*, 2009).

4.2b ESTIMATED CROP DISTRIBUTION MAPS OF THE WORLD: HARVESTED AREA OF SORGHUM



Harvested area (hectares per cell*)

1–100 | 100–200 | 200–400 | 400–800 | 800–1 600 | 1 600–3 200 | >3 200

* Harvested areas of less than 1 hectare per cell are not shown on the map.

Source: drawn from SPAM data (You *et al.*, 2009).

to map it (Thornton *et al.*, 2002; Kruska *et al.*, 2003; Kruska, 2006), make any explicit attempt to investigate the actual composition of crop or livestock production in the different systems identified. However, given that global and detailed spatial data are now available for many of the major crop and livestock species, we are in a position to look at how these are distributed across the different systems and in what combinations they tend to occur in different places.

An obvious reason to incorporate empirical crop and livestock data in the classification of Thornton *et al.* (2002) is to make adjustments to the areas designated livestock only, grasslands (LG), mixed rainfed (MR) and mixed irrigated (MI), based on the modelled distributions of crops and livestock. Areas classified as rangeland (LG), but where reported statistics suggest that cropping also occurs, can be reassigned to the mixed rainfed category (MR). A further 'crops only' category can be introduced in areas where empirical data suggest that few if any livestock occur in potentially mixed farming areas.

Table 4.3 lists the main adjustments that could result from including reported or modelled crop and livestock data with the livestock production system maps. Three of the potential adjustments reflect inconsistencies in the crop cover data layers; if the livestock production system and SPAM mapping approaches were harmonized to the extent that they used exactly the same estimates of agricultural land cover, then these adjustments would not occur.

Notenbaert *et al.* (2009) have made such adjustments to the livestock production systems maps, using a threshold of 10 percent, and shown that the discrepancies are quite extensive.

A second reason for incorporating empirical crop and livestock data is to classify the livestock production system classes further, and in particular to break down the mixed farming areas. Notenbaert *et al.* (2009) have included the SPAM crop data following the adjustments to mixed farming areas discussed above. They classified the 20 SPAM crops into 4 functional groups: 1) cereals

TABLE 4.3 MAIN ADJUSTMENTS THAT COULD RESULT FROM INCLUDING EMPIRICAL CROP (SPAM) AND LIVESTOCK (GLW) DATA WITH THE GLOBAL LIVESTOCK PRODUCTION SYSTEMS CLASSES, AND THE CONDITIONS REQUIRED FOR THE ADJUSTMENTS TO BE MADE

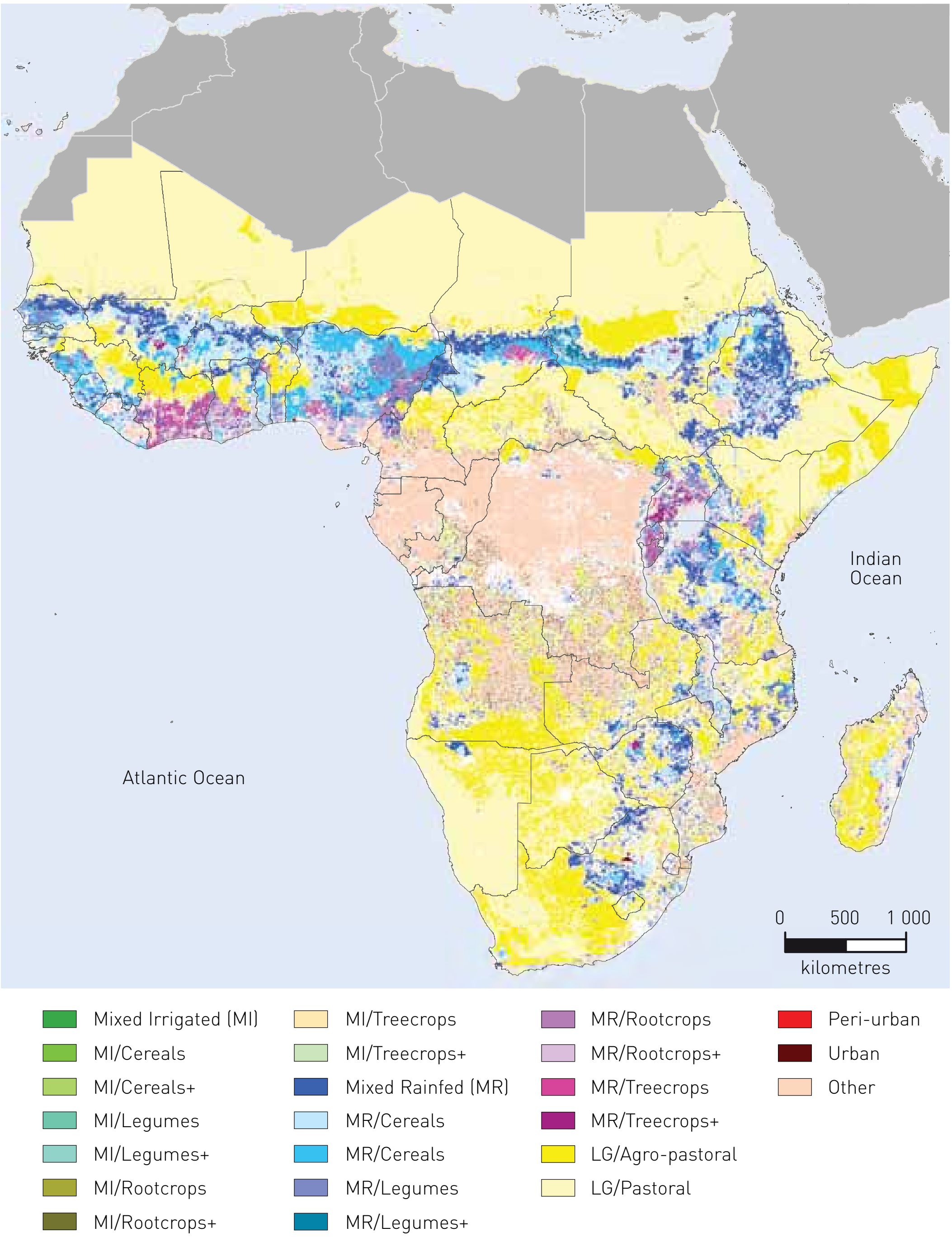
Original system	Revised system	Conditions	Comment
LG	LG	SPAM = no crop GLW = livestock	No change
LG	MR	SPAM = crop GLW = livestock	Reflects inconsistencies in crop cover data layers
LG	Rainfed crop only (CR)	SPAM = crop GLW = no livestock	Reflects inconsistencies in crop cover data layers
MR	MR	SPAM = crop GLW = livestock	No change
MR	LG	SPAM = no crop GLW = livestock	Reflects inconsistencies in crop cover data layers
MR	Rainfed crop only (CR)	SPAM = crop GLW = no livestock	No livestock in potentially mixed (rainfed) areas
MI	MI	SPAM = crop GLW = livestock	No change
MI	Irrigated crop only (CI)	SPAM = crop GLW = no livestock	No livestock in potentially mixed (irrigated) areas

(maize, millet, sorghum, rice, barley and wheat); 2) legumes (beans, cow peas, soy beans and groundnuts); 3) root crops (cassava, (sweet) potato and yams); and 4) tree crops (cocoa, coffee, cotton, oil palm, banana). They then estimated the densities of each group as a whole, and subcategorized the livestock production systems to include the major functional crop grouping(s). Notenbaert *et al.* (2009) further used the SPAM data to subdivide the rangeland (LG) systems into pastoral (with no cropping) and agropastoral systems (where livestock keeping is supplemented by low levels of crop production). They did this by reassigning rangeland areas to agropastoral where the SPAM layers indicate cropping to occur but at less than 10 percent (areas with more than 10 percent having already been re-classified as mixed farming areas). In sub-Saharan Africa, the resulting agropastoral areas covered 19 percent of the total land area, and were home to almost 10 percent of the human population, plus some 15 million cattle.

Figure 4.3 shows the resulting map for sub-Saharan Africa (a plus sign appended to the major crop group indicates that it covers less than 60 percent of the area, and that other group(s) are also important). The Figure shows the cereal-dominated systems to be particularly prevalent in Eastern Africa, while in central and western Africa, the tree and root crop systems also cover large areas of land.

Table 4.4 shows the average farmed area for the four functional groups (cereals, legumes, roots and tree crops) and the mean livestock density (for bovines, small ruminants, pigs and poultry) across the livestock production systems. Values are summarized by the World Bank regions in 2010. Later in the book the same strata are applied to report the distribution of rural poor livestock keepers across the livestock production systems. Consistent with their definition, the potential livestock-only systems have none or limited areas farmed with legumes, roots and tree crops. However, the land cover information and subsequent adjustments based on climate and human population are less precise in identifying the distribution of the area farmed with cereals. Consequently, cereals cultivation is also found in the livestock-only systems of the different regions. Unsurprisingly, the mixed irrigated areas show the highest proportions of farmed area. Overall mixed farming systems (both rainfed and irrigated) concentrate the highest densities of livestock. The distribution of poultry seems somewhat unrelated to the livestock production systems. As observed earlier, the current mapping method relies heavily on land cover data using *ad hoc* interpretation of land cover categories as a proxy for the potential distribution of livestock. However, poultry might be more loosely associated with land cover aspects compared with cattle or other ruminants. This suggests that the livestock production systems classification is better suited to mapping the distribution of potential systems for ruminants rather than for monogastric species. The climatic distribution (hyper-arid, arid and semi-arid, humid and sub-humid, temperate/tropical highland) of the mixed rainfed systems varies across the regions. Nevertheless there is a clear pattern that associates the cultivation of cereals to the distribution of bovines. In the more arid countries of the Middle East and North Africa, bovines are typically replaced by sheep and goats. Eastern and southern Asian regions report significant proportions of farmed area and relatively high livestock densities in urban areas. This calls for refinement of the current method to capture more completely the different urban conditions, as well as peri-urban agriculture, across the regions. It also suggests a need to harmonize the classification and mapping of livestock production systems and the modelling of livestock distributions.

4.3 THE LIVESTOCK PRODUCTION SYSTEMS MAP (VERSION 3) FOR SUB-SAHARAN AFRICA, EXTENDED TO INCLUDE SPAM CROP DATA CLASSES



Source: adapted from Notenbaert *et al.* (2009).

TABLE 4.4 CROP AND LIVESTOCK GROUPS BY LIVESTOCK PRODUCTION SYSTEM (VERSION 5)*

		LGY	LGA	LGH	LGT	MRY	MRA	MRH	MRT	MIY	MIA	MIH	MIT	Urban	Other
EAP	Cereals	0	0	2	0	6	8	9	8	10	17	32	31	21	3
	Legumes	0	0	1	0	2	8	2	3	3	8	3	8	5	1
	Root crops	0	0	0	0	0	0	2	1	0	0	3	1	2	0
	Tree crops	0	0	0	0	0	1	1	0	0	1	1	3	1	0
	Bovines	2	0	8	2	4	28	18	20	12	37	27	37	27	13
	Small ruminants	39	11	2	29	5	48	10	64	9	40	15	101	61	14
	Pigs	2	0	6	2	23	47	45	57	43	50	100	120	99	39
	Poultry	67	5	94	18	373	337	591	660	764	378	1 169	2 263	1 818	426
EECA	Cereals	0	5	11	1	5	18	17	16	27	31	11	20	11	0
	Legumes	0	0	0	0	0	2	2	1	3	3	1	1	1	0
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	1	0	0	0	1	0	0	0	5	0	3	1	0
	Bovines	0	11	0	1	1	14	16	9	0	25	41	18	11	2
	Small ruminants	3	51	0	3	2	47	15	8	18	48	74	24	13	2
	Pigs	2	0	0	0	21	1	5	19	0	1	7	8	9	1
	Poultry	13	124	0	9	275	321	364	144	0	306	298	284	237	29
LAC	Cereals	0	1	2	1	1	4	5	5	6	15	12	7	7	1
	Legumes	0	0	2	1	1	3	5	1	2	3	4	2	3	1
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	0	1	1	1	5	2	2	1	2	0
	Bovines	0	7	37	8	8	20	53	24	148	27	51	30	25	8
	Small ruminants	0	6	9	20	6	12	5	22	0	12	11	38	7	3
	Pigs	0	1	3	3	7	6	8	10	0	21	13	14	10	3
	Poultry	19	41	94	98	55	154	231	291	9	375	358	502	279	80
MENA	Cereals	0	1	0	11	10	14	15	19	27	37	17	27	19	6
	Legumes	0	0	0	1	1	1	7	1	2	4	19	6	2	1
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	1	0	1	0	3	3	4	2	1	0
	Bovines	0	2	54	7	0	9	31	9	92	25	25	19	17	21
	Small ruminants	1	20	117	62	8	83	60	75	109	76	57	62	66	86
	Pigs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Poultry	6	85	1 420	248	30	427	1 518	444	873	616	1 638	349	541	689

(Continued)

TABLE 4.4 CROP AND LIVESTOCK GROUPS BY LIVESTOCK PRODUCTION SYSTEM (VERSION 5)* *(Continued)*

		LGY	LGA	LGH	LGT	MRY	MRA	MRH	MRT	MIY	MIA	MIH	MIT	Urban	Other
SA	Cereals	5	2	1	1	25	22	24	9	57	39	61	19	34	11
	Legumes	0	0	0	0	1	12	3	2	4	11	5	1	9	5
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	1	4	1	0	0	5	1	0	4	1
	Bovines	9	11	29	6	44	88	91	43	136	138	164	69	105	62
	Small ruminants	6	39	5	6	37	74	56	47	187	84	175	91	75	41
	Pigs	0	0	23	3	0	2	9	9	0	5	4	8	4	5
	Poultry	24	48	370	102	381	166	402	520	430	199	821	294	288	247
SSA	Cereals	0	1	2	4	0	8	7	12	0	21	16	14	8	1
	Legumes	0	0	0	0	0	4	2	2	0	4	3	2	2	0
	Root crops	0	0	1	0	0	1	5	1	0	1	6	1	2	0
	Tree crops	0	0	1	0	0	1	2	2	0	2	3	2	1	0
	Bovines	0	6	3	12	4	22	13	55	7	44	35	100	20	8
	Small ruminants	0	15	5	27	8	39	22	55	16	76	36	77	49	11
	Pigs	0	0	0	1	0	1	4	2	1	1	16	2	5	2
	Poultry	3	11	10	26	12	64	98	91	47	105	162	292	487	55
HIC	Cereals	0	1	4	2	2	17	4	22	6	18	13	29	8	1
	Legumes	0	0	1	0	1	1	2	9	0	1	8	10	3	0
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	1	0	0	0	2	0	0	2	9	1	1	0
	Bovines	0	3	24	3	4	11	33	23	8	22	15	32	18	5
	Small ruminants	2	6	30	2	5	58	79	13	5	36	12	7	12	5
	Pigs	1	1	3	1	46	15	26	35	64	23	17	74	23	5
	Poultry	23	34	165	9	213	133	527	410	791	370	356	701	421	109

Developing regions and high income countries are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

EAP = East Asia and the Pacific; **EECA** = Eastern Europe and Central Asia; **LAC** = Latin America and the Caribbean;
MENA = Middle East and North Africa; **SA** = South Asia; **SSA** = Sub-Saharan Africa; **HIC** = High Income Countries.

* For the crop groups the average farmed area from the SPAM dataset (You *et al.*, 2009) is presented (percentage of each livestock production system area farmed with a given crop group); for the livestock groups the mean livestock density from GLW (FAO, 2007a) is presented (numbers per km^2).

AD HOC EXTENSION OF THE MAPPED LIVESTOCK PRODUCTION SYSTEMS CLASSIFICATION

For some applications, the use of a livestock-based classification such as that of Seré and Steinfeld (FAO, 1996) or those based on it, is not appropriate by itself, simply because there will be situations in which details are needed concerning important communities of people whose livelihoods are not partially dependent on livestock.

An example of a study that involved the rather *ad hoc* extension of the livestock production systems map was that of climate change and vulnerability in Africa (Thornton *et al.*, 2006). In that study the livestock systems were supplemented with some of the farming system categories from Dixon *et al.* (2001). As noted above, this farming systems classification is based on a principal livelihoods approach, and has been used to assess general trends in the poverty levels associated with each system. Because the classification itself is based largely on expert knowledge it is probably not entirely mappable using global- or continental-level datasets. In the vulnerability study an extended systems classification was derived by taking the livestock production system map Version 3 (Kruska, 2006), and for those areas that were classified as 'other' (i.e. non-livestock systems), a digitized version of the Dixon *et al.* (2001) classification was overlain to see which systems were occurring in these non-livestock areas. As a result, the 'other' category in sub-Saharan Africa was supplemented with the following five system categories from the Dixon *et al.* (2001) classification:

- Coastal artisanal fishing-based systems (principal livelihoods include marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry and off-farm work).
- Forest-based systems (cassava, maize, beans and cocoyams).
- Highland perennial-based systems (banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry and off-farm work).
- Rice-tree crop systems (rice, banana, coffee, maize, cassava, legumes, livestock and off-farm work).
- Tree crop systems (cocoa, coffee, oil palm, rubber, yams, maize and off-farm work).

The root crop systems and the cereal root crop mixed systems, which also occurred in the 'other' zones but to a smaller extent, were combined into one category and added to all other areas that remained unclassified.

As might be expected given the very different ways in which the two classifications were derived, there are some mismatches between them in terms of areas that are classified inconsistently. For example, the coastal artisanal fishing system also includes goats and poultry (Dixon *et al.*, 2001), although in the global livestock production systems map produced by Kruska *et al.* (2006), these are classified as systems with no livestock. Overall, however, given the continental scale of these data sets, the match between the two systems was found to be reasonably consistent. The full set of systems is provided in Table 4.5, showing for each system the source of the system definition and the source of the mapped system.

These systems were used to assess current and possible future vulnerability to climate change in sub-Saharan Africa. Despite the uncertainties associated with the analysis, results indicated that many currently vulnerable regions are likely to be adversely affected by climate change in sub-Saharan Africa. These include the mixed arid and semi-arid systems in the Sahel (MRA), arid and semi-arid rangeland systems in parts of Eastern Africa (LGA), the mixed and highland perennial systems in the Great Lakes region of Eastern Africa (MRT, PEREN), the coastal regions of Eastern Africa (COAST), and many of the drier zones of southern Africa (LGA, MRA). More details can be found in Thornton *et al.* (2006; 2008).

TABLE 4.5 AGRICULTURAL SYSTEMS USED IN THE AFRICAN CLIMATE CHANGE VULNERABILITY STUDY, SHOWING THE SOURCE OF DEFINITION AND THE SOURCE OF MAPPING

Type	Code	Short system description	Source defined	Source mapped
"Livestock" systems	LGA	Livestock only systems, arid and semi-arid	S	K3
	LGH	Livestock only systems, humid and sub-humid	S	K3
	LGHYP	Livestock only systems, hyper-arid	K6	K6
	LGT	Livestock only systems, highland/temperate	S	K3
	MIA	Irrigated mixed crop/livestock systems, arid and semi-arid	S	K3
	MIH	Irrigated mixed crop/livestock systems, humid and sub-humid	S	K3
	MIHYP	Irrigated mixed crop/livestock systems, hyper-arid	K6	K6
	MRA	Rainfed mixed crop/livestock systems, arid and semi-arid	S	K3
	MRH	Rainfed mixed crop/livestock systems, humid and sub-humid	S	K3
	MRHYP	Rainfed mixed crop/livestock systems, hyper-arid	K6	K6
	MRT	Rainfed mixed crop/livestock systems, highland/temperate	S	K3
"Non-livestock" systems	RITRE	Rice-tree crop systems	D	D
	TREEC	Tree crop systems	D	D
	URBAN	Built-up areas	G	G
	COAST	Coastal artisanal fishing-based systems	D	D
	FORST	Forest-based systems	D	D
	PEREN	Highland perennial-based systems	D	D
	OTHER	Others (including root-crop-based & root-based mixed systems)	S & D	K3

S = Seré and Steinfeld (FAO, 1996); **K3** = Kruska *et al.* (2003); **K6** = Kruska (2006);
D = Dixon *et al.* (2001); **G** = GLC 2000 (Mayaux *et al.*, 2004).

Source: adapted from Thornton *et al.* (2006).

This kind of approach could be extended globally, although there is probably limited utility in attempting to combine classification systems that are not based on the same criteria. Moreover, it assumes that the 'other' category in the mapped livestock production systems does not support livestock, whereas the annexes of FAO (2007a) show this not to be the case: many livestock fall into the areas classified as 'other' according to the modelled livestock distributions. In the example above, this provided a stop-gap means of being able to say something about non-livestock systems in the absence of detailed crop layers. Now that these layers are available it probably makes more sense to pursue a strategy to derive systems maps based on a set of coherent principles and datasets, using the crop and livestock data described above.

5 Accounting for intensive livestock production

In recent decades there has been enormous growth in livestock production, driven by increasing demand for animal-source foods among large segments of the world's population. Developing countries account for the main share of this increase (Delgado *et al.*, 1999). The driving forces behind this growth have principally been population growth and changes in dietary preferences associated mostly with increasing wealth and urbanization. Growing demand for animal-source foods has important implications for agricultural production systems and for producers in poor rural areas, who need to adapt continuously to the changing environmental, social, economic, market and trade circumstances (Parthasarthy Rao *et al.*, 2005). This adaptation can take place in different forms, such as expansion of cultivated areas, intensification of production, and closer integration of crop and livestock (Powell *et al.*, 1994). Globally, livestock production has responded to increasing demand primarily through a shift from extensive, small-scale, subsistence, mixed crop and livestock production systems towards more intensive, large-scale, geographically-concentrated, commercially-oriented, specialized production units. Monogastric species (pigs and poultry) in particular, by virtue of their high feed conversion ratios and short generation intervals, are well suited to rapid intensification of production. It is estimated that more than half of global pork production and 70 percent of poultry meat is now produced in intensive systems (Steinfeld *et al.*, 2006). In many parts of Africa and Asia producers may be engaged in an intermediate, semi-intensive type of production system, usually in mid-sized family farms. Moreover, some producers intensify some but not all aspects of their production – animal health care or genetic improvement, for example – adding a further layer of complexity to the process of defining, identifying and mapping intensive production. Small-scale dairying in the highlands of East Africa is a good example: there, milk production may often be increased via dietary improvement rather than genetic improvement.

Intensification results when farmers specialize in the production of a single commodity. This enables them to invest in more targeted technologies and facilities and to access distribution markets more readily; ultimately, this leads to improved economies of scale. Other factors contributing to the intensification of production include better veterinary care, better farm management practices, access to external service providers, and tighter control of the production environment through factors such as light, temperature and humidity. The use of highly productive breeds can also result in intensification. These are often internationally traded from developed to developing countries and tend to replace or be crossbred with local animals. The better feed conversion rates of this improved livestock in turn affects growth rates, yields and reproductive efficiency (Steinfeld *et al.*, 2006).

Intensification may further lead to a degree of mechanization of operations on the farm, at which point production may become 'industrial'. The intensification of animal production is not necessarily associated with the process of industrialization, though. Traditional small-scale production systems may intensify the production of their outputs without becoming mechanized: for example, by increasing the inputs of labour, by adopting improved breeds, by using commercial feeds and concentrates, and by procuring services. An example of this is dairy production in northern India, where large numbers of smallholders contribute to the provision of milk for the surrounding urban markets.

When the process of intensification gives way to industrialization, two further observations can usually be made. The first is the arrival of the 'big players': large multinational firms predominate in industrialized systems, vertically controlling all levels of production, processing and distribution of outputs. In this case livestock keepers typically become contract farmers, receiving most of their inputs from the large companies (often including piglets and day-old chicks), who then buy the fattened animals for processing and distribution. Although this process may enhance the quality and safety of commodities produced, the advantages for smallholders are questionable: they often bear disproportionate risks in production and incur high levels of indebtedness (Gura, 2008).

The second effect of industrialization is that production becomes geographically concentrated. The importance of land resource availability and suitable agro-ecological conditions in livestock distribution has been progressively replaced by other factors, such as cost of land, proximity to input and output markets, and availability of infrastructure and storage facilities. The optimal location of production is a balance between proximity to output markets and procurement of inputs – feed in particular. Locations close to urban areas allow direct access to centres of demand with consequently low transportation costs, but here there is always strong competition from other potential uses for the same land; the land therefore commands high prices. Conversely, when infrastructure becomes adequate, proximity to areas where feed is produced, imported or processed, presents advantages in terms of reducing the cost of inputs, of which feed typically accounts for 60–70 percent in intensive systems (Lutz, 1998). Locating further from consumption centres is usually also associated with lower land and labour prices and lower environmental standards to adhere to (Steinfeld *et al.*, 2006).

The implications of this rapid growth in demand and supply of animal-source foods are manifold. While presenting opportunities for many involved in the livestock sector, this impressive growth also poses significant challenges in terms of threatening poor people's livelihoods, introducing animal and public health risks, reducing the diversity of animal genetic resources, and imposing a strain on the environment. These issues are discussed at length in recent publications such as FAO (2009) and Steinfeld *et al.* (2010).

The livestock sector makes important contributions to food security and poverty reduction. It is estimated that about 70 percent of the world's 1.4 billion extreme poor depend in one way or another on livestock (FAO, 2009). In many cases livestock sector growth and associated structural changes may threaten this role of livestock, as smallholders are squeezed out of market participation by barriers such as sanitary and other quality standards, and unfavourable economies of scale. Intensification and, in particular, industrialization, result in an increase in the overall level of production, but the number of smaller farmers involved usually declines. In China, for example, many small farmers have given up sideline poultry production during the last decade: the total number of poultry farms declined to 35 million in 2005 from over 100 million in 1996, a drop of nearly 70 percent (Bingsheng and Yijun, 2007). Animal disease emergence and spread, including the zoonotic pathogens that spill over from animals to humans, is also closely linked to changes in production environments (see, for example, FAO (2007b), for a discussion of the possible mechanisms). A further consequence of the spread of intensive production is a loss of animal genetic diversity. Holstein-Friesian cattle, for example, have spread to some 164 countries, and the Large White breed of pig is now present in 139 countries (FAO, 2007c). Livestock already use one-fourth of the global terrestrial surface as grazing land, and claim one-third of global cropland for feed grain production. Soybean production has risen by some 7 percent per year over the last two decades (FAOSTAT data), largely in order to produce livestock feed. As these proportions grow to meet demand for animal-source food, livestock will impose an increasing burden on the environment in terms of heavy utilization of natural resources for water provision, feed production and grazing.

Other burdens will include pollution from effluents in concentrated production systems, and GHG emissions. The environmental impacts of livestock production are discussed at length in FAO (2006c).

It is important to understand in detail the driving forces behind the intensification and concentration of livestock production in order to determine where intensification is occurring now, and to predict where it is likely to occur in the future. Such information will guide research, development and policies that assist people in adapting to these changing circumstances, and will help to mitigate the negative effects that may arise through such changing patterns of production.

MAPPING INTENSIVE LIVESTOCK PRODUCTION SYSTEMS

Detailed data on the distribution of intensive livestock production units are not readily available for most countries; modelled estimates of these, or proxies thereof, are needed instead. The locations of intensive and industrial livestock systems depend on many characteristics. GIS and remote sensing technologies, combined with available national and subnational statistics and global raster datasets – such as land cover, accessibility to markets, human population distributions and livestock distributions – present new opportunities to identify and map these systems. One approach would be to categorize areas of intensive production using some readily available statistics that can be considered as indicators of intensification. Candidate data might include the share of crops used as feeds, distance to markets, and livestock densities, to give three examples. An alternative approach might employ modelling techniques in which some measure of livestock intensification is taken as a dependent variable and modelled using a number of explanatory variables. Training data comprising some known values of the predicted variable would be used to extract a series of explanatory variables, and to define a relationship that could then be applied to the entire area, to make predictions regarding the distribution of livestock intensification.

Various approaches have been developed to map intensification of livestock production. Notenbaert *et al.* (2009) proposed a system to identify mixed farming areas that are prone to intensification, taken from the Thornton *et al.* (2002) classification. Such areas were defined as having both good market access and high agricultural potential. Gilbert *et al.* (2004) developed an approach that exploited the observed relationship between national output and input ratios (total meat produced divided by annual stock number) and the proportion of poultry owned by smallholders in a number of southeast Asian countries. A further approach, developed here, uses reported data on the number of animals produced in intensive systems for various administrative units and identifies density thresholds for modelled livestock distributions, above which the reported numbers of livestock raised intensively are accounted for. The approach also exploits output/input ratios to group countries with similar 'intensity factors', within which the average thresholds are used to extrapolate the distribution of intensive livestock production. The sections below describe these three approaches in detail.

MAPPING AREAS WITH POTENTIAL FOR INTENSIFICATION

The original mapped livestock production system classification (Thornton *et al.*, 2002) has little to say about the location of intensive or potentially intensifying agricultural systems. A simple classification scheme was implemented by Notenbaert *et al.* (2009) that included a measure of intensification potential and separated the areas with a high potential for intensification from the pastoral and more extensively managed mixed systems. This resulted in four broad classes:

- Agro-pastoral and pastoral systems.
- Mixed crop–livestock systems in which natural resources are most likely to be extensively managed.
- Mixed crop–livestock systems in which natural resources can be managed to intensify the productivity of the system.

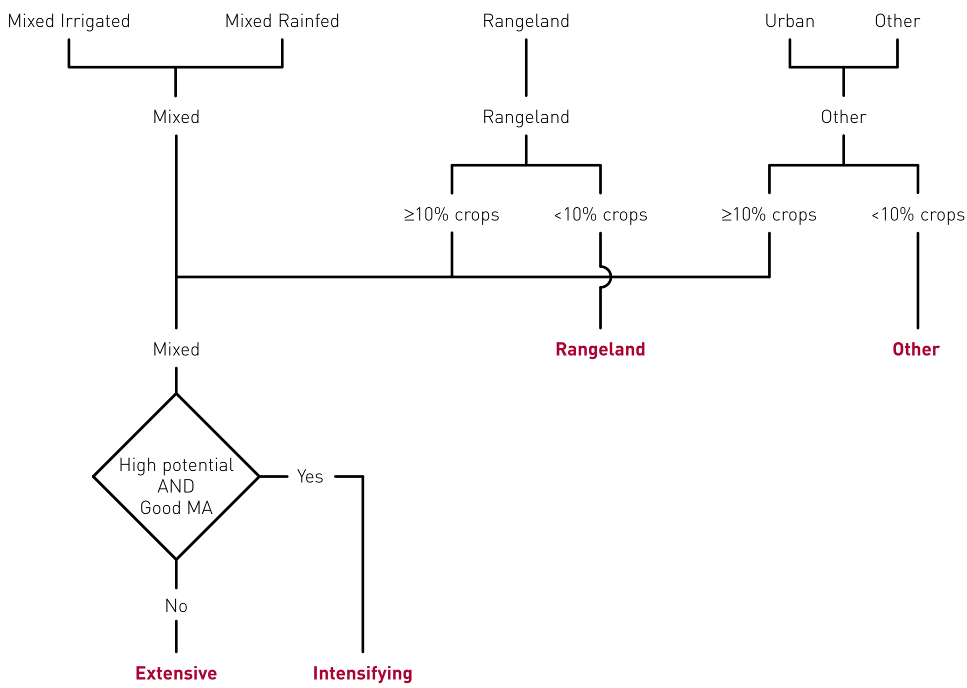
- Others, which include an amalgamation of urban, forest-based and landless systems.

The agropastoral/pastoral (livestock only) systems correspond to the three grassland-based (LGA, LGH, LGT) categories of the livestock production systems map (Version 4), with the additional constraint (further to the rangeland land cover definition) that there is less than 10 percent of the total land area covered by crops, according to the SPAM crop layers developed by You *et al.* (2009).

The crop–livestock systems correspond to the six mixed rainfed and mixed irrigated (MRA, MRH, MRT, MIA, MIH and MIT) categories of the livestock production systems map (Version 4), together with all other areas that have 10 percent or more of the area under crop, according to the crop layers from You *et al.* (2009).

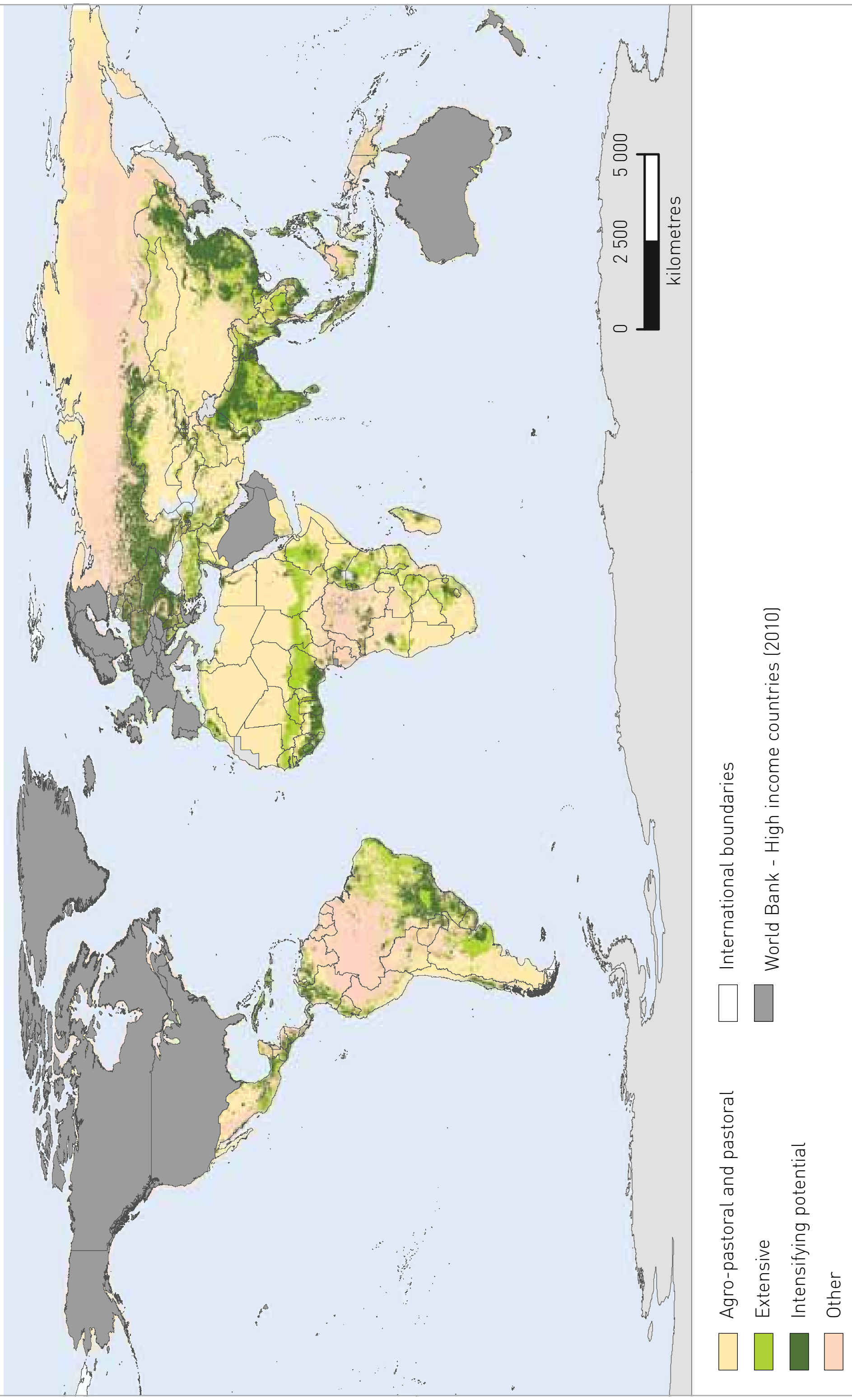
To differentiate mixed 'intensifying' systems, two additional indicators were included: one related to high agricultural potential, and another related to good market access. The assumption was made that mixed systems that are in high-potential areas and are close to large population centres and markets would have the best conditions for intensification of production. Areas with high agricultural potential were defined as those either equipped for irrigation, based on data from Siebert *et al.* (2007) or endowed with a growing period of more than 180 days per year, as estimated by Jones and Thornton (2005), using the methods described in Jones and Thornton (2003). Good market access was defined as being within 8 hours' travel of a population centre with 250 000 or more inhabitants, estimated using a GIS cost surface analysis (Nelson, 2008).

5.1 FLOW CHART OF THE PROCESS USED TO DEFINE AND MAP INTENSIFYING LIVESTOCK PRODUCTION SYSTEMS



Source: adapted from Notenbaert *et al.* (2009).

5.2 THE GLOBAL DISTRIBUTION OF THE POTENTIALLY INTENSIFYING SYSTEMS



Source: adapted from Notenbaert *et al.* (2009).

Figure 5.1 shows a flow chart of the classification process to derive the different production system categories, starting from the livestock production system map (Version 4). The resulting map is shown in Figure 5.2. Table 5.1 provides statistics on land areas, human population and cattle numbers, by system, for selected regions of the world (Notenbaert *et al.*, 2009).

Table 5.1 reveals that the mixed crop–livestock systems occupy slightly more than 30 percent of the land area. Although the larger proportion of mixed systems are estimated to be under extensive management (60 percent), most of the population inhabiting the mixed systems can be found in the areas with high intensification potential (70 percent). The big exception is sub-Saharan Africa, where only 40 percent of the population of the mixed areas (27 percent of the total population of sub-Saharan Africa) can be found in these potentially intensifying systems.

The mixed intensive systems have the highest population densities in the selected regions: some 280 people per km^2 compared with about 80 people per km^2 in the more extensive mixed systems, about 28 people per km^2 in the 'other' category, and only about 8 people per km^2 in pastoral and agropastoral systems. The high population densities in the potentially intensifying systems are likely to place heavy demands on the environment.

Cattle densities are also generally highest in the mixed intensifying systems: about 25 tropical livestock units[13] (TLU) per km^2 compared with some 16 TLU per km^2 in the extensive mixed systems. While the pastoral and agropastoral systems boast the largest absolute numbers of cattle in the selected regions, these are distributed across much larger areas and occur at relatively low densities of about 4 TLU per km^2. Sub-Saharan Africa is the only region where the extensively managed mixed areas have higher cattle densities than the areas with high intensification potential – approximately 11 compared with 8 TLU per km^2, respectively. This is probably largely because of the expansive humid and sub-humid areas of West Africa, which have good cropping potential but where the major tsetse challenge prevents a more intensified production of cattle. Intensification in these areas tends to be crop-based, and is driven by the demand for food in

[13] Tropical livestock units (TLU) are used to provide an equivalent estimate of livestock biomass. One TLU is equivalent to 250 kg, where one bovine is equivalent to 1 TLU, and a sheep or a goat to 0.1 TLU.

TABLE 5.1 LAND AREAS (IN MILLIONS OF KM^2), HUMAN POPULATION (IN MILLIONS) AND CATTLE NUMBERS (IN MILLIONS OF TLUS), BY SYSTEM, FOR SELECTED REGIONS OF THE WORLD

Farming system	Region	Area in 2000	Population in 2000	Cattle in 2000
Agro-pastoral and pastoral	CSA	5.4	40.5	64.18
	EA	5.5	41.3	12.67
	SA	0.5	19.2	6.19
	SEA	0.2	2.2	1.70
	SSA	13.4	80.2	36.68
	WANA	10.2	111.7	8.46
Total		**35.2**	**295.1**	**129.88**
Mixed extensive	CSA	3.5	100.7	67.24
	EA	1.7	195.4	20.32
	SA	1.6	371.9	71.96
	SEA	1.2	85.3	10.20
	SSA	5.1	258.7	55.53
	WANA	0.9	87.2	5.32
Total		**14.0**	**1 099.2**	**230.55**
Mixed intensifying potential	CSA	2.4	221.2	69.43
	EA	2.3	938.5	34.38
	SA	1.8	844.6	109.52
	SEA	1.1	347.2	13.84
	SSA	1.5	168.2	11.71
	WANA	0.6	154.4	6.01
Total		**9.8**	**2 674.1**	**244.89**
Other	CSA	8.8	125.8	41.83
	EA	1.5	104.2	9.79
	SA	0.4	69.5	8.65
	SEA	1.9	40.4	7.07
	SSA	4.1	109.2	6.77
	WANA	0.2	31.3	1.39
Total		**16.9**	**480.3**	**75.50**

Regional groupings of countries are as listed in Thornton *et al.* (2002).

CSA = Central and South America; **EA** = East Asia; **SA** = South Asia; **SEA** = Southeast Asia; **SSA** = sub-Saharan Africa; **WANA** = West Asia and North Africa.

Source: adapted from Notenbaert *et al.* (2009).

the highly-populated coastal areas and the production of cash crops for export (Fernández-Rivera *et al.*, 2004).

Other systems such as forests occupy significant areas of land, notably in Latin America and sub-Saharan Africa. As the demand for food, feed and energy grows, there will be increasing pressure for these areas to be converted to agricultural land in order to satisfy the demands of a growing population, particularly that of the burgeoning urban areas. This is supported, for example, by the findings of Rosegrant *at al.* (2009), who suggest increases in cropland extent of 28 percent in sub-Saharan Africa and 21 percent in Latin America by 2050.

The maps and tables presented highlight considerable differences between regions. These differences reflect the variability in livestock-crop integration, agricultural potential, population densities and access to markets and services in different regions of the world. Mixed intensive systems in fertile areas with suitable growing conditions, plus relatively low population densities, abound in Central and South America; in others places, such as Southeast Asia, land availability is a constraint. While sub-Saharan Africa still has suitable land for increased intensification, it faces other constraints such as huge population increases and inequality in land distribution. Furthermore, a lack of investment and poor provision of basic services prevent better use being made of the available natural resources. It is essential to acknowledge these structural differences, because options and opportunities for sustainable growth in productivity and poverty reduction will be largely dependent on them.

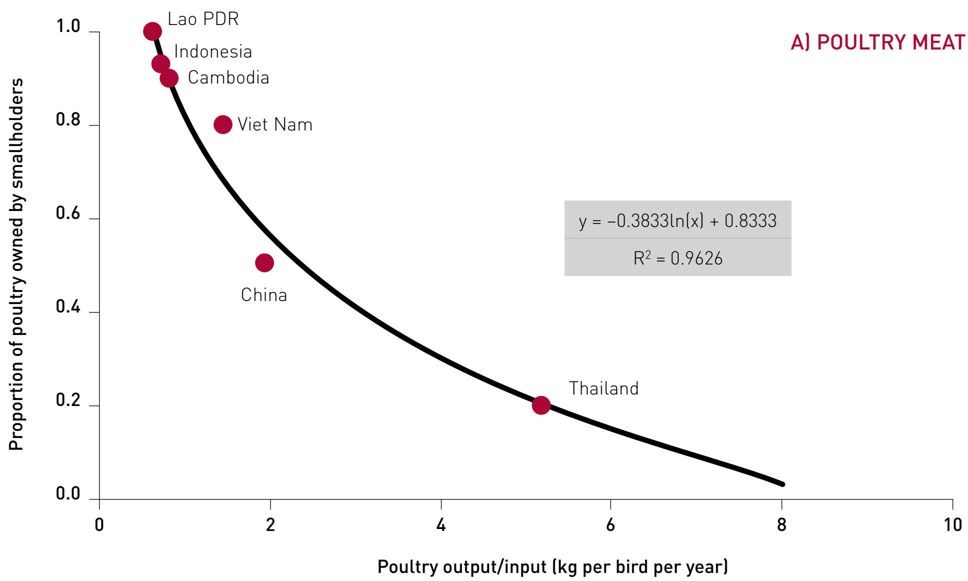
MAPPING INTENSIVE PRODUCTION BASED ON SMALLHOLDER DISTRIBUTIONS

An earlier attempt to map intensive poultry production systems in Southeast Asia combined national statistics (extracted from FAOSTAT) and GIS data on the agricultural population and poultry distributions (Gilbert *et al.*, 2004). A highly significant statistical relationship was found between national output/input ratios (total meat produced by annual stock number) and the proportion of poultry owned by smallholders in 6 Southeast Asian countries for which these proportions were reported (Figure 5.3a).

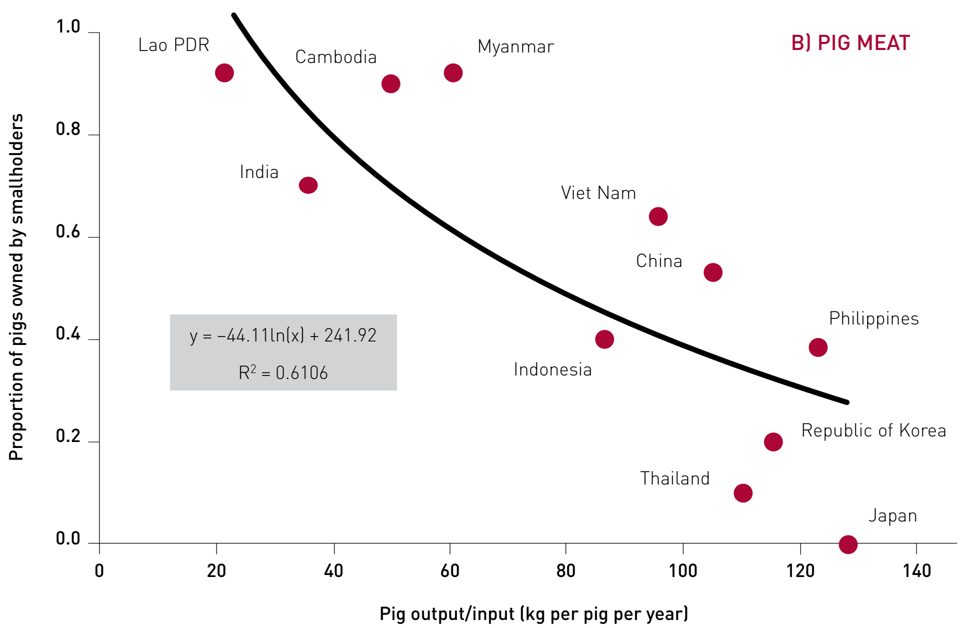
The regression equation was used to estimate the proportion of animals held by smallholders as a function of output/input ratio in countries for which no data were available on the proportions of smallholders. This proportion was then multiplied by the poultry population to derive the total number of birds raised in smallholder systems, and these were apportioned among the agricultural population – estimated from FAOSTAT statistics – to estimate the average number of poultry held per smallholder. This average smallholder stocking rate was then applied to a raster layer of agricultural population distribution, derived using FAOSTAT 2002 national agricultural population figures, to rescale the Landscan 2002 population maps (Budhendra *et al.*, 2002) and thereby obtain the distribution of poultry held in smallholder systems. These were then subtracted from a map of modelled total poultry distributions (Gerber *et al.*, 2005) to yield a raster layer of poultry produced in intensive systems.

The methodology described above has been replicated here, using the relationship shown in Figure 5.3a, but applying it to more recent national poultry statistics from FAOSTAT 2005, updated maps of poultry distributions from FAO (2007a), and FAOSTAT 2005 estimates of national agricultural population figures. Here, the approach has also been used to map extensive and intensive pig production in Asia, using reported data on the proportions of pigs raised under extensive conditions from 11 countries in the region (Figure 5.3b), and the equivalent data on pig numbers and distributions for 2005 and of smallholders for the same year, as those described above. The results are given for poultry and pigs in Figure 5.4 and Figure 5.5 respectively, which show the densities of each raised under extensive and intensive production conditions, based on the relationships shown in Figure 5.3.

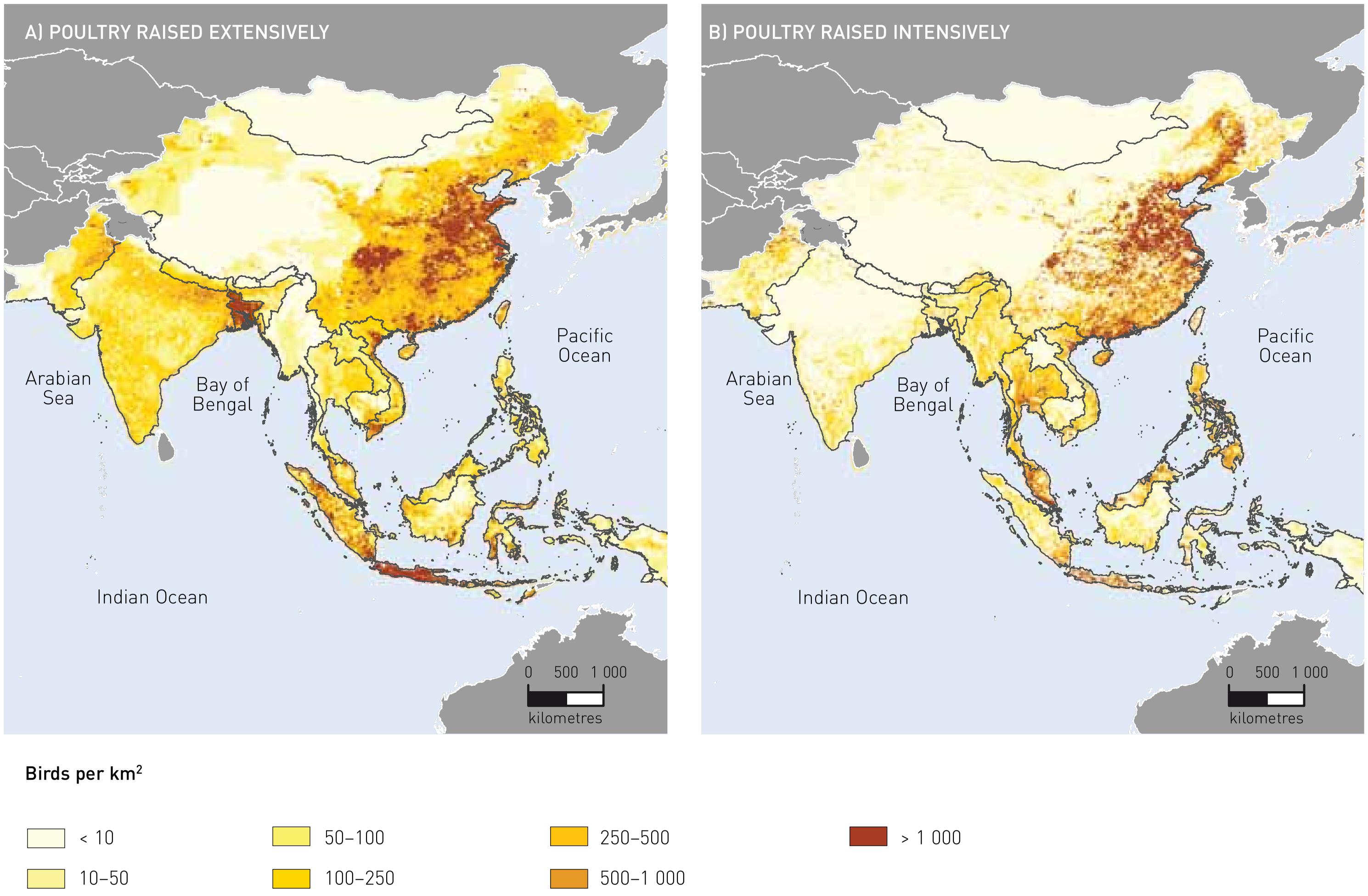
5.3 RELATIONSHIPS BETWEEN THE PROPORTIONS OF MONOGASTRIC LIVESTOCK OWNED BY SMALLHOLDERS AND NATIONAL OUTPUT/INPUT RATIOS (TOTAL MEAT PRODUCED DIVIDED BY ANNUAL STOCK NUMBER) IN A NUMBER OF ASIAN COUNTRIES



Source: adapted from Gilbert *et al.* (2004).



5.4 DISTRIBUTION OF POULTRY DENSITIES IN ASIA (BIRDS PER KM^2) BASED ON SMALLHOLDER DISTRIBUTIONS, FOLLOWING THE METHOD OF GILBERT *ET AL.* (2004)



5.5 DISTRIBUTION OF PIG DENSITIES IN ASIA (HEAD PER KM^2) BASED ON SMALLHOLDER DISTRIBUTIONS, FOLLOWING THE METHOD OF GILBERT *ET AL.* (2004)

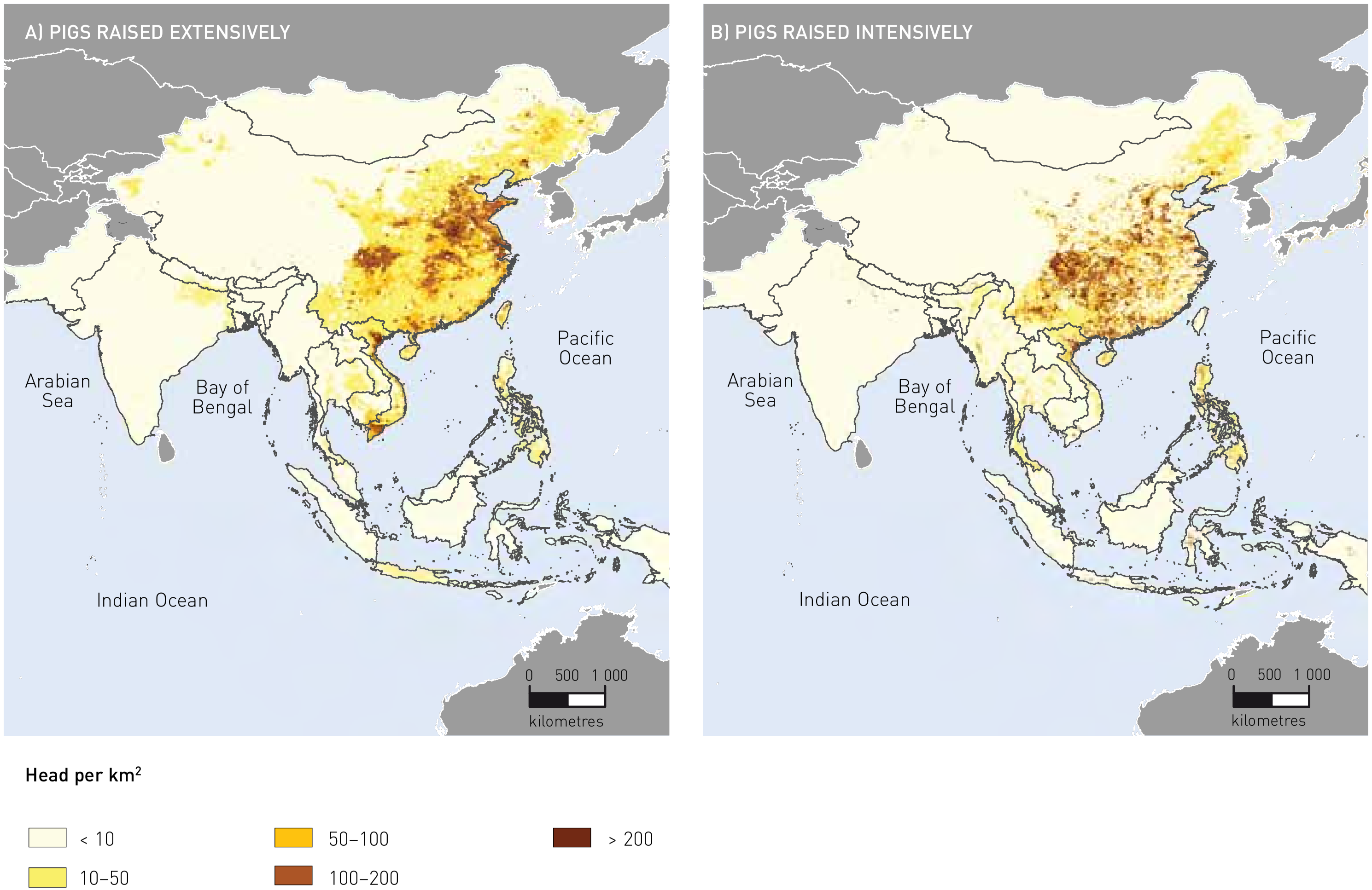


TABLE 5.2 SUBNATIONAL DATA AVAILABILITY ON INTENSIVELY RAISED MONOGASTRIC LIVESTOCK SPECIES IN ASIA

Country	Species	Definitions given	Admin. level	Year	Data source
India	Pig and poultry	Indigenous (traditional) breeds vs improved cross-breeds	3 (Districts)	2003	National census
Indonesia	Poultry	Commercial vs backyard	2 (Provinces)	2003	Department Pertanian Republik Indonesia
Laos	Poultry	Commercial vs backyard	2 (Districts)	1999	National Statistical Centre, State Planning Committee
Malaysia	Poultry	Commercial vs backyard	2 (Districts)	2001	Department of Veterinary Services
Philippines	Poultry	Commercial vs backyard	2 (Provinces)	2006	Bureau of Agricultural Statistics
Thailand	Pig and poultry	Commercial vs backyard	2 (Provinces)	2001	Provincial Livestock Office, Department of Livestock Development

The distributions of extensively-raised poultry and pigs necessarily reflect the distribution of the rural population, and show them to be widespread throughout the region. The distribution of intensively raised poultry is more focused – around the very dense population centres in eastern China, for example – and tends to be prolific in the more developed countries such as Singapore, Malaysia and Japan. For pigs, the main intensive production centres appear to be in China and northern Viet Nam.

MAPPING INTENSIVE PRODUCTION BASED ON LIVESTOCK DENSITIES

An alternative methodology, described below, is based on the allocation of reported statistics on the numbers of animals raised under intensive and extensive conditions, and the estimation of a threshold animal density by which to distinguish between intensive and extensive systems. Official statistics on this subject are by no means complete, however. Where they do exist they may be reported nationally or by some subnational administrative unit; often, indirect estimates are provided. The basic assumption in this approach is that intensive production coincides with high livestock densities. To identify areas with high densities of livestock, the GLW data (FAO, 2007a) were used. From the GLW distribution maps, for each administrative unit where statistics are available on the number of intensively raised livestock of a particular type, pixels are assigned to intensive production, starting from those with the highest densities of that livestock type, until the number of animals reportedly raised under intensive conditions is reached for that administrative unit. With this technique pixels are classified as either intensive or extensive for a given livestock type; the approach does not allow for the coexistence of intensive and non-intensive systems in the same pixel.

Available sources of information on numbers of livestock kept intensively include national censuses, surveys, online statistical databases and web portals such as GLiPHA. Table 5.2 shows the information for some Asian countries where a distinction between intensive and extensive production of pig and poultry meat was reported. It must be noted that different countries may vary in their definitions of what constitutes intensive production, so the results are not fully standardized.

To extrapolate these estimates to countries where the share of intensive production is not known, countries were categorized into groups sharing similar 'intensity factors', defined separately for pigs and poultry. The intensity factors were based on two indicators: 1) the number of slaughtered animals divided by the total number of stock, and 2) the total amount of meat produced divided by the total number of stock, i.e. the output/input ratio described above. The combined indicators should better reflect the degree of intensification of livestock production, since productivity can be increased by increasing off-take rates (given specifically by the first indicator) or by increasing the amount of meat produced per animal (also included in the second indicator). National data were downloaded from FAOSTAT and intensity factors were calculated; then countries were classified into three groups using a statistical clustering technique. For each species within each group of countries sharing similar intensity factors a threshold animal density was defined, above which pixels in the GLW livestock distribution maps were attributed to an intensive production system. The threshold density was calculated for the administrative units for which statistics were available as the average of the threshold densities at which all intensively raised livestock (of that type) were accounted for. This threshold was then applied to countries sharing similar intensity factors. For pigs the threshold densities were: > 80, > 120, and > 150 head per km^2 for intensity factors 1, 2 and 3, respectively. For poultry, the equivalent threshold densities were: > 400, > 500, and > 700 birds per km^2. The basic assumption is that countries with low intensity factors share a lower proclivity to intensification and may support higher animal densities through a large number of smallholders rather than through intensification of production.

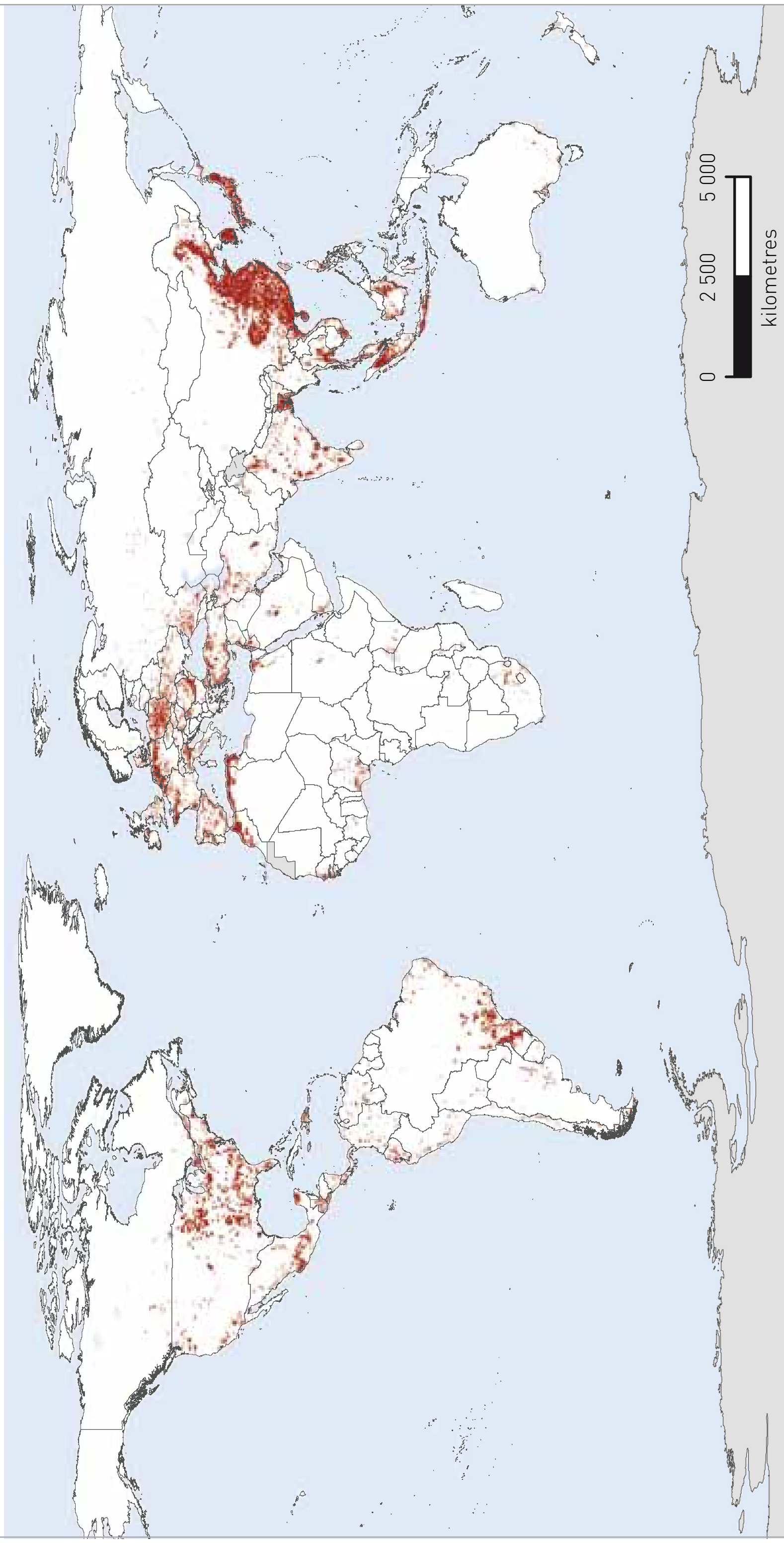
Figure 5.6 shows the global distribution of intensive production of poultry and pigs estimated using the method described above. As expected, intensive poultry production systems are more widespread than pig systems, since intensive production is more common for poultry and because pigs are absent from many countries. Of the pixels assigned to intensive monogastric production, 69 percent contain only poultry, 10 percent contain only pigs, and 21 percent contain both species under intensive production. By combining maps of intensification with the GLW density maps for the year 2005, it is possible to estimate the numbers of monogastric livestock raised in intensive systems for different countries and regions (Tables 5.3 and 5.4).

TABLE 5.3 NUMBER OF PIGS RAISED IN INTENSIVE SYSTEMS IN 2005 (BASED ON LIVESTOCK DENSITIES) FOR THE MAJOR DEVELOPING REGIONS OF THE WORLD

Region	Total numbers of pigs (millions)	Numbers in intensive systems	Proportion of pigs in intensive systems (%)	Share as a proportion of global total (%)
East Asia and Pacific	559.32	385.83	69.0	68.7
China	*488.75*	*362.98*	*74.3*	*64.6*
Eastern Europe and Central Asia	57.35	16.79	29.3	3.0
Latin America and Caribbean	85.51	14.65	17.1	2.6
Middle East and North Africa	0.25	0.01	5.6	0.0
South Asia	18.11	1.47	8.1	0.3
India	*16.97*	*1.31*	*7.7*	*0.2*
Sub-Saharan Africa	23.53	4.95	21.0	0.9
All regions	**744.09**	**423.70**	**56.9**	**75.5**
High income countries	231.65	137.79	59.5	24.5
Total	**975.73**	**561.49**	**57.5**	**100**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.
Data for China and India also included separately.

5.6a GLOBAL DISTRIBUTION OF INTENSIVE POULTRY PRODUCTION SYSTEMS IN 2005 BASED ON LIVESTOCK DENSITIES



5.6b GLOBAL DISTRIBUTION OF INTENSIVE PIG PRODUCTION SYSTEMS IN 2005 BASED ON LIVESTOCK DENSITIES

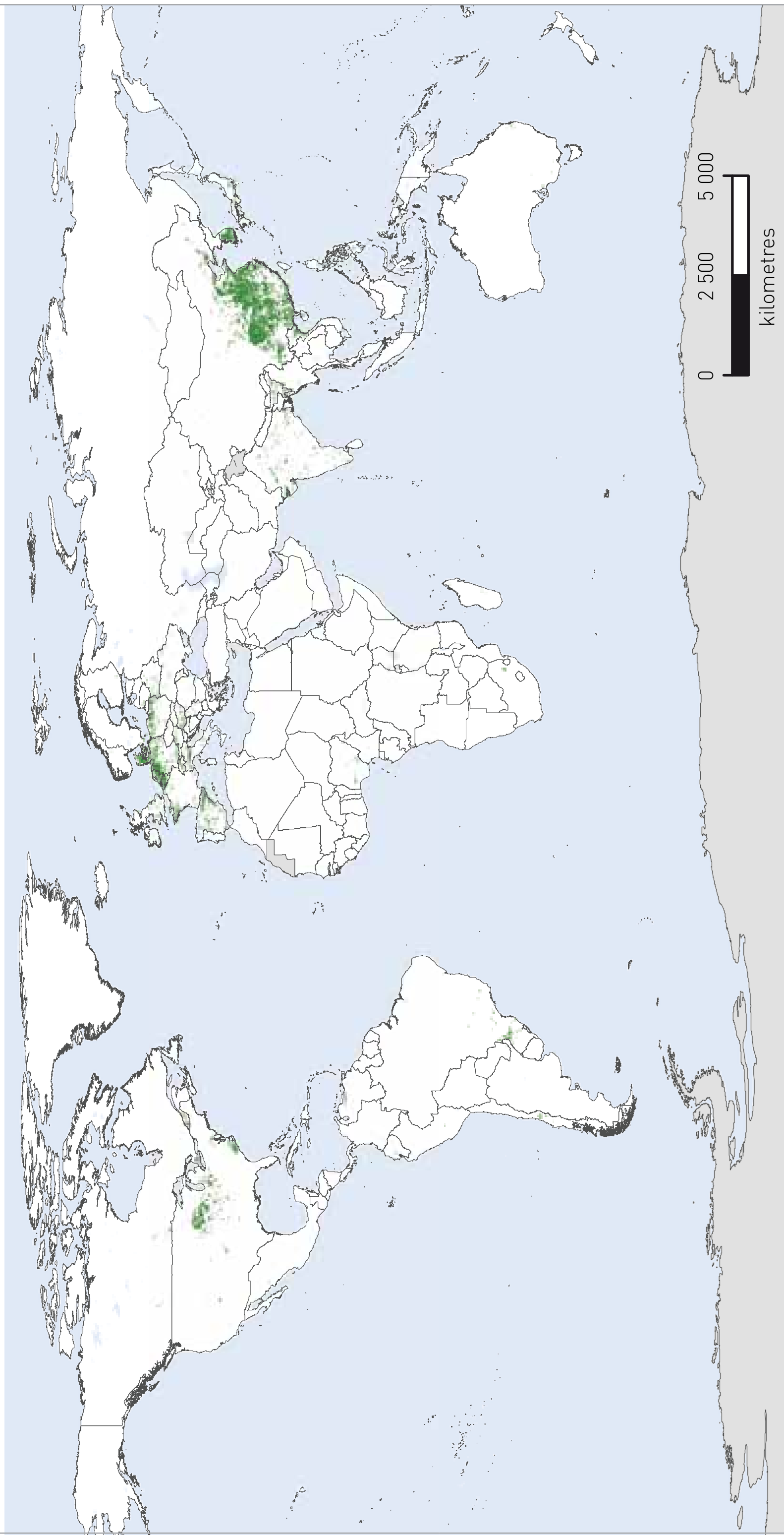


TABLE 5.4 NUMBER OF POULTRY RAISED IN INTENSIVE SYSTEMS IN 2005 (BASED ON LIVESTOCK DENSITIES) FOR THE MAJOR DEVELOPING REGIONS OF THE WORLD

Region	Total numbers of poultry (millions)	Numbers in intensive systems	Proportion of poultry in intensive systems (%)	Share as a proportion of global total (%)
East Asia and Pacific	7 325.88	5 769.45	78.8	46.2
China	*5 260.36*	*4 737.63*	*90.1*	*38.0*
Eastern Europe and Central Asia	1 233.21	586.77	47.6	4.7
Latin America and Caribbean	2 343.16	1 487.93	63.5	11.9
Middle East and North Africa	998.77	572.82	57.4	4.6
South Asia	1 104.34	327.45	29.7	2.6
India	*759.32*	*119.36*	*15.7*	*1.0*
Sub-Saharan Africa	908.75	264.50	29.1	2.1
All regions	**13 914.11**	**9 008.93**	**64.7**	**72.2**
High income countries	4 034.69	3 467.49	85.9	27.8
Total	**17 948.80**	**12 476.42**	**69.5**	**100.0**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.
Data for China and India also included separately.

Globally it is estimated that more than half of the pigs (57 percent) are raised under intensive conditions (Table 5.3). This concurs with the estimate of Steinfeld *et al.* (2006). China, the world's leading producer of pig meat, accounts for 64 percent of the world's intensively-raised pigs, with a rapid intensification of production having occurred over the last decade in order to meet the massive increase in demand. A similar process has taken place in Viet Nam and the Republic of Korea. The other two main production areas for pigs are concentrated in the United States of America (USA) and the European Union. High income countries account for 24 percent of global intensive production.

Poultry production shows a similar pattern to that of pig production, but the relative and absolute numbers are higher. About 70 percent of global poultry production comes from intensive systems (Table 5.4), with all regions exhibiting higher levels of intensification compared with pig production. The distribution of poultry is not limited by social or religious factors and high levels of inputs (intensification) are required to control physical conditions such as humidity and temperature, particularly in hot and dry climates where the environment does not offer optimal conditions for livestock raising. In the Middle East and North Africa region 57 percent of poultry are raised in intensive conditions. Again, China and the USA are the top producers of poultry meat from intensive production, but other countries too raise significant numbers of poultry under intensive conditions: Brazil, Indonesia, Mexico and Japan are examples.

Table 5.5 disaggregates the numbers of pigs and poultry raised under intensive conditions according to livestock production system (Version 5). Similar patterns of intensive production are seen between the pig and poultry sectors. Those systems classified as 'other' (i.e. land cover classes that are not predominantly crop or rangeland) account for about one-quarter of the global intensive production of monogastric livestock. There are also disproportionately high numbers (relative to land area) of intensively-raised pigs and poultry in urban areas, reflecting the geographical concentration of production centres close to the burgeoning urban markets.

TABLE 5.5 NUMBERS (IN MILLIONS) AND PROPORTIONS OF PIGS AND POULTRY IN 2005 RAISED UNDER INTENSIVE CONDITIONS BY GLOBAL LIVESTOCK PRODUCTION SYSTEM (VERSION 4)

Livestock production system	Area	Pigs		Poultry	
	%	Number	%	Number	%
Rangeland	**41.9**	**7.7**	**1.4**	**721.3**	**5.8**
LGY	2.8	0.2	0.0	9.2	0.1
LGA	23.2	2.8	0.5	474.0	3.8
LGH	2.5	1.4	0.2	125.2	1.0
LGT	13.4	3.3	0.6	112.9	0.9
Mixed rainfed	**17.9**	**215.2**	**38.7**	**4 326.8**	**35.0**
MRY	0.0	0.4	0.1	5.4	0.0
MRA	5.6	11.6	2.1	557.1	4.5
MRH	6.1	84.9	15.3	1 729.7	14.0
MRT	6.2	118.3	21.3	2 034.7	16.5
Mixed irrigated	**2.7**	**110.9**	**20.0**	**2 246.0**	**18.2**
MIY	0.0	0.1	0.0	2.9	0.0
MIA	1.2	3.4	0.6	203.3	1.6
MIH	0.6	38.3	6.9	590.2	4.8
MIT	0.9	69.0	12.4	1 449.7	11.7
Urban areas	**2.9**	**74.8**	**13.5**	**1 944.8**	**15.7**
Other	**34.6**	**146.8**	**26.4**	**3 110.9**	**25.2**
Total	**100**	**555.4**	**100**	**12 349.9**	**100.0**

CONCLUSIONS AND DISCUSSION ON INTENSIFICATION

Three quite different approaches to mapping intensive livestock production have been reviewed above. The first (Notenbaert *et al.*, 2009) aims to identify areas with potential for intensification, while the second two separate out statistics on total production into intensive and extensive. The Gilbert *et al.* approach (2004) uses the distribution of smallholder producers to achieve this, while the other relies solely on the (modelled) densities of the livestock themselves. The Notenbaert *et al.* (2009) approach has the advantage that it is directly linked to a broader classification scheme (Thornton *et al.*, 2002) and therefore provides further, more detailed, branches of that. Problems with this approach include that it is not based on any actual statistics and that it does not distinguish between different types of livestock.

The approach developed by Gilbert *et al.* (2004) has many positive aspects but also has some potential drawbacks. In its favour, it primarily estimates smallholder poultry production – linked closely to the distribution of smallholders. For social applications this may be particularly useful. Furthermore, by combining the maps of smallholder production and intensive production, the proportions of poultry raised in each system can be estimated. This may be particularly useful in applications relating to the emergence and spread of disease, where the relatively poor sanitary conditions – usually associated with smallholder production – are brought into the vicinity of extremely high densities of animals in intensive systems, possibly resulting in elevated risk of disease emergence. A potential drawback is the large number of steps involved, which will result in propagation of errors in the input data. While the relationship illustrated in Figure 5.3a has a highly respectable value of R^2, it is clear that if Thailand were removed (for example) the graph would be a rather different shape. A further problem is the ambiguity in the definitions of rural and agricultural populations and of the agricultural population involved in livestock activities. The results rely heavily on an assumption that the agricultural population is equivalent to the rural population. The effects of these ambiguities would be difficult to anticipate, but improvements could certainly be made in terms of reliability and precision of input data.

The third approach to mapping intensive livestock production is the most closely linked to empirical data on livestock raised in intensive systems, but has the disadvantage that areas are designated as either extensive or intensive – it does not allow for the coexistence of both systems. At very fine resolution that may not be a problem, but it could be a significant drawback if results are aggregated to coarser resolutions. The poor availability of standardized statistics on the numbers of livestock raised under intensive conditions is currently a limitation of this approach. Furthermore, the approach relies quite heavily on the GLW modelled livestock distributions. We know that the environmental approaches underpinning the GLW maps are probably much more reliable at predicting extensive production – which is more strongly driven by the environment – than they are at predicting the more intensive systems, which are more geographically focused and are decoupled from the land resources required for the production of their main input: feed. There is considerable scope for fine-tuning the methodology as and when more information is made public.

The appropriateness of these different methods, or adaptations thereof, may rather depend on the context of their application. More work needs to be done to explore these, and possibly other approaches too, in greater detail, and in particular to compare the results against detailed data on the actual distributions of intensive production units (where these data are available).

6 Linking livestock production systems to rural livelihoods and poverty

One of the overarching objectives of understanding and mapping livestock production systems is to explore the impacts of these systems, and changes thereof, on people's livelihoods. For those whose livelihoods are highly dependent on farming, the types of production systems in which they are engaged or could become so has a significant bearing on their incomes, welfare and food security. In this section an attempt is made to link production system information with welfare and livelihoods, through three case studies. In the examples from Uganda and Viet Nam, detailed household survey data are explored in an attempt to disaggregate the mixed systems further. In each case the resulting systems classifications are analysed in relation to poverty statistics. In the third example from the Horn of Africa, livelihood data are used directly to map livestock production systems. While these case studies may be insightful in themselves, it is further hoped that from the specific lessons learned, patterns will emerge that may apply more generally and thus make a contribution to improving attempts at developing a global classification.

LIVESTOCK SYSTEMS AND POVERTY IN UGANDA

Uganda is a largely rural, agricultural society: about 88 percent of the population lives in rural areas. Some 40 percent of the rural population live below the poverty line, accounting for 95 percent of the poor in the country as a whole. Most of these depend on agriculture as their primary source of livelihood (Fan *et al.*, 2004). For the majority of Ugandans the agricultural sector is the main source of livelihood, employment and food security. The sector provided 73 percent of employment in 2005/06, and most industries and services in the country are dependent on it (UBOS, 2009). Smallholder production dominates the agricultural sector and crop-based agriculture is dominant within this, with bananas, cereals, root crops and oil seeds being the main food crops. Tea and sugar plantations are primarily large-scale commercial efforts (Matthews *et al.*, 2007), while other important cash crops are coffee, cotton and tobacco. Cash crops are the primary sources of export earnings.

Despite its importance, overall growth in agricultural output has been falling. A growth rate of 7.9 percent in 2000/01 was down to 2.6 percent in 2007/08 (UBOS, 2009; NPA, 2010). Agriculture's contribution to gross domestic product (GDP) fell from 20.6 percent in 2004 to 15.6 percent in 2008 (UBOS, 2009). While growth rates in overall agricultural output have declined, the livestock sector is growing in response to increasing demand for animal-source foods. Livestock production contributed 1.6 percent to total GDP in 2008 (UBOS, 2009). The number of cattle in the country doubled from 5.5 million in 2002 to 11.4 million in 2008 (UBOS, 2009). The numbers of sheep and goats more than doubled during the same period, and the number of pigs and chickens increased by 88 percent and 59 percent, respectively (MAAIF and UBOS, 2009).

About 71 percent of all households in Uganda owned livestock in 2008 (MAAIF and UBOS, 2009). Smallholders and pastoralists dominate the livestock sector, owning 90 percent of Uganda's cattle and almost all of the country's poultry, pigs, sheep and goats (Turner, 2005). Ugandans reliant solely upon crop agriculture are more likely to be poor than those whose production systems extend beyond crops to include livestock or fishing (Okidi *et al.*, 2004). For most Ugandan households, however, livestock is not the main source of cash income, ranking only second or third in its contribution (Ashley and Nanyeenya, 2002). Rather, the animals serve as a source of food, as a store of wealth, confer social status and, moreover, form an integral part of mixed production systems by providing draught power, fuel, manure and transport, and a profitable use for crop residues. Pastoralists are mainly found in the northeast and in the southwest of the country, where human population densities and rainfall are low. In other parts of the country, agropastoralism and mixed-farming systems dominate, alongside some commercial beef and dairy outfits, mainly located in Mbarara District in the southwest and around Kampala.

A number of classifications of agricultural production systems has been developed for Uganda. For example, NEMA (1996) distinguished five systems: 1) northern and eastern cereal–cotton–cattle; 2) intensive banana–coffee; 3) western banana–coffee–cattle; 4) west Nile cereal–cassava–tobacco; and 5) Kigezi afromontane. Musiitwa and Komutunga (2001) developed a classification which again was split into five classes, but with little overlap with the former: 1) long-rain unimodal systems (northern and west Nile systems); 2) transitional zone (Teso, Lango and banana–cotton–finger millet systems); 3) banana and coffee system; 4) montane systems (Elgon, Kabale-Kisoro and Ruwenzori); and 5) pastoral systems (Karamoja and the southwestern pastoral systems). Closely related are national estimates of agro-ecological zones. For example, Wortmann and Eledu (1999) distinguished 33 agro-ecological zones, including landscape, soils, land use, climate and cropping systems, each of which they described in detail.

The classification schemes above are highly specific to Uganda, while the more widespread classifications such as Dixon *et al.* (2001) and Thornton *et al.* (2002) tend to lack the required level of detail to be of real practical use at country level. Below, data on crops and livestock from an agriculture module of a national census have been used to explore a data-driven approach to the characterization of mixed production systems in Uganda. The resulting systems are then linked to welfare estimates.

Methods

Data on crops and livestock were obtained from the 2002 Uganda National Housing and Population Census (UBOS, 2004). The crop data comprised the number of plots of various crops for each of the 962 subcounties, defined as a piece of land within the holding on which a specific crop or crop mixture is cultivated. Crops included in the analysis were maize, millet, sorghum, rice, oil crops (groundnuts, soybeans, sesame), roots and tubers (cassava, sweet potatoes, Irish potatoes), banana, coffee, cotton, and pulses (beans, cow peas, field peas, pigeon peas). Livestock data were gathered and taken to be the number of cattle, goats, sheep, pigs and poultry in each administrative unit; these were grouped into ruminant and monogastric species.

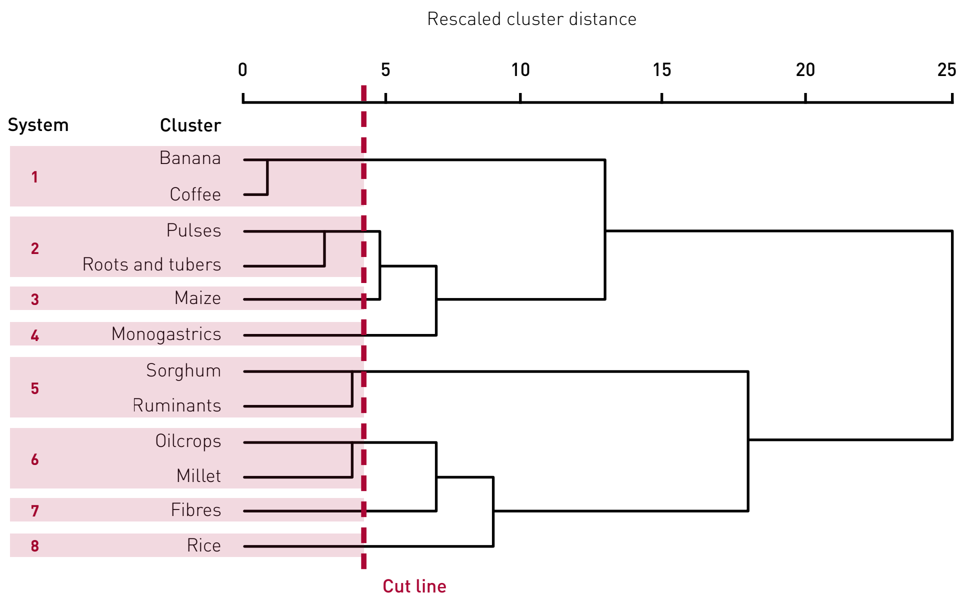
Cluster analysis identifies relatively homogeneous groups of cases based on selected characteristics, so that variation within groups is minimized and variation between groups is maximized (Kaufman and Rousseeuw, 1990). An explorative hierarchical cluster analysis was first used to visualize similarities among the variables used, followed by K-means clustering, which was used to create the clusters and assign cluster values to each case. Twelve crop and livestock variables were considered for 962 Ugandan subcounties. The squared Euclidean distance was chosen as the proximity measure, and representative clusters were identified using the final cluster centres, which represent the average value on all clustering variables of each cluster's member, and the Euclidean distance between final cluster centres.

The clusters obtained were then mapped and characterized in terms of a number of environmental and demographic variables, including poverty estimates. Furthermore, they were compared directly with the livestock production systems classification of Thornton *et al.* (2002) using a correspondence analysis (Greenacre, 1984).

Results

The dendrogram from the hierarchical cluster analysis (Figure 6.1) was used to assess the cohe-

6.1 DENDROGRAM OF THE CLUSTER ANALYSIS, SHOWING THE CUT LINE USED TO DISTINGUISH EIGHT SYSTEMS



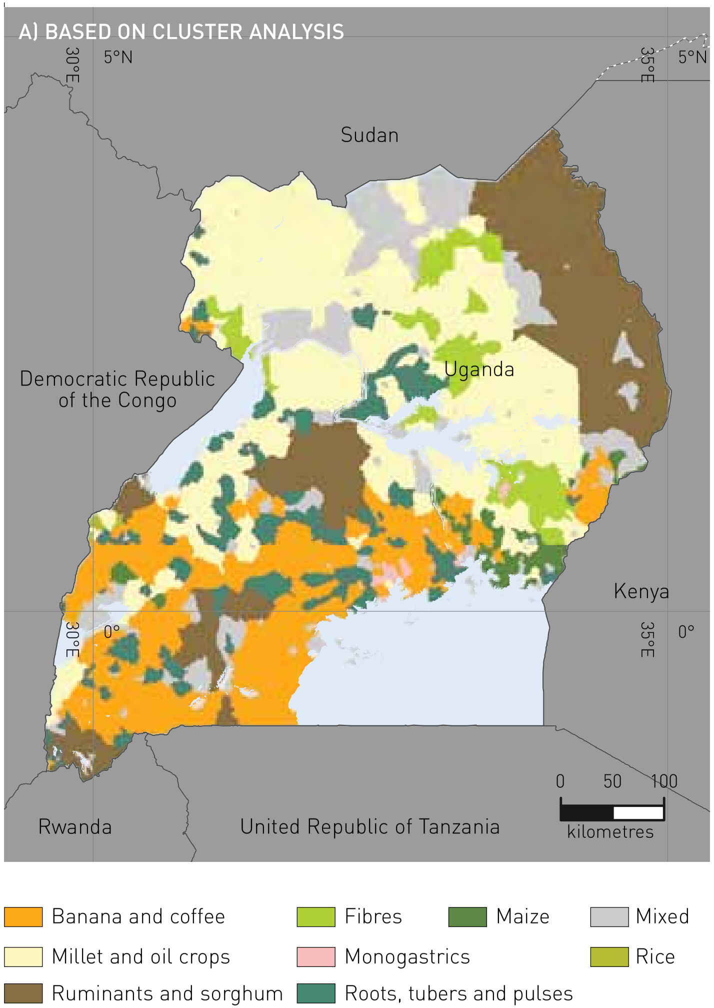
siveness of the clusters, and determine the appropriate number of clusters to retain. Using a heuristic approach, the tree was cut (shown by the vertical red line in Figure 6.1) so as to yield eight clusters with a reasonable number of subcounties in each (shifting the cut line to the left would increase the number of clusters; shifting it to the right would reduce that number).

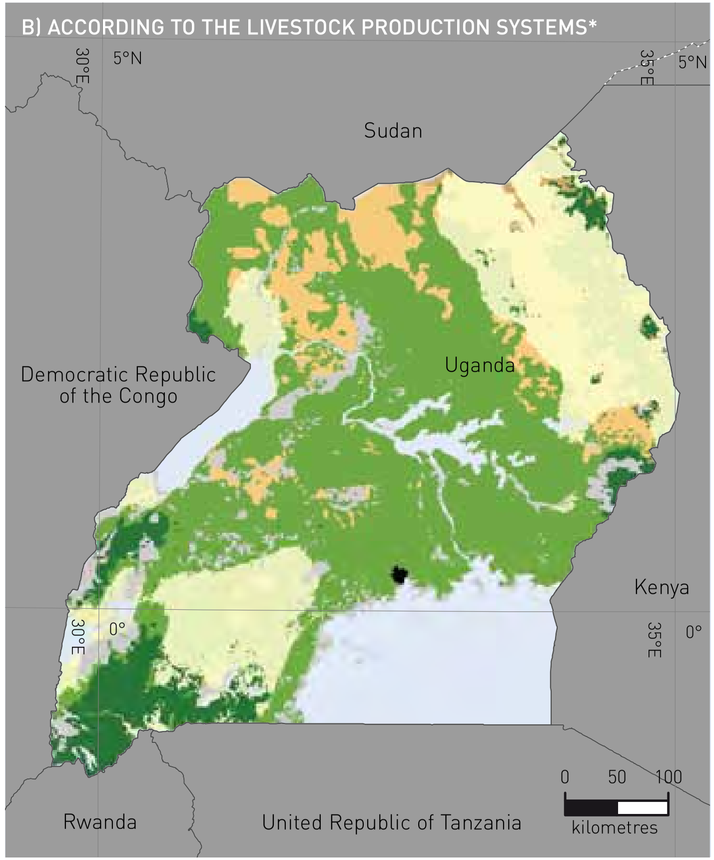
These eight clusters accounted for 793 (82.4 percent) of the subcounties. To these, a further system called 'mixed' was added, which was represented by 169 (17.5 percent) subcounties. In this class the values of the final cluster centres were very similar for all the variables used, which is why they were not readily included in any of the other clusters. The result was nine representative systems: 1) banana and coffee; 2) roots, tubers and pulses; 3) maize; 4) monogastrics; 5) ruminants and sorghum; 6) millet and oil crops; 7) fibres; 8) rice; and 9) mixed.

Figure 6.2 shows the spatial distribution of these, and Table 6.1 shows their values for a number of environmental and demographic variables. Tables 6.2 and 6.3 show the values for livestock densities and crop production by system.

The ruminants and sorghum system is typical in the northeast of Uganda, which is of generally low agricultural potential, low rainfall (average LGP is about 140 days), low population density, and where poverty rates are high. This system also occurs in central and southwest Uganda (with the exception of Mubende District, which has more forests and cropped areas) corresponding broadly overall to the area known as the 'cattle corridor'. The majority of cattle are kept in these areas, which are characterized by poor market access and low population densities. The monogastric system, dominated by pigs and poultry, is distributed in peri-urban areas around Kampala and other urban centres. The banana and coffee system, in which more than eight million rural Ugandans are engaged, is concentrated in the highland areas of Mount Elgon at the Kenyan border, in Nebbi District in the northwest (though less intensively), and on the shores of

6.2 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN UGANDA





* Version 3 (Kruska, 2006).

TABLE 6.1 SUMMARY OF SELECTED ENVIRONMENTAL AND DEMOGRAPHIC VARIABLES (LAND AREA, POPULATION, PERCENTAGE OF POOR PEOPLE, ELEVATION, LENGTH OF GROWING PERIOD, PERCENTAGE OF POOR HOUSEHOLDS, AND MEAN WELFARE VALUES) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA

System	Land area km²	Land area %	Mean elevation (m)	LGP (days)[a]	Rural population[b]	Number of households[c]	Percent poor[c]	Mean monthly per adult equivalent expenditure (USh)[d]
Banana and coffee	40 505	20.0	1 349	205	8 060 170	2 159	28.4	15 555
Roots, tubers and pulses	16 401	8.1	1 227	213	2 072 510	549	30.6	15 652
Maize	4 059	2.0	1 271	225	952 841	267	41.9	14 909
Monogastric	779	0.4	1 156	246	88 523	50	4.0	18 990
Ruminants and sorghum	40 205	19.8	1 271	142	1 023 030	427	52.5	11 832
Millet and oil crops	67 070	33.0	1 021	208	4 946 350	1 345	49.9	14 310
Fibres	10 821	5.3	1 042	206	1 434 180	366	55.5	14 047
Rice	299	0.1	951	224	47 375	6	66.7	12 824
Mixed	22 832	11.2	1 122	191	1 115 840	280	40.4	13 766

[a] Jones and Thornton (2005) [b] CIESIN *et al.* (2004) [c] UBOS (2003) [d] In 2002 US$1 was equivalent to USh1 739.7

TABLE 6.2 LIVESTOCK DENSITIES (NUMBER PER KM²) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA. LIVESTOCK DATA EXTRACTED FROM THE GRIDDED LIVESTOCK OF THE WORLD MAPS (FAO, 2007a)

System	Cattle	Sheep	Goats	Pigs	Poultry
Banana and coffee	56.77	16.45	80.05	14.14	124.40
Roots, tubers and pulses	30.51	8.03	40.24	12.21	92.29
Maize	31.53	4.52	68.03	27.68	242.73
Monogastrics	52.68	12.41	52.46	8.54	97.05
Ruminants and sorghum	25.98	6.22	17.32	3.11	63.21
Millet and oil crops	25.86	4.18	26.22	9.04	133.18
Fibres	39.93	6.29	38.18	10.94	287.20
Rice	5.22	2.54	55.87	1.34	18.03
Mixed	21.93	6.36	25.47	8.98	107.51
Uganda	**32.92**	**7.74**	**37.87**	**9.60**	**121.47**

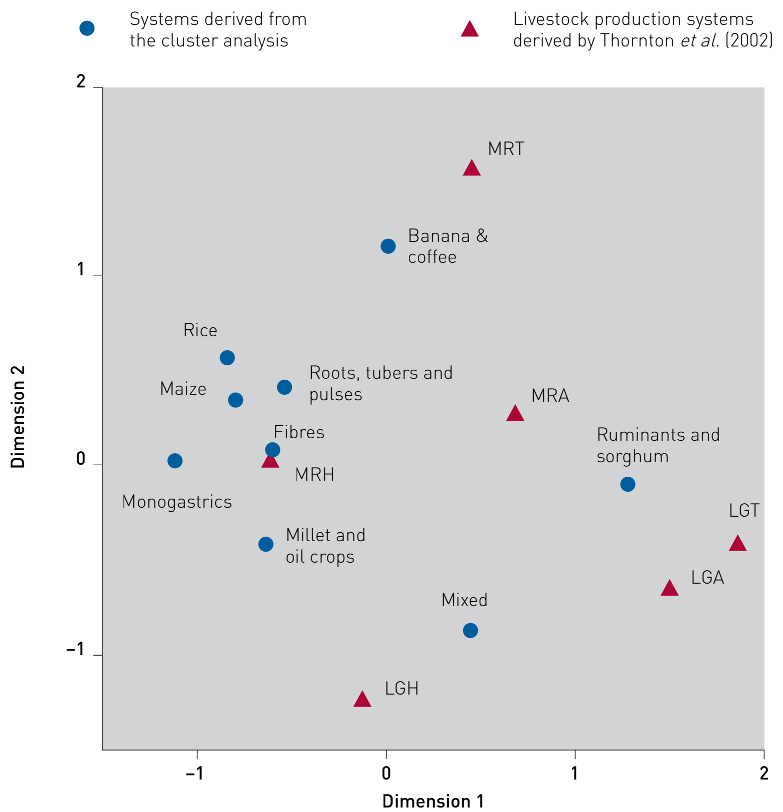
Lake Victoria – characterized by high soil fertility and a bimodal rainfall pattern. It is based on the production of bananas as the main food crop and coffee as the main cash crop. About 20 percent of Ugandans still derive their livelihood directly from coffee; 95 percent of these are smallholders (ADF, 2005). The mixed system (crop–livestock) is common, accounting for 11 percent of the land area and 5.7 percent of the rural population. In this system crop and livestock production are well integrated: crops benefit from manure from livestock while the latter feed on the residues of the crops (ADF, 2002). The roots and tubers, and pulses system and the maize system are more evenly distributed, though less prolific in northern Uganda. The fibres system is concentrated in the drier areas of the northern and eastern regions, where most of the cotton production (cotton is an important cash crop) is

TABLE 6.3 TOTAL CROP PRODUCTION (TONNES) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA. CROP DATA WERE EXTRACTED FROM THE SPAM* CROP DISTRIBUTION MAPS

System	Banana and plantains	Beans	Cassava	Coffee	Cotton	Groundnuts	Maize	Millet	Potatoes	Rice	Sorghum	Soyabeans	Sugarcane	Sweet potatoes	Wheat
Banana and coffee	5 642 713	79 530	852 456	58 940	4 906	23 925	153 156	61 629	103 590	3 651	42 505	153 156	419 558	488 930	976
Roots, tubers and pulses	1 110 077	35 189	338 368	16 152	2 758	9 994	63 228	35 492	38 317	3 029	21 109	63 228	140 189	193 900	0
Maize	318 137	22 292	257 022	5 959	1 989	5 444	58 091	28 249	17 070	14 570	5 869	58 091	66 119	117 179	10 061
Monogastrics	27 075	1 579	47 590	1 038	0	121	459	3 663	1 863	205	6	459	6 158	2 410	0
Ruminants and sorghum	873 758	35 772	255 488	18 786	587	7 208	144 648	41 911	83 273	1 004	64 114	144 648	152 847	153 166	682
Millet and oil crops	889 988	131 248	1 813 187	13 641	26 187	60 618	455 855	215 050	96 238	33 407	136 465	455 855	493 428	846 134	12
Fibres	152 386	31 266	551 473	5 992	23 228	13 579	58 281	71 537	50 537	43 437	33 399	58 281	121 134	157 816	0
Rice	4 143	450	2 356	0	0	32	0	2	532	167	34	0	3 633	234	0
Mixed	894 881	51 027	366 476	10 730	4 708	12 101	97 404	38 797	23 190	3 856	31 815	97 404	133 200	208 037	20
Uganda	**9 913 158**	**388 353**	**4 484 416**	**131 238**	**64 363**	**133 022**	**1 031 122**	**496 330**	**414 610**	**103 326**	**335 316**	**113 691**	**1 536 266**	**2 167 806**	**11 751**

* SPAM data from You *et al.* (2009).

6.3 CORRESPONDENCE ANALYSIS PLOT BETWEEN AGRICULTURAL SYSTEMS DERIVED FROM THE CLUSTER ANALYSIS AND THE LIVESTOCK PRODUCTION SYSTEMS, VERSION 1, USING THE OVERLAPPING AREA AS A MEASURE OF CORRESPONDENCE (SYMMETRICAL NORMALIZATION)



concentrated. These two regions are also largely occupied by the millet and oil crops system.

The results of the correspondence analysis between these systems and those of Thornton *et al.* (2002) are given in Figure 6.3, which shows some agreement. The correspondence is quite close 1) between the livestock-only systems (LGA and LGT) and the ruminants and sorghum cluster; and 2) between the banana and coffee cluster and the highland zones of the mixed, temperate and tropical highland system (MRT). Agricultural production in the rest of Uganda overlaps mainly with the mixed, humid and sub-humid (MRH) system, which occupies 47.7 percent of Uganda's land area.

The values in Table 6.4 show the proportion of overlap between clusters and production systems mapped by Thornton *et al.* (2002), obtained from a cross tabulation of the row and column variables.

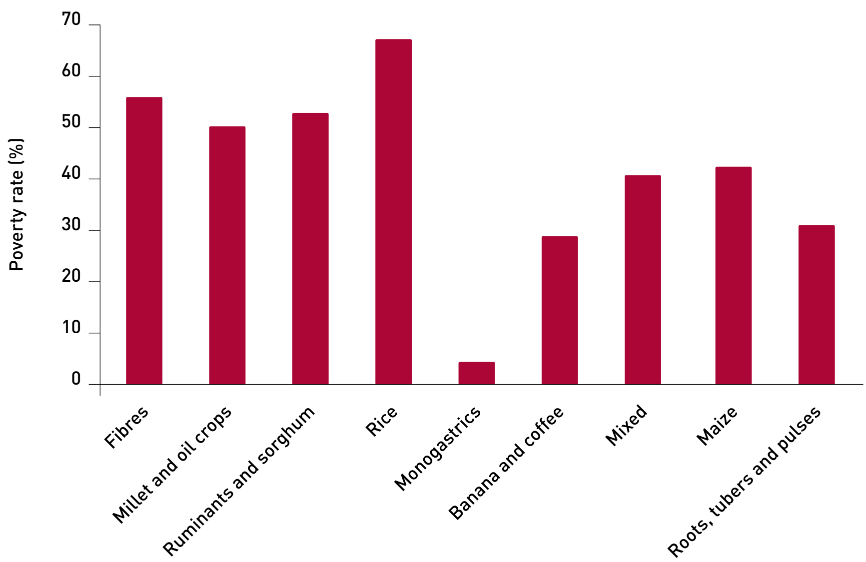
Poverty incidence was evaluated by extracting welfare estimates for the 5 497 geo-registered rural households included in the 2002/2003 Uganda National Household Survey (UBOS, 2003). About 39 percent of these households are classified as poor, and the average monthly per adult equivalent expenditure of these poor households is 14 495 Uganda shillings (USh) (SD = 4 038, N = 2 111). Table 6.1 shows poverty rates and average expenditure levels for the nine agricultural

TABLE 6.4 CORRESPONDENCE BETWEEN AGRICULTURAL SYSTEMS IN UGANDA DERIVED FROM THE CLUSTER ANALYSIS AND THE LIVESTOCK PRODUCTION SYSTEMS*

Cluster	Livestock production system							
	MRH	MRA	MRT	LGH	LGA	LGT	Urban	Other
Banana and coffee	34.5	17.8	18.3	8.8	3.3	2.5	8.0	6.9
Roots, tubers and pulses	53.1	8.4	6.9	11.9	4.0	1.0	4.3	10.5
Maize	60.4	3.6	6.2	5.1	3.0	0.3	15.2	6.2
Monogastrics	48.3	0.0	0.0	8.5	0.0	0.0	39.9	3.3
Ruminants and sorghum	17.1	45.4	8.1	4.4	18.9	2.1	1.5	2.4
Millet and oil crops	61.3	7.6	0.2	19.4	4.2	0.1	3.1	4.1
Fibres	60.5	12.7	0.0	13.6	6.5	0.0	5.9	0.8
Rice	48.5	0.0	10.2	4.6	0.0	1.2	8.3	27.2
Mixed	26.0	18.8	4.0	27.3	14.8	1.3	3.7	4.2

* Version 1 from Thornton *et al.* (2002).

6.4 AVERAGE POVERTY RATES BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA



production systems derived; these average poverty rates are illustrated in Figure 6.4. If we exclude the rice system represented only by 0.1 percent of Uganda's land area, then the ruminants and sorghum system, the fibres system, and the millet and oil crops system account for the highest percentages of poor people (Figure 6.4). Though the sample size is quite small (n = 50), those engaged in the monogastric system are by far the best off, with only 4 percent living below the poverty line and average expenditures of nearly 19 000 USh per month per adult equivalent. Also fairing well are the banana and coffee system and the roots, tubers and pulses system, which have poverty rates of about 30 percent and average expenditures of some 16 000 USh per month per adult equivalent.

Conclusions

Uganda has emphasized agricultural sector development as a strategy for raising rural incomes and reducing rural poverty (NEMA, 2005). Developing sustainable and productive farming systems is essential for poverty eradication and sustained economic growth in rural Uganda.

To date, production systems have largely been defined by researchers and policy-makers through expert knowledge and *a priori* characterization (Dixon *et al*., 2001). The use of multivariate statistical techniques, such as cluster analysis, to identify farm types is not new (Köbrich *et al*., 2003) but a lack of data usually precludes this kind of approach at large scale. An explorative approach has been developed here that can help to provide reliable and realistic information about agricultural production systems in Uganda, showing distinct patterns for mixed farming systems. While this analysis represents an independent methodology based on detailed empirical data, its repeatability is highly dependent on the level of data available at national, regional or global levels. During recent years much effort has gone into modelling global crop distributions (You *et al*., 2009) and livestock densities (Robinson *et al*., 2007; FAO, 2007a). While it may be possible to repeat this approach at global or regional scales using these modelled livestock and crop data, comparable information on livelihoods is still missing at the same levels of consistency and spatial resolution.

AGRICULTURAL SYSTEMS AND POVERTY IN VIET NAM

Of Viet Nam's 80 million population, nearly 80 percent live in rural areas and 67 percent of the total labour force works in agriculture. Economic reforms over the past 20 years have resulted in individual farming households replacing the cooperatives and state-owned farms as the basic unit of agricultural production, and farmers have become increasingly free to decide for themselves what to grow on their land. Rice remains the most important crop, but horticultural production and perennial crops such as coffee, pepper, tea and mulberry have been produced in increasing quantities. Livestock has gained importance as a source of income for many of the rural poor. While fisheries and aquaculture make an important contribution to the rural economy along parts of Viet Nam's coast, in the river deltas and, to a lesser extent, in a few upland areas on the shores of the larger lakes, forestry activities provide an important share of rural household incomes in many of the mountainous regions.

Viet Nam is broadly divided into eight agro-ecological regions. The poor mountainous upland areas of the northern part of the country, the northeast and the northwest regions, as well as the mountainous parts of the north central coast and south central coast, are characterized by very low population densities, underdeveloped market infrastructure and little commercialized agriculture. Agriculture in these areas is largely based on upland rainfed mixed-cropping systems, dominated by rice and corn, with most households raising some cattle, pigs and chickens.

The Red River Delta, the Mekong River Delta, and the southeast are densely populated and close to major urban areas, with comparatively low poverty rates and well developed markets. The agricultural systems here are dominated by irrigated intensive paddy rice cultivation, which in the Mekong River Delta is often mixed with aquaculture systems. Livestock production is an important commercial activity, with industrial pig, broiler and dairy production. The lowlands of the north central coast and the south central coast have moderate population densities and poverty rates. Markets tend to be underdeveloped in the northern part and somewhat better developed in the southern part. The fishing industry is important, particularly in the south. Irrigated and rainfed rice cultivation dominates, though cash crops such as peanuts, coffee and rubber are increasingly grown, too. There is limited dairy and beef cattle production, but buffalo production is relatively well developed and smallholders of goats and sheep are common in the dry, more southerly areas.

The central highlands and their southern foothills have low population densities. Poverty rates are high in the mountainous areas and relatively low in the plains. The area is well known for commercial tree crop production – particularly rubber, coffee and cashew nut – as well as for commercial horticulture. Beef and dairy production are relatively well developed and forestry is also important.

However, these broad descriptions hide the considerable heterogeneity of agricultural production systems within these agro-ecological regions. A spatial analysis of the 2002 Viet Nam Rural Agriculture and Fisheries Census reveals the distinctive spatial patterns in the production of the many different agricultural products, including the different livestock and crop types (Epprecht and Robinson, 2007). Such detailed information on the spatial distribution of the production of different agricultural products is useful for commodity-specific analysis and decision-making. However, the distribution of the typical household production systems, and the relationships between these systems and the livelihoods and well-being of the households that operate within them, cannot easily be grasped.

The system classifications of Dixon *et al.* (2001) and Thornton *et al.* (2002) described above were developed at a global scale, and have relatively little practical use at the national scale. More detailed national production system classifications for Viet Nam that would be of greater practical use do not currently exist. The availability in Viet Nam of detailed agricultural census and household survey data presents the opportunity to explore a data-intensive modelling approach to agricultural production systems classification. An attempt has been made here to develop and map a national agricultural production systems classification for Viet Nam using the best available national data sets. The classification scheme described below deals with agricultural production systems in general but addresses the livestock components in particular detail.

Methods

The approach taken involves two main steps: 1) the statistical classification of households based on sample survey data; and 2) an 'extrapolation' of the predominant commune-level production system from the sample communes to the entire country by applying a neural network to detailed census and spatial data.

The stage 1 categorization of production systems was based on data from the 2002 Viet Nam Household Living Standards Survey (VHLSS), which covers a sample of 29 530 households in 2 900 communes, from a total of 10 500. A breakdown of household income sources enabled household level production systems to be determined in surveyed communes. The classification was very broadly determined according to the main agricultural activities: 1) arable agriculture; 2) livestock; 3) aquaculture and fisheries; and 4) forestry. The importance of each system component was measured by its respective contribution to total household income; those contributing to at least 10 percent of household income were included. The predominant production system type was then assigned to each sample commune by taking the most frequently occurring type at household level for each of the communes. This provided a commune-level production system map for the sample communes which could then be used to train a neural network applied to the more complete census data.

For stage 2, commune-level data were compiled that may contribute to explaining the occurrence of a particular production system at a particular location. These included agricultural, infrastructural, environmental and demographic variables derived from GIS layers or statistical datasets. Observed relationships between commune-level explanatory variables at survey locations and the prevalent production systems in the sample communes were used to predict the dominant production system type for each commune.

The 2002 Rural Agriculture and Fisheries Census, covering all 13.9 million rural households in Viet Nam, contains some information on agricultural production, including numbers held of different livestock species, areas planted to annual and perennial crops, area used for forestry, and area used for aquaculture. Commune level aggregates of the census data were made available for this analysis. Other relevant spatial variables were compiled and summarized at commune level, including elevation, slope, roughness, soil type, climatic data, LGP, land cover, and proximity to various types of water bodies. Population density and accessibility to various types of infrastructure and other 'targets' were also calculated for each commune. The suite of commune-level attributes that was available for all (rural) communes is summarized in Table 6.5.

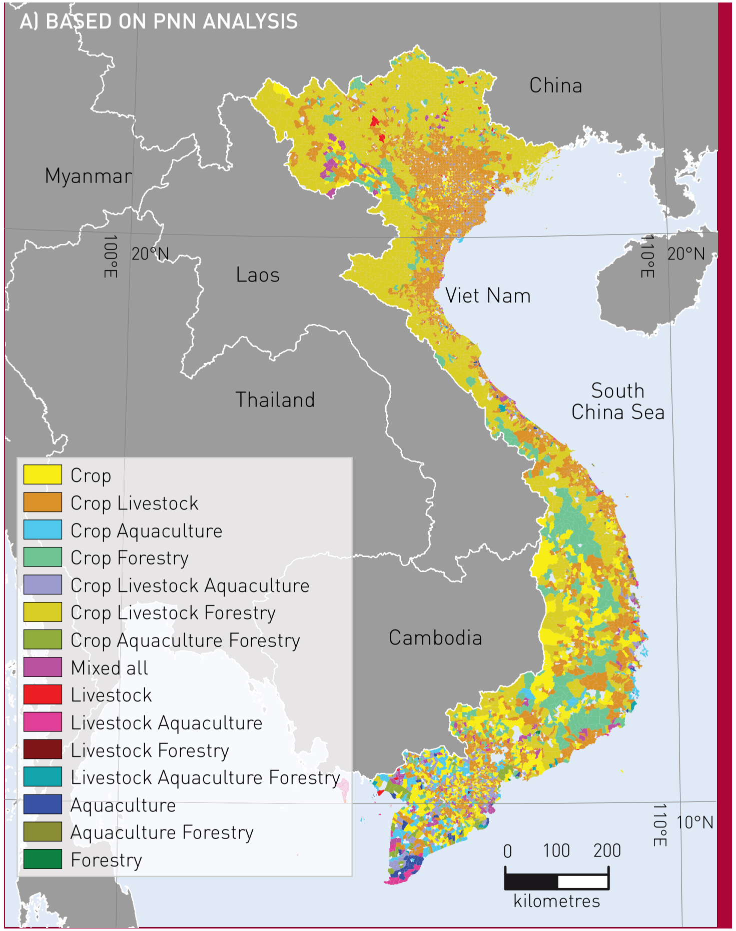
Given the large number of classes to be predicted, a probabilistic neural network (PNN) approach was chosen over conventional regression approaches, to establish relationships between the explanatory variables and commune-level production systems at survey locations, and to predict the most likely production system for non-survey locations. PNN is a pattern classification routine based on 'nearest-neighbour' algorithms (see e.g. Montana, 1992). PNN is a double layer network: the first layer calculates the distances from the input vector to the training vectors and produces a further vector containing those distances. The second layer sums the contributions for each class of inputs to produce a vector of probabilities. The routine was run on the commune data and, for each, the class that corresponded to the highest of these probabilities was assigned. In order to prevent the model from overfitting the training data – which would severely restrict its power in making predictions beyond the scope of the training data (a high risk with neural network type approaches) – the number of classes to be predicted was restricted,

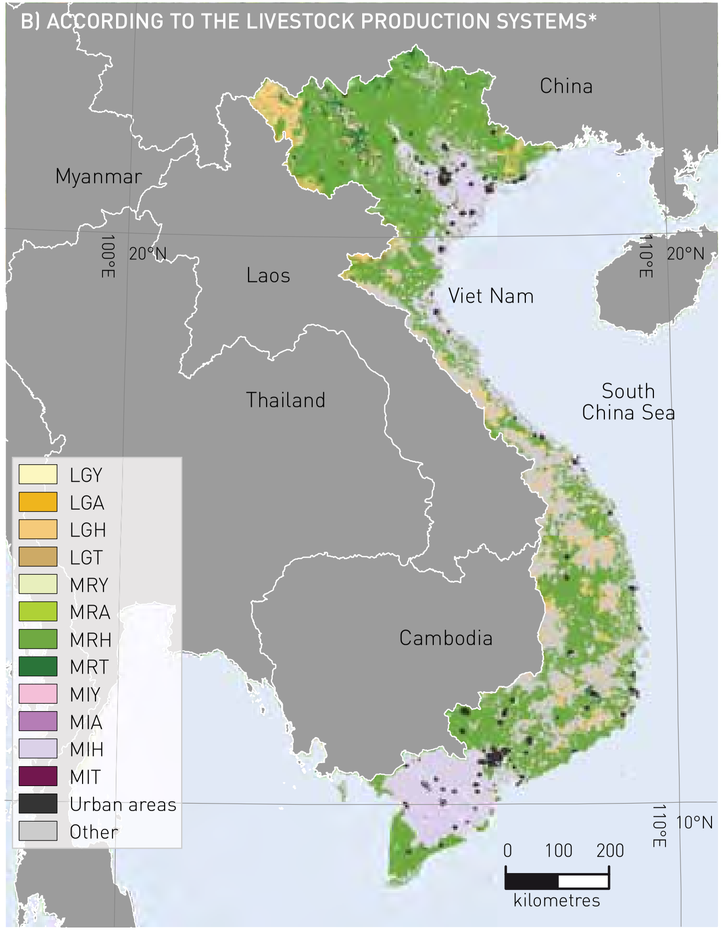
TABLE 6.5 COMMUNE-LEVEL DATA AVAILABLE FOR MODELLING DOMINANT PRODUCTION SYSTEMS

Attribute	Variable
Environmental	**Elevation**
	Slope
	Roughness
	Length of growing period
	Soil type
	Soil suitability
	Rainfall
	Temperature
	Solar radiation
	Land cover
	Agro-ecological region
Demographic	Population density (human)
	Welfare
Agricultural	Livestock densities by type (cattle buffalo, pig, chicken, duck)
	Flock/herd sizes by type (cattle buffalo, pig, chicken, duck)
	Percentage of the communal area under agricultural land
	Percentage of the communal area under forestry land
	Percentage of the communal area used for aquaculture
	Percentage of rural households that engage in animal husbandry
	Percentage of district-level rural household income from crops
	Percentage of district-level rural household income from livestock
	Percentage of district-level rural household income from aquaculture and fisheries
	Percentage of district-level rural household income from forestry
Infrastructural	**Travel distance to the sea**
	Travel distance to a large water body
	Travel distance to major cities (≥1 million people)
	Travel distance to urban areas

Variables emboldened in red are those actually used in the model.

6.5 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN VIET NAM





* Version 5 as described in Section 3.

TABLE 6.6 CONFUSION MATRIX OF PREDICTED VERSUS OBSERVED PRODUCTION SYSTEMS IN VIET NAM IN THE VALIDATION DATASET

Production system		Observed													
		C	CL	CA	CF	CLA	CLF	CAF	CLAF	L	LA	LAF	A	AF	Total
Predicted	C	**14**	5	5	2	2	5	0	0	0	1	0	1	0	**43**
	CL	2	**125**	2	7	4	1	0	4	0	0	0	0	0	**157**
	CA	2	1	**2**	0	1	3	1	1	0	0	1	0	2	**14**
	CF	6	5	0	**18**	1	0	0	0	0	0	0	0	0	**28**
	CLA	2	7	2	0	**3**	3	1	0	0	0	0	1	1	**22**
	CLF	2	24	0	6	2	**69**	0	3	0	0	0	0	0	**91**
	CAF	0	0	0	0	0	1	**2**	2	0	1	0	0	0	**6**
	CLAF	0	0	0	0	1	2	1	**0**	0	0	0	0	0	**4**
	L	0	0	0	0	1	0	0	0	**3**	0	0	0	0	**1**
	LA	0	0	0	0	0	0	0	0	0	**3**	0	2	0	**3**
	LAF	0	0	0	0	0	0	0	0	0	0	**0**	0	0	**0**
	A	0	0	0	0	0	0	0	0	0	0	0	**2**	0	**2**
	AF	0	0	0	0	0	0	0	0	0	0	0	1	**0**	**1**
	Total	**28**	**167**	**11**	**33**	**15**	**84**	**5**	**10**	**3**	**5**	**1**	**7**	**3**	**372**

C = Crop, **L** = Livestock, **A** = Aquaculture, **F** = Forestry

the number of explanatory variables was kept to a minimum, and the independent variables were classified into quintiles. To finish, the extrapolated production systems were characterized in terms of their extent, the numbers of people engaged in each, and indicative poverty levels.

Results

A basic agricultural production systems classification was thus produced, indicating the combinations of the four production systems components. The neural network model was applied to the predictor variables for all rural communes and the results were mapped. Of the 15 potential combinations of the four system components, 13 production systems were represented.

Figure 6.5a depicts the spatial distribution of these 13 systems. The model fitted the training data well (R^2 > 0.9), and appeared to classify the non-survey communes meaningfully. Furthermore, the proportional distribution of communes per production system type in the training sample compares well to the one predicted for the whole of rural Viet Nam.

To validate the model every sixth observation was excluded from the training data set, the network was re-trained, and the new network was applied to the validation data set made up of the previously excluded observations, to come up with predicted systems that could be compared with the observed systems. Table 6.6 provides the confusion matrix of predicted against observed production systems in the validation data set. Overall, 65 percent of predictions were the same as the observations (compared with an expected 26 percent), and an acceptable Kappa value of 0.53 was obtained (Cohen, 1960). Although the predictive power of the model was not exceptionally high, the table points to the main weaknesses, which lie in an overemphasis on the forestry component in the modelled systems compared with the observed systems. For example, 21 percent of 'C' communes were incorrectly classified as 'CF' and 14 percent of 'CL' communes were incorrectly classified as 'CLF'. This is probably largely explained by the modelling of the predominant communal household production systems being based on a different source of information – household sample survey data – than is the subsequent spatial extrapolation model, which is based on communal agricultural census data and environmental statistics. A household's community-based forestry activities tend to be under-reported at household level compared with commune level. This may have arisen because the household survey data contain relatively weak information on the forestry component of the household's production systems.

The spatial distribution of the predominant agricultural production systems shows some distinct geographic patterns (Figure 6.5a): crop–livestock (CL) mixed production systems dominate in the Red River Delta region and along much of the coast, whereas crop–livestock–forestry (CLF) systems dominate in much of the northern mountainous regions and in the north central region. Crop–forestry (CF) systems are prevalent in the Central Highlands region, along with crop-based production systems (C). Parts of the south central coastal areas, and particularly the Mekong River Delta, show much more patchy and fragmented distributions of production systems, where aquaculture plays an important part in many of the local production systems, most notably in the Mekong River Delta.

By comparing this map of basic agricultural production systems with the map of livestock production systems, Version 5 (Figure 6.5b), clear parallels in the spatial patterns are evident. The areas classified as mixed irrigated, humid and subhumid tropics and subtropics (MIH) in the livestock production systems map coincide in the northern and central parts of Viet Nam with the crop–livestock (CL) production system. However, the large monolithic MIH area in the Mekong River Delta region, evident in the livestock production systems map, reveals a much more diverse, differentiated and patchier picture in the production systems map of Figure 6.5a. The other main production system in Viet Nam according to the livestock production systems map is the mixed rainfed, humid and subhumid tropics and subtropics (MRH) system, which dominates many of the upland areas of Viet Nam. This relates spatially to the crop–livestock–forestry (CLF) system in the uplands of the northern and central parts of the country, and also to crop (C) and crop–forestry (CF) systems in the central highlands. While the observed spatial coincidence of the different classification schemes represented by the two maps is reassuring of their validity, the two schemes appear also to complement each other with further, independent information.

Having defined, extrapolated and mapped these production systems, they were characterized in terms of their extent, the numbers of people engaged in each, and typical poverty rates associated with them. For this characterization commune-level poverty estimates generated by IFPRI and the Institute of Development Studies were used. These were based on small area estimation techniques using data from the 1999 population census and the 1998 Viet Nam Living Standards Survey (Minot *et al.*, 2006). The results are shown in Table 6.7.

Overall, as shown in Figure 6.5a, the predominant agricultural production systems are crop–livestock (CL) and crop–livestock–forestry (CLF) systems, both in terms of area and in terms of the total population involved in these. The CL production system covers one-quarter of the rural area and predominates in almost half of Viet Nam's rural communes, covering much of the densely

TABLE 6.7 CHARACTERISTICS OF THE AGRICULTURAL PRODUCTION SYSTEMS IN VIET NAM

Production system	Area (km²)	Number of communes	Population (thousands)	Poverty incidence (%)	Poverty density (per km²)	Number of poor (thousands)
C	34 368	858	7 296	37	79	2 718
CL	77 748	4 253	29 344	41	155	12 015
CA	7 714	210	1 978	42	109	837
CF	40 124	530	2 585	51	33	1 316
CLA	7 527	434	3 724	40	200	1 507
CLF	133 374	2 252	9 538	57	40	5 397
CAF	3 761	69	802	43	92	347
CLAF	6 185	151	1 289	43	89	550
L	949	45	296	37	115	110
LA	2 015	52	504	39	97	196
LAF	679	14	109	48	76	52
A	2 355	64	626	43	115	271
AF	381	15	93	59	145	55
National	**317 180**	**8 947**	**58 185**	**44**	**80**	**25 371**

C = Crop, **L** = Livestock, **A** = Aquaculture, **F** = Forestry

populated lowlands. Half of Viet Nam's rural population, as well as nearly half of the country's rural poor, live in these areas. The average poverty rate is slightly below the national average of rural areas. In the uplands, which account for almost half of the country's area, the CLF production system dominates. There, crops, livestock and forestry each play a significant role in livelihoods, as determined by income. However, those areas that are much more sparsely populated compared with the lowlands are home only to about one-sixth of the country's rural population. More than half of the population in CLF systems live below the poverty line, placing it among the poorest systems.

Communes with a predominant household production system that involves forestry are among the poorest, whereas those involving aquaculture are typically better off. This pattern probably reflects the geographic potential of the respective areas: the lowland areas near rivers or the sea, where aquaculture is possible and access to people and markets is good, compared with the rugged upland areas that are characterized by poor accessibility, where livelihood activities are restricted by the inhospitable terrain to forestry. The more specialized production systems, where only crops or livestock predominate, are the ones with the lowest poverty rates.

Conclusions

In this summary the analysis has been restricted to combinations of the four major systems components. A next logical step would be to model more detailed production system subclasses. Test runs will show whether the many different complex classes can be extrapolated through a single model, or whether production systems will need to be modelled in a step-by-step fashion, with separate models for the major systems, the subclasses of these, and further attributes to those subclasses.

The level of detail in the VHLSS 2002 household survey would allow subcomponents to be distinguished based on proportional contribution to income, as follows. In the case of arable agriculture the dominant crop type can be further specified as either annual crops or perennial crops. For livestock the dominant types can be specified too, as pigs, chickens, water-fowl, dairy cattle, beef cattle, buffaloes or small ruminants. The importance of each system component could be measured by its respective contribution to the total household income using a minimum contribution of 10 percent as a threshold. Table 6.8 lists the 11 subclasses. However, in combination these include 10 or less classes – because with a 10 percent income threshold more than ten contributors are not possible – and this may give rise to as many as 2 046 production systems, including the class where none made a 10 percent contribution. In reality most of these potential combinations would not occur, but this approach still threatens to throw up an unwieldy number of production system classes.

Again, using available data from the household survey, each of these 11 subcomponents can be further specified according to four attributes: 1) their degree of commercialization, i.e. commercial versus subsistence production, measured by the marketed share of the total output; 2) the scale of the production, i.e. small-scale versus large-scale, measured by area planted or by numbers of animals per production unit; 3) the intensity of the production, i.e. intensive versus extensive, measured by the amount of output per unit of production, the number of livestock, the area cropped, and so on; and 4) for households with both crops and livestock, depending on whether those two components were integrated or independent (possibly measured, for each livestock type, by the proportion of income from that livestock type that is spent on feed).

Combining all possibilities of these would obviously result in an impossibly large number of production systems that would be of no use whatsoever. A more practical approach may be to map these four attributes separately and to overlay these on the systems maps.

TABLE 6.8 SUMMARY OF THE MORE DETAILED HOUSEHOLD LEVEL PRODUCTION SYSTEM CLASSIFICATION

Level 1	Level 2
Arable	Annual
	Perennial
Livestock	Dairy cattle
	Beef cattle
	Buffaloes
	Small ruminants
	Pigs
	Chickens
	Water-fowl
Aquaculture, fisheries	
Forestry	

Even with four production system components, which would result in 15 production systems, a threshold of 10 percent is possibly too low for evaluating the importance of a system component to livelihoods. By increasing this threshold to, say, 20 percent, we would end up with a more general classification that would enable some of the less widespread classes to be dropped.

There is no doubt that this approach holds much potential in production system classification. The results here have already demonstrated that a detailed breakdown of the systems in Viet Nam is possible, and that this concurs with our general understanding of these systems and how they are distributed. While the approach is of value, its application will be restricted to countries where detailed household survey and census data are available – and where these contain relevant information. This means that the household survey data must contain information on incomes, disaggregated by production system components, and that the census data contain information that is highly relevant to production systems. Countries with survey and census data meeting these criteria are relatively few and, moreover, comparable datasets across countries that would enable global or even regional analyses do not exist.

There may nevertheless be some merit in exploring the possibility of extrapolating the classified systems regionally, using regionally-consistent datasets rather than country-specific census data.

LIVELIHOOD ANALYSIS AND LIVESTOCK PRODUCTION SYSTEMS IN EASTERN AFRICA

One of the main reasons for studying agricultural production systems is to understand and therefore help improve poor people's livelihoods. In this context, it is important to explore the extent to which the environmental parameters and GIS layers used to map livestock production systems globally are capable of capturing relevant livelihood patterns, especially in rural areas of the developing world. An opportunity to shed light on the relationships between livelihoods and global environmental datasets is offered by data gathered or collated in the framework of livelihood analysis (Scoones, 1998; Carney, 2003; Seaman *et al.*, 2000).

In livelihood analysis, areas that are homogenous in terms of farming practices, consumption patterns, expenditure, trade and exchange are identified, and a range of livelihood data are assembled, often including quantitative or qualitative information on income derived from livestock and crops. Livelihood analyses have been carried out extensively in member states of the Intergovernmental Authority for Development (IGAD)[14], thus allowing a regional, livelihood-based map of livestock production systems to be created (Cecchi *et al.*, 2010).

One of the goals of the study in the IGAD region was to explore the extent to which global maps of livestock production systems may capture relevant patterns of rural people's livelihoods. The previous two case studies in this section, from Uganda and Viet Nam, used detailed, country-specific data on the distribution of agricultural commodities, or income derived from them, to define agricultural systems in a country-specific manner. This third case study was based not on household survey data, but on data obtained through rapid rural appraisal methods – mainly semi-structured interviewing of focus groups. Such data are less detailed but are explicitly linked to livelihoods. Moreover, there is a reasonable level of harmonization in the collection of livelihood data across a number of countries, meaning that it was possible to produce a regional map.

Using the ratio of income derived from livestock to that derived from crops, three categories were defined: pastoral, agropastoral and mixed farming systems. The resulting map was compared with the global map of livestock production systems (Version 4). Livelihood-based systems were further characterized in terms of the LGP, a key geospatial layer used to generate the global livestock production systems map, with a view to clarifying the relationship between this variable and production patterns on the ground.

Methods

All data collected in the IGAD region from the year 2000 onwards in the framework of livelihood analysis were collated. These included full coverage of Djibouti, Eritrea, Kenya, Somalia and Uganda. Livelihood information for a few regions in Ethiopia and Sudan was also available. Data on the average income[15] derived from livestock (L) and crops (C) were used to define three production systems as follows:

- Pastoral production systems: where $L/C \geq 4$.
- Agropastoral production systems: where $1 < L/C < 4$.
- Mixed farming production systems: where $L/C \leq 1$.

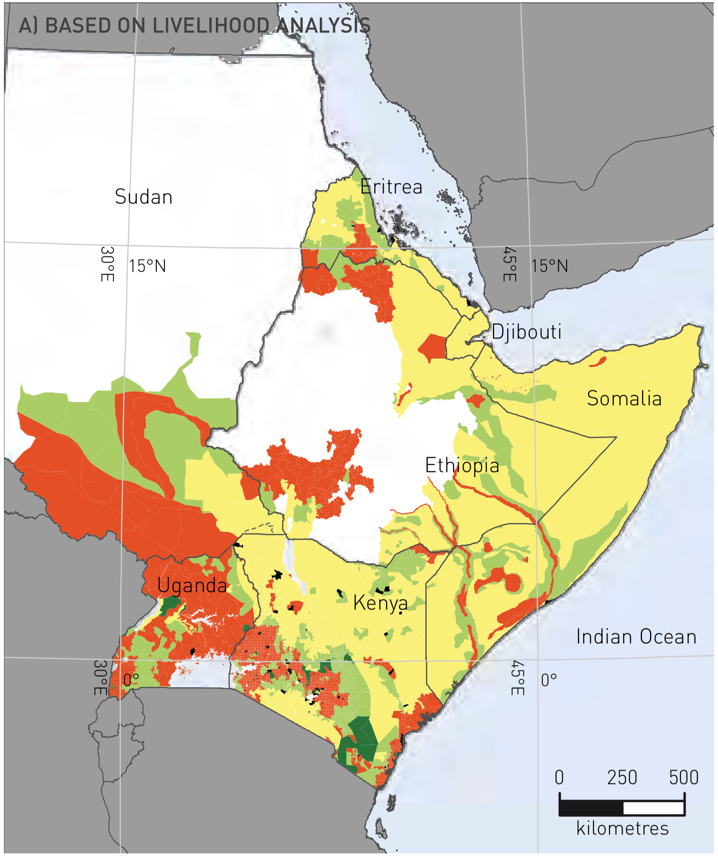
For each livelihood zone in the IGAD region that was described in livelihood studies, the dominant production system was defined based either on quantitative data, qualitative information or expert opinion. This allowed all zones to be classified into one of these three categories. The resulting map (Figure 6.6a) also includes some 'urban and other

[14] IGAD is a regional economic community comprising six countries in the Horn of Africa: Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda. At the time of writing, Eritrea's membership had been suspended.

[15] Income includes the value of the marketed production and the estimated value of subsistence production.

6.6 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN EASTERN AFRICA

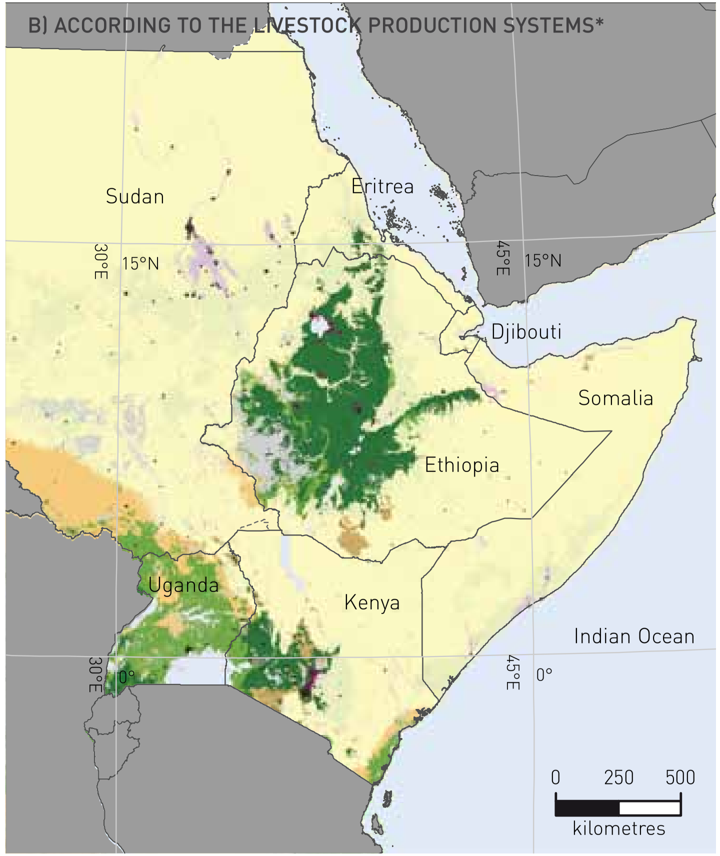
A) BASED ON LIVELIHOOD ANALYSIS



- Pastoral
- Agro-pastoral
- Mixed farming
- Urban and other areas
- Protected areas
- No data

Source: adapted from Cecchi *et al.* (2010).

B) ACCORDING TO THE LIVESTOCK PRODUCTION SYSTEMS*



* Version 4 as described in Section 3.

- LGA
- LGH
- LGT
- MRA
- MRH
- MRT
- MIA
- MIH
- MRT
- Urban areas
- Other

areas' (defined as areas where L + C is less than 10 percent of total income) and protected areas. For the sake of visual comparison, Figure 6.6b shows Version 4 of the global map of livestock production systems for the same geographical area.

The map in Figure 6.6a was matched to that shown in Figure 6.6b using correspondence analysis (Greenacre, 1984)[16]. Rural population (rather than area) was used as 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. Values of LGP (Jones and Thornton, 2005) were also extracted and analysed for the production systems shown in Figure 6.6a.

Results

Correspondence analysis showed substantial agreement between the global map of livestock production systems and the livelihood-based map, as shown in Figure 6.7 and Table 6.9.

Figure 6.7 is fairly self-explanatory since, in correspondence analysis plots, similar categories appear close to one another. However, the results for the category 'livestock only, humid and sub-humid' (LH) call for further explanation, as this category appears to be predominantly associated with mixed-farming livelihood zones. This is probably explained by the fact that, in the IGAD region, the few LH areas that exist are interspersed with 'mixed, humid and sub-humid' (MH) areas within the boundaries of zones where livelihoods depend predominantly on crops – most notably in the highly fertile green belt in Southern Sudan (SSCCSE and SC-UK, 2005). As such, the association between LH areas and mixed farming zones is likely to be an artefact of limited coverage and spatial resolution rather than a functional association. Livelihood maps at higher spatial resolution would probably not have generated this mismatch.

The relationship between livestock production systems and LGP in the IGAD region was also characterized and is shown in Figure 6.8.

Predictably, areas with low LGP values are dominated by pastoral systems and areas with high values are dominated by mixed farming. In a narrow intermediate range between 130 and 170 days, agropastoral systems are the most common (Figure 6.8a). If agropastoral and mixed farming systems are combined (Figure 6.8b), it is possible to identify the threshold separating pastoral systems from the others: 110 days. Similarly, 180 days marks the threshold between crop-dominated and livestock-dominated systems (Figure 6.8c).

In addition to LGP, the map in Figure 6.6a was matched with human population densities (CIESIN *et al.*, 2004), and land cover derived from Africover[17] (Cecchi *et al.*, 2010). The results of the analysis are not presented here, but it is worth mentioning that they indicated that different livestock production systems also show markedly different patterns with respect to population density and land cover composition. This provides further confirmation that using such datasets for global mapping of livestock production systems is not only practical but also well founded.

Conclusions

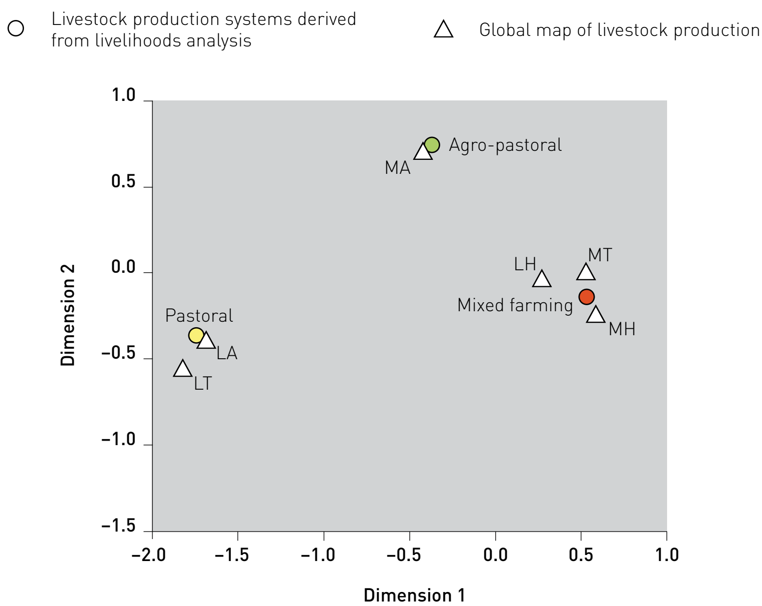
The analysis in the Horn of Africa showed that global maps of livestock production systems based on environmental datasets are capable of capturing important livelihood patterns, such as the relative contribution of livestock and crops to the average income of rural households.

It also suggested that some of the environmental datasets used for global mapping – LGP in particular – could be used to refine the classification further by distinguishing two types of mixed farming systems: agropastoral systems, where income derived from livestock exceeds that from crops, and crop-dominated mixed farming systems, where the opposite is true. A few issues need to be tackled before the results of this analysis

[16] Mixed irrigated and rainfed classes were merged for each agro-ecological category due to the relatively sparse distribution of irrigated areas in Eastern Africa.

[17] Africover: http://africover.org

6.7 CORRESPONDENCE ANALYSIS PLOT BETWEEN LIVELIHOOD-DERIVED AND GLOBAL MAP OF LIVESTOCK PRODUCTION SYSTEMS USING RURAL POPULATION AS A MEASURE OF CORRESPONDENCE (SYMMETRICAL NORMALISATION)



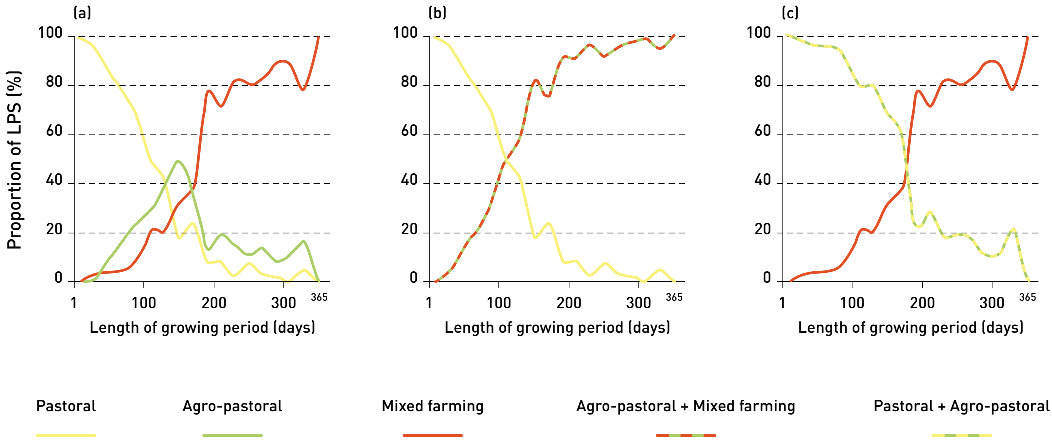
Source: adapted from Cecchi *et al.* (2010).

TABLE 6.9 CORRESPONDENCE ANALYSIS BETWEEN LIVELIHOOD-DERIVED AND GLOBAL MAP OF LIVESTOCK PRODUCTION SYSTEMS (VERSION 4) (COLUMN PROFILE BASED ON THE CORRESPONDENCE TABLE). RURAL POPULATION IS USED AS A MEASURE OF CORRESPONDENCE

		Livelihood-derived livestock production systems			
Global livestock production systems	**Code**	**Pastoral (%)**	**Agro-pastoral (%)**	**Mixed farming (%)**	**Total (%)**
Livestock only, hyper-arid	LY	97.8	0.0	2.2	100
Livestock only, arid and semi-arid	LA	64.7	26.0	9.3	100
Livestock only, temperate and tropical highland	LT	69.5	24.1	6.5	100
Livestock only, humid and sub-humid	LH	8.8	16.8	74.4	100
Mixed, hyper-arid	MY	0.0	0.0	0.0	-
Mixed, arid and sem-iarid	MA	23.6	32.4	44.0	100
Mixed, temperate and tropical highland	MT	1.2	15.5	83.3	100
Mixed, humid and sub-humid	MH	1.1	11.6	87.3	100

Source: adapted from Cecchi *et al.* (2010).

6.8 LIVESTOCK PRODUCTION SYSTEMS (DERIVED FROM LIVELIHOOD ANALYSIS) AND LENGTH OF GROWING PERIOD



Source: adapted from Cecchi *et al.* (2010).

can be used to inform global mapping. First and foremost among these is the geographical coverage. Livelihood data from other regions of the world should be analysed in a similar manner to establish whether results for the Horn of Africa have a broader validity. Second is the issue of definitions of production systems. Global mapping approaches have been loosely linked to definitions provided by Seré and Steinfeld (FAO, 1996), which combined elements of farm income with other farming practices such as the type and origin of dry matter fed to animals. Lack of data precludes the use of these definitions to map production systems from livelihood studies – hence the use of a different definition, based on the ratio between livestock-derived and crop-derived incomes. Third is the issue of mapping unit and spatial resolution. The mapping units for livelihood analysis are the livelihood zones, and these are often based, at least in part, on administrative units. By contrast, global maps are generated from gridded environmental layers at different resolutions, which are combined to predict the livestock production systems in cells of between 3 arc minutes and 30 arc seconds (approximately 5 km to 1 km at the Equator). Further analysis may help us to overcome these issues, and thus to combine the two mapping approaches in a more meaningful way.

7 Applications of global livestock production systems

Maps of production systems have a wide variety of uses, many of which were summarized in the introduction to this book. For most analyses involving spatial distributions of livestock or people that are dependent on them in one way or another, some sort of production system stratification is required to account for the different roles they play and the very diverse ways in which they operate. The subsections below provide some specific examples of how maps of livestock production systems have been used. Each begins with an introductory summary of the application, which explains the importance of using the production system stratification for that analysis. Many more examples could have been included, but the list has been restricted to four to allow a reasonable amount of detail to be included for each. Each example is taken from one of the four main areas in the livestock sector relating to global public goods, demonstrating the importance of understanding livestock production systems across the sector as a whole. These are: 1) livestock production, now and in the future; 2) livestock's impact on the global environment (GHG emissions); 3) animal health and the economics of livestock disease interventions; and 4) livestock and livelihoods, in the estimation of numbers of poor livestock keepers globally.

ALLOCATING PROJECTED LIVESTOCK PRODUCTION DATA BY SYSTEM AND REGION

This example demonstrates how the global livestock production systems map was used in an international assessment study to allocate livestock production data to live animals by system, based on the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), a global partial equilibrium model (Rosegrant *et al.*, 2009). This was done so that livestock numbers could be evaluated by region and system to assess whether assumptions about technology change were plausible or not. The large increases in livestock production projected to the 2050s can come about through increases in livestock numbers, increases in productivity per animal, or (realistically) through a combination of both of these things. In some developing countries, particularly in sub-Saharan Africa, rates of technological change have been historically slow compared with many other parts of the world. There are clearly limits to the increases in the number of livestock that might be feasible in reality, particularly in relatively extensive, and possibly fragile, livestock production systems. The work described here is a good example of 'triangulation', using one set of tools and methods to assess the outputs of a completely different set of analyses, so that certain key assumptions in the latter can be checked and modified, if necessary.

Introduction

The International Assessment of Agricultural Science and Technology for Development (IAASTD) was initiated in 2002 by the World Bank and FAO, to analyse the potential of agricultural knowledge, science, and technology, to reduce hunger and poverty, to improve rural livelihoods, and to work towards environmentally, socially and economically sustainable development. The Assessment was set up against the background of an estimated one billion people or more who are currently at serious risk of malnourishment. The unequal distribution of food, and conflict over control of the world's dwindling natural resources, present a major political and social challenge to governments and policy-makers, exacerbated by climate change and growth in the world's population to a projected 9.2 billion people by 2050. At the time when the

IAASTD was being established there was worldwide market turbulence, a commodity prices boom, volatility in the oil market, and record high food prices. The IAASTD was an ambitious inter-governmental report that sought to bring together Northern and Southern perspectives to drive the agricultural agenda for the next 50 years. Whether it succeeded or not is open to question and the process was not without its share of controversy (Scoones, 2009). The ultimate impact of the work remains to be seen, especially given it long-term aims.

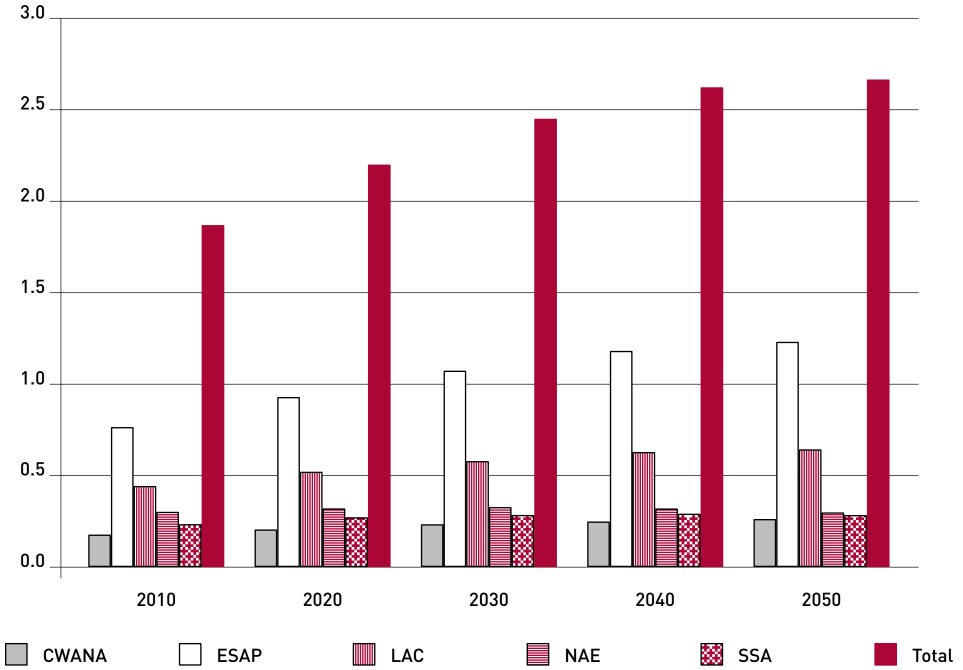
The IAASTD involved some quantitative modelling of 'plausible futures', originally designed to use the same scenarios that had been used in the Millennium Ecosystem Assessment. For various reasons the scenarios aspect of the IAASTD was heavily reduced, but some scenario work was carried out (Rosegrant *et al.*, 2009). This work revolved around the IMPACT model, which was used to look at different agricultural development options (Rosegrant *et al.*, 2002). IMPACT uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions for 32 crop, livestock and fish commodities. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. Future productivity growth is estimated by its component sources, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension and education, markets, infrastructure and irrigation. IMPACT produces results for 281 Food Producing Units (FPUs), arising from the intersection of 115 countries or regions with 126 river basins. The model projects the share and number of malnourished pre-school children in developing countries as a function of average per capita calorie availability, the share of females with secondary schooling, the ratio of female to male life expectancy at birth, and the percentage of the population with access to safe water. It generates annual projections for irrigation-based, livestock-based, and non-agricultural water withdrawals and depletion. It also projects other factors such as: irrigated and rainfed crop area, yield, and production; the demand for food, feed and other uses, and the corresponding price levels and trade levels of these; livestock numbers, and the corresponding levels of production, yield, demand, prices and trade of livestock. IMPACT deals with the kilograms of meat and milk produced; in order to estimate the number and location of live animals in relation to different development pathways, therefore, some spatial modelling needed to be done. Evaluating the number of live animals in (particularly) tropical livestock systems was an important part of assessing whether some of the assumptions of technological change in the IMPACT model were in fact reasonable. For example, would some sets of assumptions lead to gross (simulated) overstocking of fragile rangelands in some parts of the world?

Methods

Fundamental to the analysis is the global livestock production systems classification, Version 3, described above. There were two parts to the analysis. First, global livestock systems were mapped for the baseline year (2000) and for the 'reference run' of the IAASTD to 2030 and 2050[18]. The reference run imagines a world developing over the next decades as it does today, without anticipating deliberate interventions requiring new or intensified policies in response to projected developments: current policy pathways are expected to continue

[18] For the reference run, population growth was based on the medium variant projections of the UN and economic growth assumptions were loosely based on the TechnoGarden scenario of the Millennium Ecosystem Assessment (MEA, 2005). Agricultural productivity assumptions were also based on the TechnoGarden scenario and on FAO interim report projections to 2030/2050 (FAO, 2006b). Growth in non-agricultural sectors was projected to be lower than in the agricultural sector. The non-agricultural GDP growth rates were likewise based on the MEA TechnoGarden scenario but with adjustments, so as to align with World Bank medium-term projections.

7.1 PROJECTED NUMBER OF BOVINES TO 2050 IN THE REFERENCE WORLD OF THE IAASTD, BY REGION*



CWANA = Central and West Asia and North Africa, **ESAP** = East and South Asia and the Pacific,
LAC = Latin America and the Caribbean, **NAE** = North America and Europe, **SSA** = sub-Saharan Africa.

Source: adapted from Thornton (2010).
* Regional groupings of countries are as listed in Rosegrant *et al.* (2009).

until 2050. To map global livestock systems into the future, the appropriate country-level human population projections for these years were applied to the systems classification. In addition, the climate change estimates were used to generate data on the length of growing period (number of days per year) to 2030 and 2050 for the reference run (details are given in Rosegrant *et al.*, 2009). For the second part of the analysis the livestock numbers that were generated as output from the IMPACT model for the reference run to 2030 and 2050 were used. These data were at the resolution of the 281 FPUs of the IMPACT model. IMPACT outputs the number of livestock slaughtered per year, and these were converted to live animal equivalents using country-level ratios of live-to-slaughtered animals from FAOSTAT for 1999–2001 (the same base that was used for the IMPACT simulations). To estimate changes in grazing intensity, the extent of each system type within each FPU was estimated, and livestock numbers within each FPU were allocated pro-rata to each system within the FPU. Future scenarios were based on existing global ruminant livestock distribution maps for current conditions, to derive the livestock allocation proportions appropriate to each system within each FPU.

For these analyses, the 11 livestock production systems of Thornton *et al.* (2002) were collapsed to three: rangeland systems, mixed systems (rainfed and irrigated), and 'other' systems. These other systems include the intensive landless systems, both monogastric (pigs and poultry) and ruminant. Results were then calculated and reported according to these three broad systems.

TABLE 7.1 GRAZING INTENSITIES IN RANGELAND SYSTEMS TO 2030 AND 2050 IN THE REFERENCE WORLD, BY REGION* (TLU PER HECTARE)

	2000	2030	2050
CWANA	0.052	0.077	0.083
ESAP	0.044	0.067	0.067
LAC	0.188	0.293	0.318
NAE	0.052	0.063	0.060
SSA	0.062	0.090	0.090
Globe	0.064	0.094	0.098

Source: adapted from Rosegrant *et al.* (2009).
* Regional groupings of countries are as listed in the source.

Results

The results for the IMPACT livestock numbers, reallocated by system type within each FPU to 2050, were re-amalgamated to broad regions: sub-Saharan Africa (SSA), Latin America and the Caribbean (LAC), Central and West Asia and North Africa (CWANA), East and South Asia and the Pacific (ESAP), and North America and Europe (NAE). In the reference run, IMPACT results underscore the shifting growth in cereal and meat consumption from developed to developing countries. Annual demand for meat will increase by between 6 and 23 kilograms per person worldwide by 2050, and the absolute increase is projected to be largest in LAC and ESAP, with demand doubling in SSA. Consequently, the IMPACT model projects large and rapid increases in livestock populations. For example, between 2000 and 2050, the global cattle population is projected to increase from 1.5 billion to 2.6 billion (Figure 7.1), and the global goat and sheep population from 1.7 billion to 2.7 billion.

Table 7.1 presents regional estimates of grazing intensity in the reference world. These were calculated as TLUs (see footnote 13) for bovines, sheep and goats in the rangeland system, per hectare of rangeland system occurring in each region. Ruminant grazing intensity in the rangelands increases in all regions in the reference run, but there are considerable regional variations. In LAC, for instance, average grazing intensities are expected to increase by about 70 percent, from 0.19 in 2000 to 0.32 TLU per hectare in 2050. Most of these increases will result from higher inputs in the grazing systems in the humid and sub-humid savannas. The increases are expected to be lower in CWANA and SSA, and for the latter, grazing intensities are expected to be fairly stable after 2030 – cattle numbers will have peaked by 2040 and there are expected to be fewer in 2050 than in 2030 (see Figure 7.1). Small ruminant numbers by 2050 are not significantly above those for 2030, while at the same time the model indicates some loss of grazing land in SSA to marginal mixed rainfed systems. Grazing intensities change relatively little in NAE. Given typical stocking rates of 10–15 hectares per animal in the arid and semi-arid grazing systems, these results of the reference run imply considerable intensification of livestock production in the humid and sub-humid grazing systems of the world, but particularly in LAC.

Conclusions

Meeting the substantial increases in demand for food will have profound implications for agricultural systems in general and for livestock production systems in particular. For meat in developing countries, increases in the number of animals slaughtered have accounted for 80–90 percent of production growth during the past decade. Although significant improvements in animal yields are projected, growth in numbers will continue to be the main source of production growth. In developed countries in the future, carcass weight growth will contribute an increasing share of livestock production growth as expansion of numbers is expected to slow; numbers may even contract in some regions. For developing countries, livestock production systems will need to intensify if future demand for meat is to be met. In parts of Asia this may continue to involve the industrialization of pig and poultry production systems, while in sub-Saharan Africa the critical role of smallholders in meat and milk production is likely to continue through sustainable intensification, where this can occur (Herrero *et al.*, 2010).

In the analysis reported here, the rate of conversion of rangeland to mixed systems has probably been underestimated. Furthermore, the impact of infrastructural development was not taken into account, so the projected changes in grazing intensities are also likely to be underestimated. The analysis also makes implicit assumptions about the relative share of production that is projected to come from the rangeland versus the mixed systems in the future, in terms of relative animal numbers. Even so, given the fragility of semi-arid and arid rangelands, particularly in sub-Saharan Africa, the massive shifts in production to the wetter and mixed systems that are implied could have considerable environmental impacts in the reference world.

MAPPING METHANE EMISSIONS FROM AFRICAN LIVESTOCK

This example demonstrates how the livestock production systems classification methods described above have been used to quantify methane emissions from livestock. It is taken from Herrero *et al.* (2008). The mapped livestock production systems classification (Version 3) is useful for studies estimating GHG emission from livestock for a number of reasons. First, it permits the quantification of diets for animals in different production systems and distinguishes between different agro-ecologies, which is useful for representing differences in quality and quantity of grass and forage species. Second, it distinguishes system types with very different feeding practices. For example, the diets of animals raised in mixed systems are more complex, comprising a larger number of feed ingredients than do the diets in pastoral systems. The intensity of resource use also varies between different livestock systems. For example, the use of concentrates in mixed systems in the high potential highlands (MRT) is higher than in other systems.

Given that animal numbers, diets and other factors can be projected into the future at different rates of change for different systems, hotspots of increased GHG emissions can be located to help identify system-specific mitigation strategies.

Introduction

Africa has around 250 million cattle and 500 million sheep and goats in a variety of production systems, ranging from pastoralist communities to mixed crop–livestock systems with different levels of intensification (FAO, 2007a). The spatial distribution of these different systems as well as the livestock populations is partially dependent on agro-ecology, market access, access to natural resources, population density and urbanization, as well as cultural determinants (Thornton *et al.*, 2002). These systems and the demand for livestock products are changing rapidly as a result of a range of drivers, which include increasing population density, urbanization, increasing incomes and associated food preferences, climate change and land use change. In Africa, it is expected that the numbers of ruminants will increase substantially to satisfy the growing demand for meat and milk.

Ruminants in different production systems have access to different types and quantities of feeds; they therefore have different levels of production and excretion and emit different quantities of GHGs. Because of a lack of data, however, the Intergovernmental Panel on Climate Change (IPCC) used an average figure of 32 kg methane per TLU (see footnote 13) per year for African ruminants, irrespective of the production system under which they are raised and thus irrespective of their diet (IPCC, 2006). The IPCC study aimed to disaggregate and determine the amounts and spatial distribution of methane emissions from livestock in the different production systems in Africa in 2000 and 2030. The objectives were: 1) to understand the contribution of different production systems to total methane emissions in Africa; 2) to refine the methane emission factors used by the IPCC for further studies; 3) to estimate future emissions accounting for climate change and systems evolution; and 4) to compare GHG emissions from livestock in Africa against those from other sources. Full details of this work are presented in Herrero *et al.* (2008).

Methods

The dynamic estimation of the spatial distribution of methane emissions from ruminant livestock by production system required information on the prevailing production systems, their spatial distribution, and how they are likely to evolve. To this end, seven categories from Version 3 of the mapped livestock production systems classification (Kruska, 2006) were used. Three subsystems were distinguished for rangeland and rainfed mixed agriculture – arid and semi-arid, humid and sub-humid, and temperate/tropical highlands – representing the six main systems in Africa, with other systems pooled into an 'other' category. Recent (2005) estimates of cattle, sheep and goat numbers in each production system were taken from the GLW database (Robinson *et al.*, 2007; FAO, 2007a) and converted into TLUs. The demand for livestock products, estimated from trends in consumption, was derived from FAOSTAT data. Africa was divided into regions, and diets for cattle, sheep and goats were estimated for the different production systems using a set of generic feed types. These were modified by region to represent differences in the main feeds used, their quality and the quantity fed. Dynamic models of digestion in ruminants were used to determine the relationships between what animals consume and the methane that they produce. These models have the advantage that intake can be predicted and can vary depending on diet quality, therefore making the estimations of production, excretion and GHG emissions more accurate.

Results

Table 7.2 presents the methane emission factors estimated by livestock production system and by region. The average emission factor for African domestic ruminants is 31.1 kg methane per year per TLU, which is similar to the value of 32 kg methane per year per TLU, estimated by the IPCC (IPCC, 2006). Overall differences in emission factors between regions, irrespective of production system, were found to be small in range, from only 29 to 33 kg methane per year per TLU. However, depending on the type of production system, emission factors were far more variable, ranging from 23 to 37 kg methane per year per TLU. The largest emissions were found in the more intensive mixed rainfed systems, especially in the humid and tem-

TABLE 7.2 ESTIMATED METHANE EMISSION FACTORS (KG METHANE PER YEAR PER TLU) BY PRODUCTION SYSTEM AND REGION* IN AFRICA

System	Region					Average by system
	East Africa	Southern Africa	West Africa	Central Africa	The Horn + North Africa	
LGA	26	26	21	23	21	**23**
LGH	33	33	27	29	27	**30**
LGT	40	40	34	35	34	**36**
MRA	30	27	25	25	27	**27**
MRH	33	34	32	34	34	**33**
MRT	38	36	36	37	38	**37**
Other	33	33	29	30	38	**37**
Average by region	**33**	**33**	**29**	**30**	**30**	**31**

LGA, LGH, LGT = livestock only arid, humid and temperate systems, respectively.
MRA, MRH, MRT = mixed rainfed arid, humid and temperate systems, respectively.
Other = mixed irrigated systems and the 'Other' and 'Urban' categories.

Source: adapted from Herrero *et al.* (2008).
* Regional groupings of countries are as listed in the source.

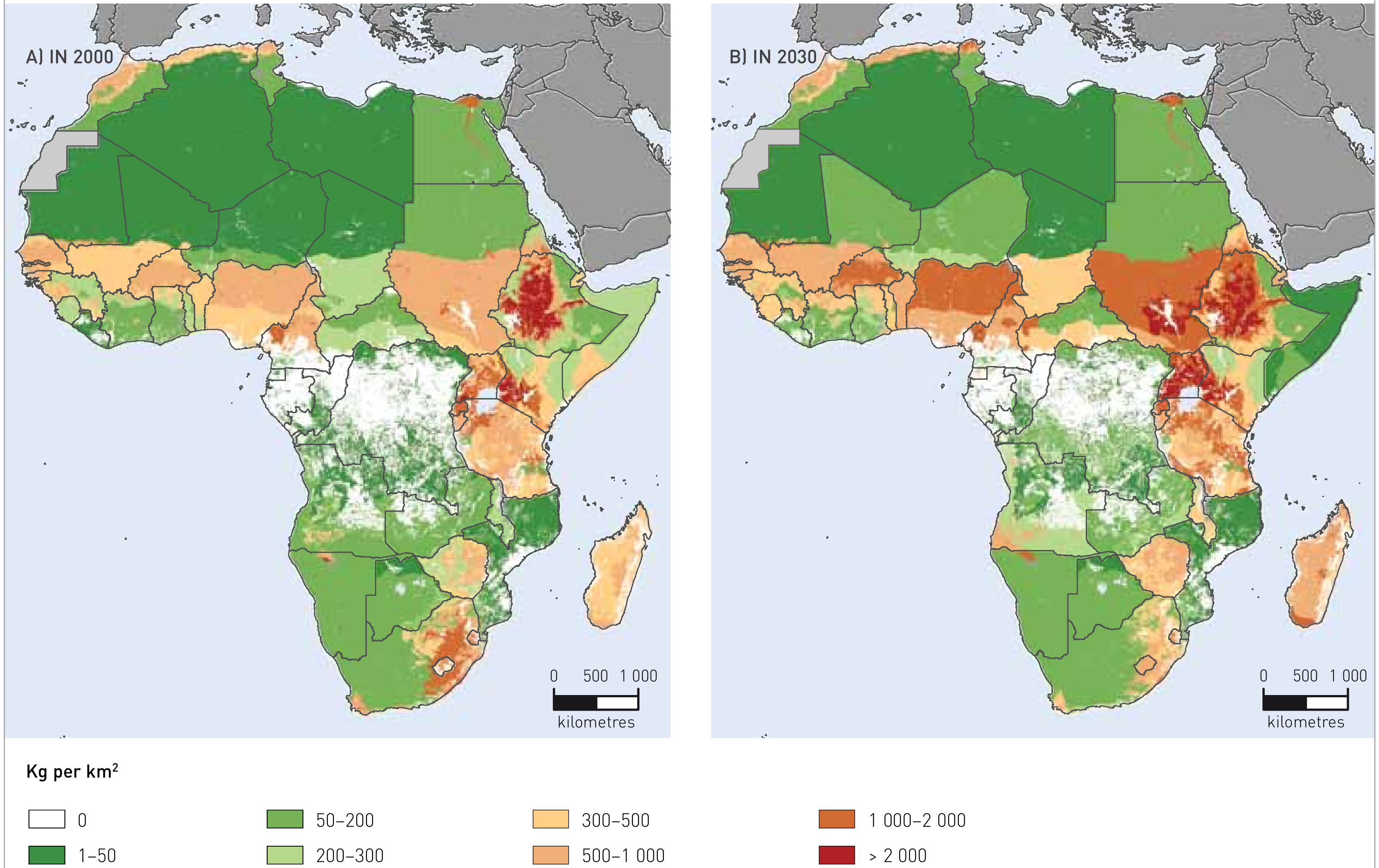
TABLE 7.3 TOTAL METHANE EMISSIONS BY DOMESTIC RUMINANTS IN DIFFERENT LIVESTOCK PRODUCTION SYSTEMS IN AFRICA 2000–2030

Methane from enteric fermentation by livestock production system	2000 Total methane in million kg					2030 Total methane in million kg					Differences 2000–2030 As a proportion of 2000 values				
	cattle	goats	sheep	total	Methane per km²	cattle	goats	sheep	total	Methane per km²	cattle	goats	sheep	total	Methane per km²
LGA	1 704.6	211.8	290.5	2 206.9	123.6	2 187.4	266.2	327.9	2 781.5	157.3	0.28	0.26	0.13	0.26	0.27
LGH	217.7	24.6	14.6	256.9	179.5	261.1	29.4	14.9	305.4	318.8	0.20	0.20	0.02	0.19	0.78
LGT	175.1	9.1	28.5	201.2	772.8	71.6	5.8	18.3	95.7	842.6	−0.59	−0.36	−0.36	−0.52	0.09
Total (LG)	*2 097.4*	*245.4*	*333.6*	*2 665.0*	*136.3*	*2 520.1*	*301.4*	*361.1*	*3 182.7*	*169.7*	*0.20*	*0.23*	*0.08*	*0.19*	*0.24*
MRA	2 190.9	164.2	166.3	2 521.5	650.6	4 273.0	328.1	292.3	4 893.4	986.5	0.95	1.00	0.76	0.94	0.52
MRH	494.2	71.9	38.9	605.1	427.5	804.0	160.8	71.0	1 035.8	587.8	0.63	1.24	0.82	0.71	0.37
MRT	1 120.2	36.6	56.4	1 213.2	1 932.3	885.2	26.8	42.2	954.2	2 958.2	−0.21	−0.27	−0.25	−0.21	0.53
Total (MR)	*3 805.3*	*272.8*	*261.7*	*4 339.8*	*733.2*	*5 962.2*	*515.7*	*405.5*	*6 883.4*	*977.1*	*0.57*	*0.89*	*0.55*	*0.59*	*0.33*
Other	451.0	49.0	41.9	541.9	135.3	614.6	79.3	62.7	756.7	203.5	0.36	0.62	0.50	0.40	0.50
Total methane (enteric fermentation)	**6 353.7**	**567.3**	**637.1**	**7 546.7**	**256.0**	**9 097.0**	**896.5**	**829.3**	**10 822.8**	**366.7**	**0.43**	**0.58**	**0.30**	**0.43**	**0.43**
Total methane from manure	**190.6**	**17.0**	**19.1**	**226.4**	**7.7**	**272.9**	**26.9**	**24.9**	**324.7**	**11.0**	**0.43**	**0.58**	**0.30**	**0.43**	**0.43**
Total methane	**6 544.4**	**584.3**	**656.2**	**7 773.1**	**263.7**	**9 369.9**	**923.4**	**854.2**	**11 147.5**	**377.7**	**0.43**	**0.58**	**0.30**	**0.43**	**0.43**

LGA, LGH, LGT = livestock only arid, humid and temperate systems, respectively.
MRA, MRH, MRT = mixed rainfed arid, humid and temperate systems, respectively.
Other = mixed irrigated systems and the 'Other' and 'Urban' categories.

Source: adapted from Herrero *et al.* (2008).

7.2 THE SPATIAL DISTRIBUTION OF METHANE EMISSIONS FROM AFRICAN DOMESTIC RUMINANTS



Source: adapted from Herrero *et al.* (2008).

perate regions where feed intakes, diet quality and diversity, and production outputs are all higher, and in the temperate rangeland systems, where the quality of the rangelands permits higher feed intakes and production outputs.

The total methane emissions from African domestic ruminants for 2000 and 2030 are presented in Table 7.3. Total methane emissions from cattle, sheep and goats were estimated at 7.8 million tonnes per year for 2000, with 84 percent produced by cattle. This is equivalent to about 3 percent of the methane emissions from all sectors and 10 percent of methane emitted by livestock globally. The projections suggest that this amount will increase to 11.1 million tonnes per year by 2030 – 42 percent more than in 2000 – driven mainly by increases in livestock numbers. The distribution of methane emissions largely follows the livestock distribution. Most emissions come and will continue to come from ruminants in mixed rainfed crop–livestock systems, where the most numerous livestock populations are and for which in some cases the highest emission factors occur. Mixed rainfed systems contributed to 58 percent of the total emissions in 2000. This figure is estimated to increase to 64 percent by 2030, mainly resulting from livestock population increases and intensification of production, driven by population increases and demographic change.

Arid and semi-arid areas contributed 63 percent of the methane emissions from the continent in 2000. In 2030, this figure is projected to increase to 71 percent of total emissions, mainly as a result of production systems changes caused by climate change (reductions in LGP) and increases in livestock numbers.

Though the data are not shown here, the study estimated that the largest methane emissions in 2000 came from The Horn of Africa (2.47 million tonnes per year), followed by West, South, East, Central and North Africa (1.46, 1.39, 1.34, 0.48 and 0.39 million tonnes per year, respectively). These estimates will experience increments of different magnitudes by 2030. For example, methane emissions are likely to increase by 79 percent in West Africa by 2030, while other regions will experience increases ranging from 16 percent (Southern Africa) to 69 percent (Central Africa). Figure 7.2 shows the spatial distribution of methane emissions for 2000 and projected estimates in 2030.

Conclusions

When considering GHG emissions from livestock it is essential to differentiate between systems and regions: large differences occur between the different African livestock production systems. These emissions are governed largely by the distribution of livestock and the ways in which the distribution and abundance is expected to change, to satisfy increasing demand for animal-source food.

Herrero *et al.* (2008) have shown that methane emissions from ruminants, which are the most important sources of methane in Africa, are modest in relation to global estimates of methane estimations from ruminants. That said, GHG emissions from African livestock show some of the largest projected increases compared with those in other parts of the world. Adaptation and mitigation will be essential as Africa adheres to the international protocols for reductions of emissions in the future.

MAPPING THE BENEFITS FROM TRYPANOSOMOSIS CONTROL IN EAST AFRICA

The application described here demonstrates how livestock production system classifications can be used differentially to paramaterize herd models for the purpose of impact assessment – in this case, the impact in terms of monetary benefits of trypanosomosis removal in East Africa. The application is described fully in Shaw *et al.* (in press). The mapped global livestock production systems classification (Thornton *et al.*, 2002; Kruska *et al.*, 2003) was evaluated for the purpose, but was deemed to lack sufficient detail to capture some of the important systems characteristics that would give rise to large differences in the benefits of disease removal – in particular, the use of improved dairy cattle and the use of oxen for draught power. Consequently, an alternative approach to classifying and mapping livestock production systems in the Horn of Africa was developed. Pastoral, agropastoral and mixed farming systems, as described in Cecchi *et al.* (2010) and summarized above, were further characterized to account for dairy and draught power.

The levels of benefits accruing from potential disease elimination were shown to be highly dependent on the particular livestock production system, illustrating the importance of accounting for systems in impact assessment. The approach outlined here for trypanosomosis intervention can readily be applied to other diseases, as long as their impacts on livestock production parameters in the different systems can be estimated with reasonable confidence.

Introduction

In this study, an example is given of how maps of livestock production systems can be used in complex geospatial models whose goal is to prioritize interventions against livestock diseases. The model, which incorporates an econometric component, also illustrates how some studies may need a more detailed characterization of livestock production systems than is presently provided by global datasets.

The study (Shaw *et al.*, in press) focused on African animal trypanosomosis (AAT), or nagana, a parasitic disease transmitted by the tsetse fly (genus: *Glossina*). AAT causes morbidity, mortality and reduced productivity in livestock, especially in cattle, as well as affecting rural development and livelihoods more generally by limiting land use options and hindering a balanced use of natural resources. In Eastern Africa, nagana is present at different levels of endemicity within the areas infested by tsetse. Deciding where and how to intervene against this poverty related disease is a multifaceted problem, requiring that socio-economic dimensions also need to be taken into account.

Methods

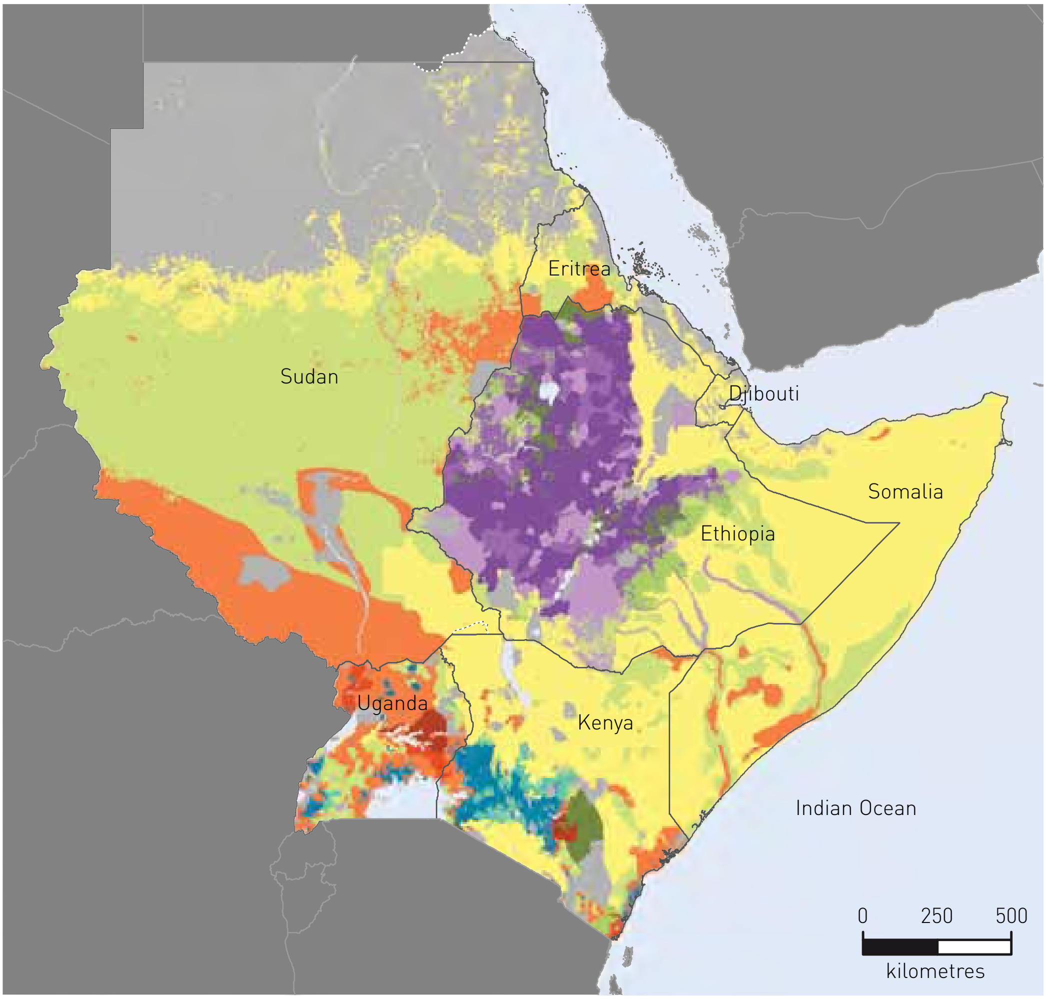
Monetary maps representing the benefits of AAT removal over a 20-year period were generated for countries in the IGAD region, using a series of geospatial datasets and several integrated models. Importantly, a regional map of cattle production systems was needed to give the econometric herd models an explicit geographic dimension. The benefits of AAT removal were estimated by calculating cattle-based income in two different scenarios: with and without AAT.

Regarding mapping of cattle production systems, the starting point was the livelihood-based map of livestock production systems already presented in Figure 6.6a, where the gaps in livelihood data – in parts of Sudan and Ethiopia – were filled through environmental modelling (Cecchi *et al.*, 2010). This was preferred to the mapped global production systems classification mainly because the inclusion of the 'agropastoral' category allowed a more precise definition of system-specific production parameters such as milk yields, calving rates and meat off-take. However, to capture fully the variations in cattle production parameters in this region, categorization in pastoral, agropastoral and mixed-farming systems was still inadequate: further characterization of dairy systems and draught oxen usage was necessary.

To this end two levels of usage of grade cattle for dairy production were defined: low (less than 20 percent of cattle being dairy animals) and high (more than 20 percent). Similarly, three levels of usage of oxen were distinguished: low (less than 10 percent of cattle being draught oxen), medium (between 10 and 20 percent), and high (more than 20 percent). Because of the specificities of oxen usage in Ethiopia, a separate set of production parameters was defined for mixed farming in this country.

Overall, 12 cattle production systems were defined and mapped. Each was then characterized in terms productivity by setting herd parameters under both scenarios: with and without AAT.

7.3 CATTLE PRODUCTION SYSTEMS IN EASTERN AFRICA



Pastoral

Agro-pastoral
Low oxen
Medium oxen
High oxen
High dairy

Mixed farming (general)
Low oxen
Medium oxen
High oxen
High dairy

Mixed farming (Ethiopia)
Low oxen
Medium oxen
High oxen

Unsuitable for ruminants

Source: adapted from Shaw *et al.* (in press).

TABLE 7.4 KEY BASELINE INPUT PARAMETER FOR BASIC CATTLE SYSTEMS WITH AND WITHOUT (SHOWN IN BRACKETS) AAT

Parameter	Basic system				
	Pastoral	Agro-pastoral	Mixed general	Mixed Ethiopian region	Grade dairy
Mortality (% per year)					
Female calves	20 (17)	18 (15)	16 (13)	24 (20)	21 (18)
Male calves	25 (22)	20 (17)	18 (15)	26 (22)	26 (23)
Adult females	7 (6)	7 (6)	8 (7)	9 (7)	12 (10)
Work oxen	9 (7)	8 (7)	9 (7)	10 (8)	n.a.
Fertility and milk					
Calving rate (% per year)	54 (58)	52 (56)	51 (55)	49 (54)	53 (57)
Lactation off-take (litres per year)	275 (296)	285 (306)	300 (322)	280 (301)	1 900 (2 042)
Days oxen work per year	80 (88)	100 (108)	130 (139)	80 (86)	0 (0)

Source: adapted from Shaw *et al.* (in press).

Results

The map in Figure 7.3 shows the 12 cattle production systems used as a stratification scheme for subsequent econometric modelling.

Table 7.4 shows the model parameters assigned to the 5 basic systems in the two different scenarios: with and without AAT.

The map of cattle production systems and the related production parameters were used for subsequent geospatial modelling, which included herd growth and spatial spread of cattle over a 20-year period. The final outputs of the model were then presented as a map of the financial benefits that would be realized from AAT removal, expressed as US$ per km^2 (Figure 7.4).

Conclusions

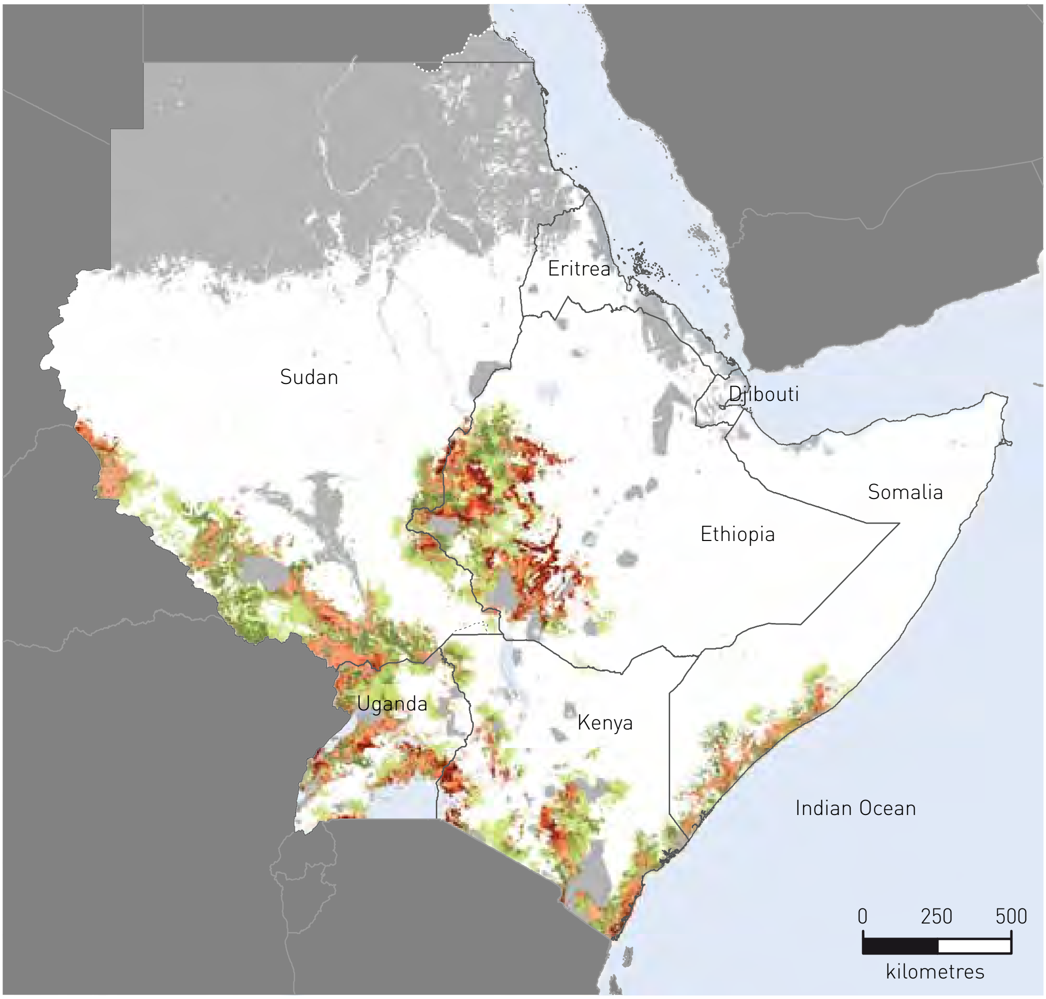
The map of benefits from trypanosomosis removal in the Horn of Africa can assist decision-makers to prioritize interventions by highlighting areas where the financial return on investment is highest. The study also illustrates how information on livestock production systems can be combined with econometric and agro-ecological modelling in a spatially explicit framework. However, results also demonstrate that global maps of livestock production systems still fall short of distinguishing livestock production systems in sufficient detail for such modelling. In this example, the definition and mapping of additional production system details was needed in order to capture, at least in part, the key mechanisms through which livestock contribute to livelihoods in Eastern Africa. In particular, adequate consideration for dairy animals and draught oxen was essential to describe the monetary value of cattle in the region.

This research clearly points to challenges in developing global maps of livestock production systems capable of incorporating, or being linked to, quantitative production parameters. It also describes how these shortcomings in the global datasets might be addressed, at least at a regional level.

DISTRIBUTION OF RURAL POOR LIVESTOCK KEEPERS

This final example demonstrates how maps of livestock production systems have been used to estimate the distribution of 'rural poor livestock keepers': rural people who fall below the poverty line and who also keep livestock. Given the limited general availability of detailed subnational poverty data, using a global livestock production system classification (Thornton *et al.*, 2002; Kruska *et al.*, 2003)

7.4 THE MAPPED BENEFITS FROM THE REMOVAL OF AFRICAN ANIMAL TRYPANOSOMOSIS (AAT) IN THE HORN OF AFRICA



US$ per km² over a 20 year period

- > 12 500
- 10 000–12 500
- 7 500–10 000
- 5 000–7 500
- 2 500–5 000
- 1 000–2 500
- 500–1 000
- 10–500
- <10
- Unsuitable for ruminants

Source: adapted from Shaw *et al.* (in press).

presents a way in which this can be done, albeit in an extremely approximate fashion. For targeting purposes, even a rough understanding of where rural poor livestock keepers may be located can be of considerable value. Poverty rates at the national level are regularly updated by the Word Bank and are published in documents such as the annual Human Development Report. These poverty data cannot simply be overlain on livestock population data and human population data: not all rural people keep livestock, and not all rural people are poor. The major challenge is, how can rural populations be characterized in a way that would allow some useful information to be generated about where resource-poor livestock keepers are likely to be located? This has been achieved at ILRI (Thornton *et al.*, 2002; 2003) using data that were published by LID (1999). This allowed the estimation of proportions of poor livestock keepers as a percentage of the total poor, by livestock production system. It might reasonably be supposed that a larger proportion of people in the rangeland systems keep livestock than in the more intensive mixed systems, for example. Similarly, we can suppose that a larger proportion of livestock keepers in the rangelands in many parts of the world are poorer than livestock keepers who live in the wetter, more productive mixed systems. Indeed, many detailed poverty studies bear out these assumptions. As well as being closely linked to poverty rates in rural areas, the livestock production system classification allows different rates of livestock ownership to be applied to rural populations in a systematic way. As the coverage of detailed poverty data increases, our estimates of where the poor livestock keepers are located should improve in accuracy; but without a systems' classification, a generalized breakdown of the existing data would be almost impossible.

Introduction

Many research and development organizations have a focus on poverty reduction, which means there is a need continually to reassess how they should best operate to benefit poor people. Livestock are often extremely important for the diets and incomes of the rural poor. Understanding the role of livestock in poor people's lives, and how this role may evolve in the future in relation to a raft of drivers of global change, are issues that deserve considerable attention.

How can pro-poor livestock-related research and development activities best be targeted? To answer this question we need information on: the ways in which livestock contributes to the livelihoods of poor people; where significant groups of poor livestock keepers are located; how these populations are likely to change in size and location through time; and, how their physical environments may be expected to change in the future. The availability of information on such issues is patchy at best. In-depth study of communities in terms of sustainable livelihoods and vulnerability can provide very useful information locally, but there is often a need for poverty assessments at national, regional and even continental levels, to assist in targeting research and development activities that can have an impact on large numbers of poor people. Such assessments cannot easily use case study methods because of the problems of generalization; instead, they need to rely on broader-scale approaches.

The objective of the work outlined below was to estimate the number of rural poor livestock keepers globally, and to produce maps that locate significant populations of these people. This work was originally carried out for the United Kingdom Government's Department for International Development (Thornton *et al.*, 2002; 2003). Here, we present the results of an updated analysis using human population estimates for 2010, national and international poverty estimates for 2010, and a more recent version of the global livestock production systems maps.

Methods

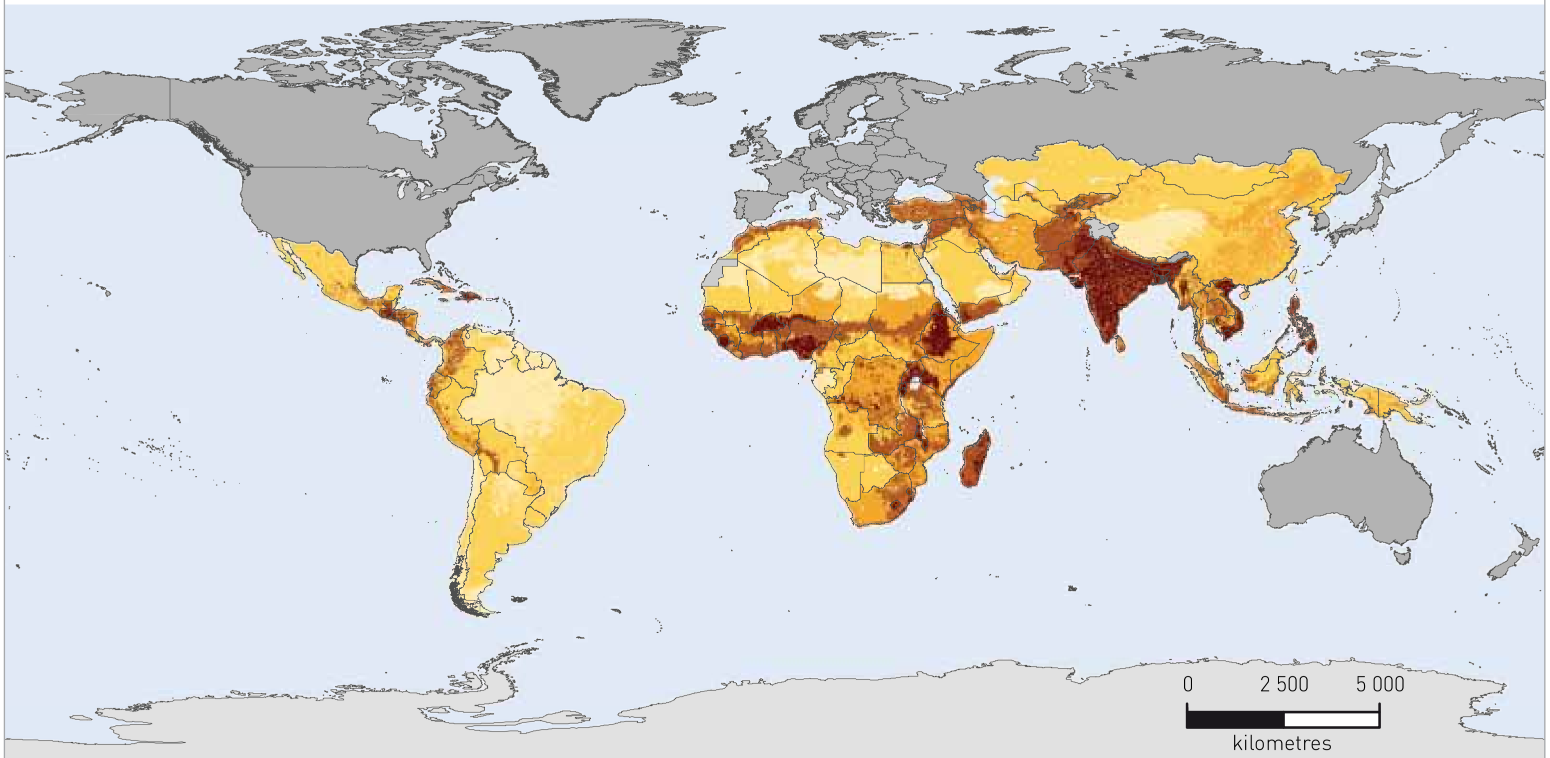
A central element of the analysis is the mapped global livestock production systems classification described in previous sections (Thornton *et al.*, 2002; Kruska *et al.*, 2003). The mapping of the classification is based primarily on land use, climate, and human population density, the latter because of the strong association between people and livestock. For these livestock systems, poverty data were attached to produce a set of poverty maps by production system and by country.

Given existing data constraints, global poverty maps still need to be based on national-level poverty rates. Case studies and more detailed country data show a higher incidence of poverty in sparsely populated and remote areas (measured by the headcount, the percentage of poor living below a poverty line) and sometimes in low potential, marginal agricultural areas. However, these spatial patterns do not appear in other locations, and not enough quantitative data yet exist to generalize over regions or to identify other general patterns. Even with national level data and with poverty measures based on household income and expenditure surveys, there is still significant room for variation in the relative and absolute numbers of poor. A major reason for these differences in the number of poor is the choice of poverty line: the threshold in income or consumption below which a household is classified as poor. Internationally comparable lines, such as the widely cited 'US$1 per day', are useful for producing continental and global totals. Data based on an international poverty line thus show the number of people that cannot purchase a roughly similar basket of necessities (World Bank, 2001). National poverty lines are needed to capture intracountry differences in economic and social status and to assess progress at a national scale. Poverty lines differ between countries and even within countries, to reflect differences in the cost of living between urban and rural areas, for example.

In the original study (Thornton *et al.*, 2002; 2003) several different data sets and poverty lines were evaluated, including the national estimates of the rural population living below the poverty line (World Bank, 2001), to compare differences in the number of poor. For the comparison with the original study, national rural poverty rates from the 2009 World Development Report (World Bank, 2009) were used. As in the previous work, reasonably recent country-level poverty data do not exist for all countries within each region. A regional population weighted average was estimated for each region and then applied to the countries with no data. It is important to note that in the original analysis (Thornton *et al.*, 2002; 2003) the high population densities associated with urban areas were not allocated to urban extents, but in this analysis the 2000 estimates of the numbers of poor livestock keepers were revised using only rural population data, which were not available at that time. This approach will tend to underestimate poor livestock keepers, because urban livestock keepers are not included. On the other hand, it corrects the problem with the older data that included urban populations and which therefore tended to overestimate the number of poor livestock keepers.

Being an average figure, the national (rural) poverty rate is not going to be equally applicable across all systems or areas within any country. However, disaggregating by livestock production system, it is possible to show numbers of poor by livestock production system, but this is only one step towards representing the distribution of poverty among livestock keepers. Poverty rates will clearly differ within and between production systems. The proportional importance of livestock to household incomes differs from one culture to another and among production systems. For example, mixed crop–livestock farmers have multiple opportunities to obtain income from a variety of sources; so, income from livestock probably contributes a smaller proportion to their household food basket. By contrast, many pastoralists depend on livestock for a large proportion of their income. A map of poverty among livestock keepers needs to account for the importance of livestock to income at the household level. At the global level, information on the importance of livestock to rural livelihoods does not exist. The approach taken has been to use differential proportions of poor livestock keepers, with respect to the total number of poor, by livestock production system. Estimates of the numbers of poor livestock

7.5 DENSITY OF RURAL POOR LIVESTOCK KEEPERS IN 2010, USING RURAL, NATIONAL POVERTY LINES, TAKEN FROM WORLD BANK (2011)



Poor livestock keepers per km²

< 0.2 | 0.2–2 | 2–5 | 5–20 | > 20

keepers in different systems were taken from LID (1999), which had been derived from poverty statistics from UNDP (1997) and other studies on livestock ownership patterns (LID, 1999). Using these data for extensive graziers (which were equated with the three livestock-only rangeland-based systems of the mapped global livestock production systems), poor rainfed mixed farmers (the three mixed rainfed systems), and landless livestock keepers (into which category all the remaining systems were lumped), the proportions of the numbers of poor people who are livestock keepers was derived in each system: 76 percent for the rangeland-based systems, 68 percent for the mixed rainfed systems, and 26 percent for the mixed irrigated and all other systems. These proportions were then applied to the numbers of poor in each system using the nationally-defined rural poverty rates.

Results

Figure 7.5 presents the density of poor livestock keepers defined as above. This updates the maps in Thornton *et al.* (2002; 2003) using: 1) 2010 rural population data; 2) updated national, rural poverty rates; and 3) a slightly different method that excludes the urban areas from the calculations. Some details have changed, but the overall impression is the same: there are particularly high densities of rural poor livestock keepers throughout South Asia (India, Pakistan and Bangladesh), and in parts of sub-Saharan Africa (particularly Nigeria, Ethiopia, Uganda, Burundi, Rwanda, Malawi, and in some systems in Kenya, South Africa and Niger). The highest densities occur mostly in the mixed crop–livestock systems: irrigated mixed systems in parts of South Asia, and the rainfed mixed systems in parts of India and in most of sub-Saharan Africa.

Regional estimates of the numbers of rural people and of poor livestock keepers in 2010 are presented in Table 7.5 and are compared with estimates for 2000, revised from Thornton *et al.* (2002). Globally, the number of poor livestock keepers has increased by 56 million (15 percent) in eight years, bearing in mind that the 2000 estimates here have been corrected to include only the rural populations, with respect to those presented in Thornton *et al.* (2002). While the numbers have declined in Latin America and the Caribbean and in East Asia and the Pacific, all other regions have seen an increase; in sub-Saharan Africa, the number has risen by 38 percent to more than 170 million.

Looking at the annualized rates of change in Table 7.5 shows that the numbers of poor live-

TABLE 7.5 ESTIMATES OF RURAL POPULATIONS AND OF RURAL POOR LIVESTOCK KEEPERS (PLKs) IN 2000 AND 2010 (ALL FIGURES ARE IN MILLIONS), USING RURAL, NATIONAL POVERTY LINES, AND THE COMPOUNDED, ANNUALIZED RATE OF CHANGE IN POOR LIVESTOCK KEEPERS FROM 2000 TO 2010

Region	Rural population		Rural PLKs		Annual change in PLKs,
	2000	2010	2000	2010	2000 to 2010
East Asia and Pacific	1 148	1 020	64	52	**−2.05%**
China	*808*	*714*	*15*	*13*	***−1.42%***
Eastern Europe and Central Asia	60	64	9	13	**3.75%**
Latin America and Caribbean	155	115	36	31	**−1.48%**
Middle East and North Africa	96	130	14	22	**4.62%**
South Asia	916	1 100	130	142	**0.89%**
India	*672*	*820*	*95*	*99*	***0.41%***
Sub-Saharan Africa	442	532	123	171	**3.35%**
All regions	**2 817**	**2 961**	**376**	**431**	**1.40%**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.
Data for China and India also included separately.

TABLE 7.6 ESTIMATES (IN MILLIONS) OF RURAL POOR LIVESTOCK KEEPERS IN 2010 BASED ON: A) NATIONAL, RURAL POVERTY LINES; B) INTERNATIONAL POVERTY LINES FOR THE VERY POOR (< US$1.25 PER DAY INCOME); AND C) FOR THE POOR (< US$2.00 PER DAY INCOME). POVERTY RATES USED ARE FROM WORLD BANK (2011)

Developing Region	Rural poor livestock keepers (2010)		
	National rural poverty line*	International	
		< US$1.25 per day	< US$2.00 per day
East Asia and Pacific	51	70	172
China	*7*	*47*	*106*
Eastern Europe and Central Asia	17	7	12
Latin America and Caribbean	29	5	10
Middle East and North Africa	23	7	13
South Asia	151	179	330
India	*107*	*143*	*259*
Sub-Saharan Africa	165	161	229
All regions	**436**	**429**	**766**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.
Data for China and India also included separately.

* These figures differ somewhat from those presented in Table 7.5 as they have been further updated using the most recent national poverty lines (World Bank 2011) making them comparable to the estimates based on the international poverty lines.

stock keepers globally have increased at a rate of about 1.4 percent per year – reductions in the numbers in East Asia and the Pacific, and Latin America and the Caribbean, being offset by considerable increases in the numbers of poor livestock keepers in all other regions. The numbers have been increasing particularly in Eastern Europe and Central Asia, the Middle East and North Africa and sub-Saharan Africa, with annual increases of 3.75, 4.62 and 3.35 percent, respectively.

In terms of the absolute numbers of poor livestock keepers, South Asia and sub-Saharan Africa dominate: 72 percent (making reference now to the revised estimates in Tables 7.6 and 7.7) of the estimated 436 million poor livestock keepers live in these two regions. While the 'livestock only' systems (based on land cover data as described in Thornton *et al.* (2002)) contain relatively few poor, most of these households are heavily dependent on livestock for their livelihoods. Almost half (47 percent) of the 65 million poor livestock keepers in livestock-only systems globally – 31 million people – are located in sub-Saharan Africa. The mixed systems contain large numbers of poor (over one billion), and the number of poor people who depend to some extent on livestock is considerable; the mixed irrigated and mixed rainfed systems host some 351 million poor livestock keepers. Furthermore, large numbers of poor non-livestock keepers also depend on livestock for their livelihoods, through engagement in the supply of inputs, services and product marketing.

As the international poverty lines do not distinguish urban from rural poverty, they are not ideal for estimating poor livestock keepers, since poverty rates usually differ so much between urban and rural areas. However, the major drawback with national poverty lines is that they are not standardized across countries, so comparisons between countries and across different regions may be invalid. In order to address this problem the numbers of poor livestock keepers have also been estimated using recent international poverty lines (Chen and Ravallion, 2008; Ravallion, 2009), allowing us to compare the estimates of poor livestock keepers based on national, rural poverty lines, and those based on the international poverty lines for the poor (< US$2.00 per day income) and the very poor (< US$1.25 per day income). The summary results are shown in Table 7.6.

Estimates based on the national poverty lines tend to be closer to those based on the US$1.25 per day line, though there are exceptions: national estimates for China are vastly lower than the international estimates, and national estimates for LAC and MENA are more than double those based on the upper international rate. A striking figure from Table 7.6 is that shifting the poverty line from US$1.25 per day to US$2.00 per

TABLE 7.7 REGIONAL ESTIMATES (IN THOUSANDS) OF RURAL POOR LIVESTOCK KEEPERS (PLKs) IN 2010 BY LIVESTOCK PRODUCTION SYSTEM BASED ON A) NATIONAL, RURAL POVERTY LINES (NRP); B) INTERNATIONAL POVERTY LINES FOR THE VERY POOR (< US$1.25 PER DAY); AND C) FOR THE POOR (< US$2.00 PER DAY). POVERTY RATES WERE TAKEN FROM WORLD BANK (2011)

Region	Livestock production systems										
	LGA*	LGH	LGT	MRA*	MRH	MRT	MIA*	MIH	MIT	Other	Rural PLKs
EAP											
NRP	42	1 082	797	1 476	30 808	3 544	155	6 558	962	5 602	51 026
$1.25	304	598	2 667	902	27 511	17 959	63	4 385	5 442	10 654	70 483
$2.00	713	1 449	5 814	2 164	70 361	41 150	151	13 521	12 363	24 780	172 467
EECA											
NRP	2 274	1	3 143	4 378	144	4 899	445	22	831	827	16 964
$1.25	1 386	< 1	2 451	1 028	26	927	319	2	733	86	6 959
$2.00	2 597	< 1	4 135	2 067	62	1 381	599	8	1 226	250	12 325
LAC											
NRP	2 457	1 213	970	2 378	12 758	3 858	199	254	119	4 366	28 572
$1.25	186	152	163	293	3 036	725	20	47	12	702	5 336
$2.00	475	312	336	681	5 255	1 366	54	94	33	1 475	10 080
MENA											
NRP	11 885	< 1	46	8 197	34	500	2 456	9	6	317	23 451
$1.25	4 633	< 1	25	1 878	12	107	475	3	3	93	7 229
$2.00	7 002	< 1	13	4 304	16	181	1 602	4	2	189	13 311
SA											
NRP	9 722	23	426	55 029	22 465	1 929	33 895	14 204	64	13 424	151 180
$1.25	4 949	31	57	68 029	28 886	1 922	40 976	17 152	63	16 915	178 982
$2.00	11 651	56	90	125 816	51 288	3 609	77 135	29 168	106	30 932	329 852
SSA											
NRP	22 582	7 456	653	51 394	41 647	28 343	432	139	179	11 701	164 525
$1.25	14 503	7 054	531	52 274	49 405	25 472	287	139	159	10 898	160 724
$2.00	20 542	9 454	746	72 317	68 157	41 622	412	188	268	15 036	228 742

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.
* Hyper-arid and arid zones have been merged for this regional analysis.

EAP = East Asia and the Pacific; **EECA** = Eastern Europe and Central Asia; **LAC** = Latin America and the Caribbean;
MENA = Middle East and North Africa; **SA** = South Asia; **SSA** = Sub-Saharan Africa.

day approximately doubles the number of poor livestock keepers – showing the large numbers of people who fall into this marginal ground.

Appendices B to F present the estimates of poor livestock keepers by country and livestock production system using these three different poverty lines: 1) national, rural; 2) international US$1.25; and 3) international US$2.00. Table 7.7 provides a summary of these estimates, by the World Bank developing regions. It shows that numbers of poor livestock keepers are generally highest in the mixed rainfed systems. The mixed irrigated systems of South Asia are the only exception to this pattern as they also concentrate large numbers of rural poor livestock keepers. As observed earlier, more effort is needed to characterize fully the 'other' category of the global livestock production systems: large numbers of poor livestock keepers fall into this loosely defined system, and clearer definitions here would assist in assessing and addressing their needs.

Conclusions

In terms of the numbers of poor and our estimates of the numbers of poor livestock keepers, based on national, rural poverty lines for 2010, the critical regions are still South Asia and sub-Saharan Africa. Some 71 percent of the estimated 430 million poor livestock keepers live in these two regions, up from 66 percent a decade earlier. While the rangeland systems contain relatively few poor, most of these households are dependent on livestock for their livelihoods. Half of the poor livestock keepers in rangeland systems globally are located in sub-Saharan Africa: nearly 60 million, based on national, rural poverty lines. The mixed systems contain large numbers of poor (over one billion), and the number of poor people who depend to some extent on livestock is considerable: the mixed irrigated and mixed rainfed systems are estimated to host more than 300 million poor livestock keepers based on national and international US$1.25 per day poverty lines, and double that many based on the international US$2.00 per day poverty lines.

Despite their obvious limitations and coarseness, the data presented on locations and densities of poor livestock keepers can still provide information of considerable use. The current information continues to be used at ILRI to prioritize and focus livestock research, and to help identify 'hotspots' at the global and regional levels that can then be investigated in more detail at higher resolution. Such hotspots can be defined in various ways depending on the purpose: as areas of high population densities of poor livestock keepers, or areas of high densities of poor people coupled with high levels of biodiversity or natural resource degradation, for example. Such information is critical for informing action agendas concerning livestock, development, and global change.

The livestock development community is dependent to a large extent on efforts by national governments and the World Bank to provide reliable estimates and updates of poverty rates. Clearly, though, the choice of poverty measure has a quite dramatic impact on the estimates of poor livestock keepers. While the international lines have the advantage that some attempt has been made to standardize them, allowing data to be merged and comparisons to be made across countries, their failure to distinguish rural from urban poverty rates is a major drawback in this context.

Estimates of poor livestock keepers are also highly sensitive to the livestock ownership rates used in the calculations. It is likely that considerable improvements to the LID (1999) estimates of livestock ownership could be made by investigating alternative information resources. Housing and population censuses sometimes contain information on livestock ownership, as do agricultural censuses. These also offer the possibility to distinguish ownership of different types of livestock, and to link this information explicitly to the global livestock production systems. Potentially the most valuable resource, however, are the living standards measurement surveys. For smaller samples of households these surveys usually contain information on livestock ownership and often contain information on proportional income derived from livestock activities. Moreover, being the data on which poverty maps are based, they offer the possibility to link livestock ownership and income explicitly to poverty at the level of the household. Armed with this information, the assumptions made in the approach described above – that livestock ownership is equally likely regardless of poverty level, and that people are equally likely to be poor, regardless of whether they own livestock – need not be made. Instead, these factors can be accounted for in the analysis. Better estimates of livestock ownership will greatly improve the precision of our estimates of livestock keepers in general, and poor livestock keepers in particular, and further contribute to spatial targeting and impact assessment.

8 Conclusions and future developments

The previous sections have reviewed the history of livestock production systems classifications and some of the attempts to map them. Examples have been presented that illustrate the diverse range of applications to which such maps have been put, and which by so doing emphasize how important it is to improve these estimates if we are to target more appropriately both the opportunities and risks that the livestock sector presents in the social, public health and environmental domains. Moreover, with the rapidly increasing demand for livestock products currently being experienced across the world, we need to develop systems that can be readily and frequently updated to monitor how livestock production systems are changing in response to growth.

The starting point for most of the attempts to define and map livestock production systems has been the classification system developed by Seré and Steinfeld (FAO, 1996). For its intended purpose, with no plan to present the data in a spatial context, the largely farm-based definitions of the systems present no problems. However, while the agroclimatic elements in the definition (LGP) can be mapped readily, the classification they adopted cannot be mapped in its entirety because spatial data on some key elements (e.g. the amount of dry matter fed to animals that comes from crop by-products) are simply not available. The spatial renditions of these systems have been a compromise resulting from the use of global spatial datasets (land cover, human population density and irrigation) to proxy the farm-based definitions (feed origins, stocking rates, the proportional value of livestock activities, and the proportional value of rainfed versus irrigated land use). Perhaps the proximity of the categories mapped by Thornton *et al.* (2002), subsequent developments thereof (Kruska *et al.*, 2003; Kruska, 2006); and the most recent, presented here, to the Seré and Steinfeld systems has in the past been overemphasized. First, the systems mapped by Thornton *et al.* (2002) can be more accurately described as estimating the 'potential' livestock production systems, since they incorporate no information on the actual distribution and abundance of livestock. Second, their mapping accuracy is heavily dependent on that of crop datasets derived from global land cover maps. As we have seen, these are remarkably variable and often inaccurate, to the extent that much of the use of other GIS layers in the Thornton *et al.* (2002) mapping is simply to overcome inaccuracies in the crop extent estimated from global land cover layers. (For example, if the crop layer were accurate, population density and LGP would not be required to reassign non cropland pixels to the mixed farming class.) Third, Thornton *et al.* (2002) do not exactly depict areas where livestock do occur (either with or without cropping) but rather areas where livestock 'may' occur. Therefore only information on livestock distribution can bridge the gap between 'potential' and 'actual' livestock production systems (Section 4).

All land use systems, including livestock production systems, can be seen as mosaics of different units of land cover and land use interconnected by spatial and functional relationships. This implies that efforts to classify livestock production systems cannot be disconnected from current efforts to develop standardized classification systems for land cover, land use, and land use systems. High resolution standardized land cover maps such as those developed by the Africover project offer an opportunity to move in this direction. These data have already been integrated with the global map of livestock production systems (Version 5), but without fully exploiting the thematic and spatial detail of this information. Although the limited and patchy availability of these high resolution land cover data make them directly useful, mainly at national or regional level, it is expected that they will guide conceptual developments also applicable to global level mapping.

Arguably, at the scale of Africover (approximately 1:100 000 to 1:200 000 – which roughly corresponds to 100 metres of spatial resolution) a substantially different mapping approach can be developed. First, these kinds of land cover data, although not perfect, provide a more reliable source of land cover information, particularly of crop cover. Hence, the current adjustments to cropland layers (e.g. those based on human population and LGP) would not be needed. Second, working with high resolution land cover maps brings to the fore the concept of scale. What is the range of scale at which livestock production systems can be meaningfully mapped? Is there a minimum mapping unit? Does this differ between production systems? And then, what are the practical implications for the mapping process?

As already discussed in the text, the gap between potential and actual systems is to be filled by integrating information on the distributions of different types of crop and livestock. A more discerning inclusion of crop data is needed if realistic mixed farming systems are to be mapped. Not all crops and not all cropping systems lend themselves to being integrated into a mixed-farming system, where the association between crops and livestock is not only spatial but functional. Ultimately, integrating information on livestock species and crop types allows us to move closer to the objective of better understanding global land use and livestock production systems. Such integration also implies the need for better harmonization between mapping livestock production systems and modelling of livestock distribution and abundance, which should address the suite of spatial data and methods used to map livestock production systems and livestock densities.

Understanding where intensification of livestock production is occurring now, and is likely to occur in the future, as demand for animal-source food in developing countries continues to grow, is important for many reasons. Three diverse methods were presented here to identify areas of intensive livestock production. However, further advancements are needed for more accurate mapping, especially because these are the areas where changes are occurring more rapidly. This would provide invaluable information for all studies on the relationships between intensifying systems and livelihoods and poverty, human and animal diseases, and environmental impacts of livestock production.

Finally, the outstanding issue of validation cannot be overlooked. As already observed by Rosegrant *et al.* (2009) only limited evaluation of the livestock production systems maps has been made. Some of the challenges in the validation of global maps are easy to picture, and include issues of definitions, data availability, resolution, statistical robustness and geographical coverage. We may still be a long way from a fully satisfactory validation of the global maps of livestock production systems. However, the slate is not blank and the available evidence is promising. A regional study summarized in this book, and covering six countries in Eastern Africa (Cecchi *et al.*, 2010) indicated that there is remarkable correspondence between global outputs based on proxy geospatial layers, and maps of pastoral, agropastoral and mixed farming systems independently derived from livelihood analysis. This regional study also highlights what should probably be a common feature of future validation efforts: to shed light on the relationship between environmental factors driving global mapping efforts, and socio-economic dimensions shaping the true nature of production systems on the ground. Meta-analyses and expert evaluation (e.g. through geo-wiki systems) might provide relatively easy and affordable solutions for global validation.

Sachs *et al.* (2010) call for a new global data collection and dissemination network to track the many impacts of different farming practices on the environment. There are considerable challenges ahead if the global population is to be fed sustainably and healthily in 2050. Classifying and mapping global agricultural production systems is not an end in itself, but is a necessity if we are to evaluate efficiently different technology and policy options, and to target effectively where they may be applicable.

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10 Appendices

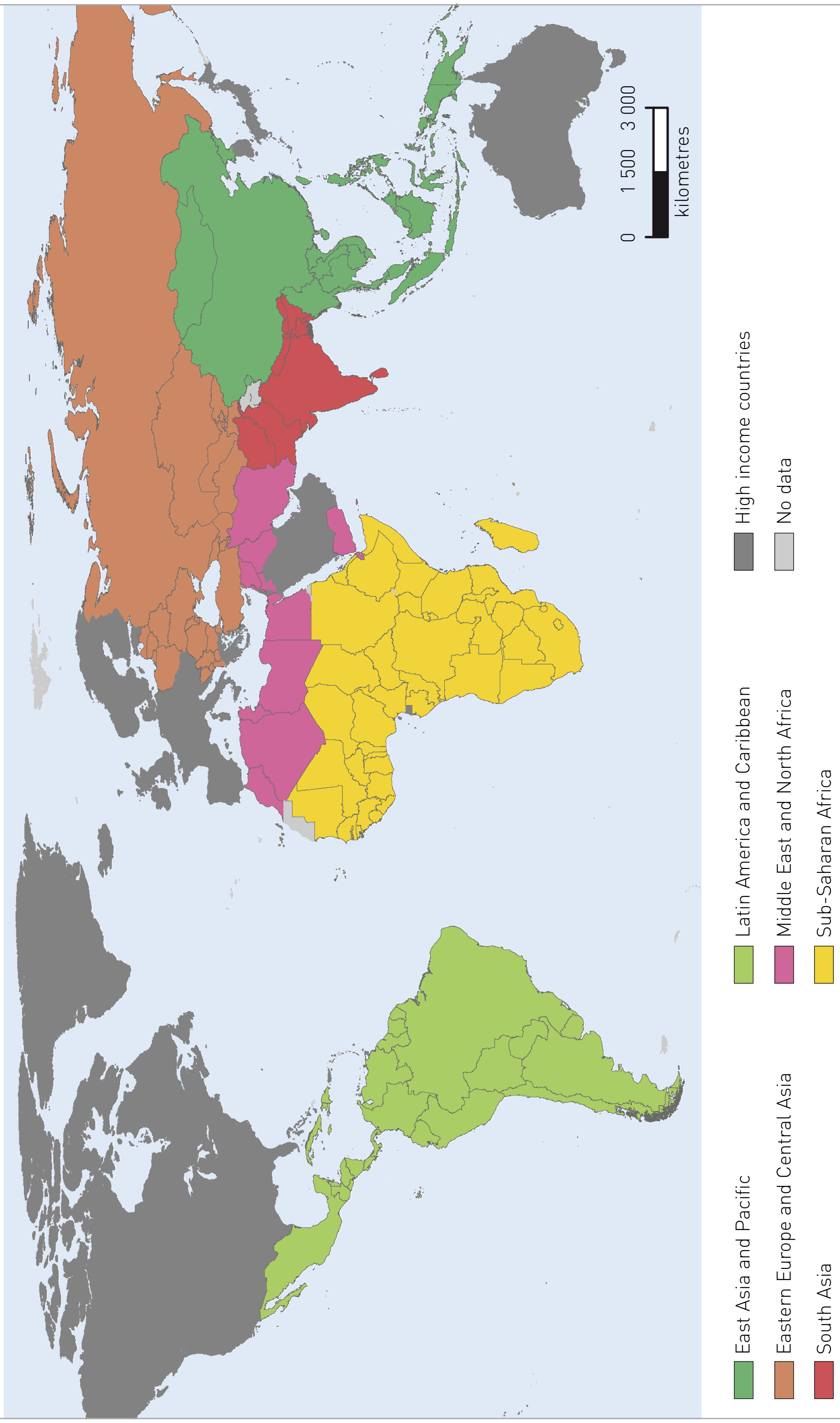
These appendices provide regional views of the distribution of livestock production systems and detailed tables with numbers of rural poor livestock keepers. Appendix A lists the 2010 World Bank regions and related country income groupings that were used in the analysis (World Bank 2010).

Appendices B to G open with regional maps of livestock production systems. The livestock production systems used in the appendices are those from Version 5, described in Section 3 of this publication (see Table 3.1). For the purpose of this analysis of rural poor livestock keepers, the hyper-arid and arid production systems were aggregated into a single arid category. These appendices then provide detailed tables of the numbers of rural poor livestock keepers by country and by livestock production system. The spatial distribution of the rural population is derived from the GRUMP dataset (CIESIN, 2005), which was adjusted to match the 2010 UN rural and urban population totals for each country. The tables contain estimated numbers of rural poor livestock keepers using poverty rates based on three different poverty lines: 1) national, rural; 2) international US$1.25 (extreme poor); and 3) international US$2.00 (poor). Poverty rates were taken from World Bank (2011).

APPENDIX A

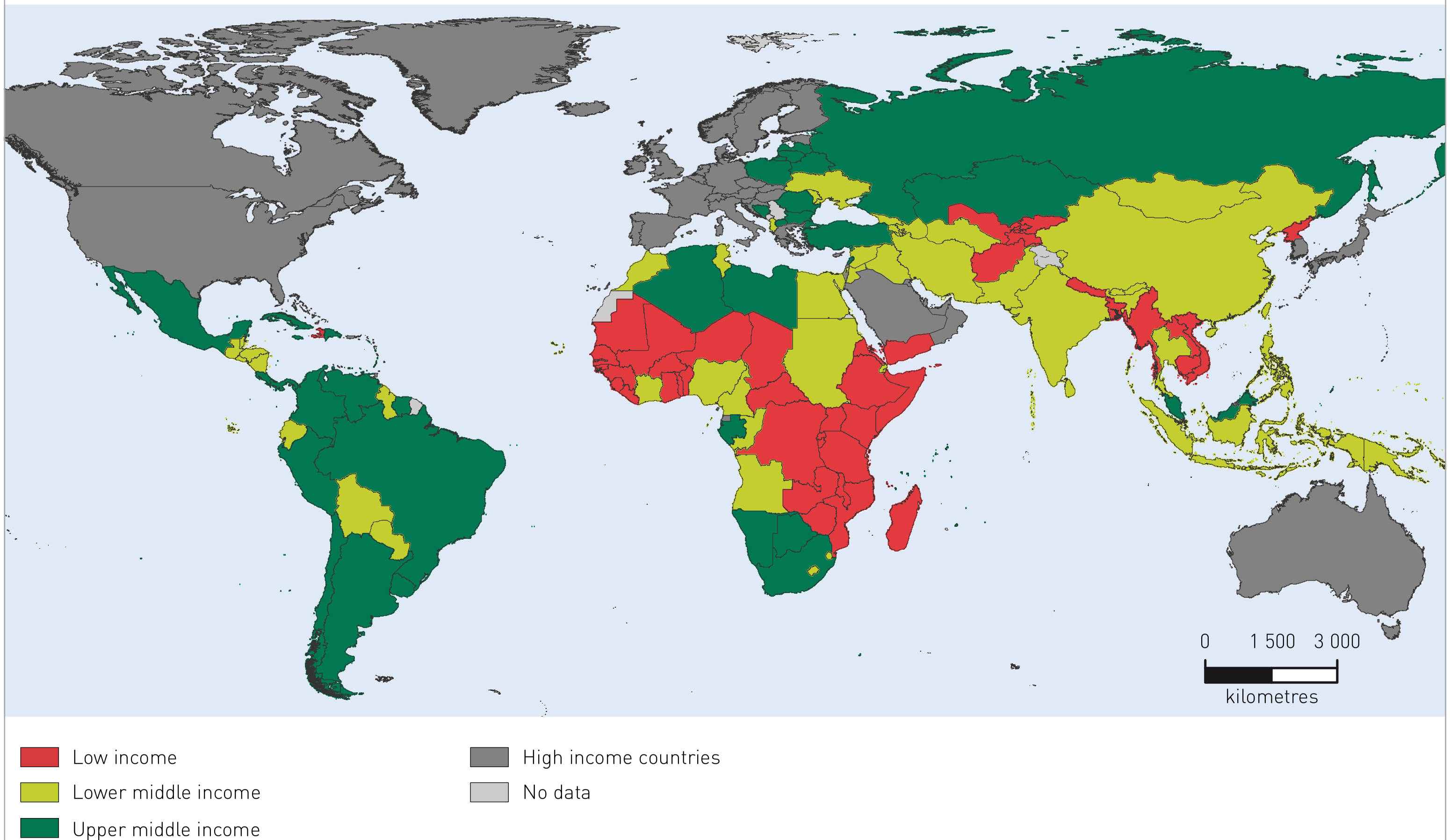
COUNTRIES GROUPED UNDER THE 2010 WORLD BANK DEVELOPING REGIONS AND COUNTRY INCOME GROUPINGS

A.1 DEVELOPING REGIONS AND HIGH INCOME COUNTRIES



Source: data from World Bank (2010).

A.2 COUNTRY INCOME GROUPINGS



Source: data from World Bank (2010).

A.3 THE 2010 WORLD BANK DEVELOPING REGIONS AND COUNTRY INCOME GROUPINGS

Developing countries

East Asia and Pacific

American Samoa, Cambodia, China, Democratic People's Republic of Korea, Fiji, Indonesia, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia (Federated States of), Mongolia, Myanmar, Palau, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Timor-Leste, Tonga, Vanuatu, Viet Nam.

Eastern Europe and Central Asia

Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Republic of Poland, Romania, Russian Federation, Serbia and Montenegro, Tajikistan, The former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Ukraine, Uzbekistan.

Latin America and Caribbean

Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Uruguay, Venezuela.

Middle East and North Africa

Algeria, Djibouti, Egypt, Iran (Islamic Republic of), Iraq, Jordan, Lebanon, Libyan Arab Jamahiriya, Morocco, Syrian Arab Republic, Tunisia, West Bank and Gaza, Yemen.

South Asia

Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka.

Sub-Saharan Africa

Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

High income countries

Andorra, Antigua and Barbuda, Aruba, Australia, Austria, Bahamas, Bahrain, Barbados, Belgium, Bermuda, Brunei Darussalam, Canada, Cayman Islands, Croatia, Cyprus, Czech Republic, Denmark, Dhekelia and Akrotiri SBA, Equatorial Guinea, Estonia, Faroe Islands, Finland, France, French Polynesia, Germany, Greece, Greenland, Guam, Guernsey, Hong Kong, Hungary, Iceland, Ireland, Isle of Man, Israel, Italy, Japan, Jersey, Kuwait, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Netherlands Antilles, New Caledonia, New Zealand, Northern Mariana Islands, Norway, Oman, Portugal, Puerto Rico, Qatar, Republic of Korea, San Marino, Saudi Arabia, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Trinidad and Tobago, U.K. of Great Britain and Northern Ireland, United Arab Emirates, United States of America, United States Virgin Islands.

Low income countries

Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic People's Republic of Korea, Democratic Republic of the Congo, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Kenya, Kyrgyzstan, Lao People's Democratic Republic, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Senegal, Sierra Leone, Somalia, Tajikistan, Togo, Uganda, United Republic of Tanzania, Uzbekistan, Viet Nam, Yemen, Zambia, Zimbabwe.

Source: World Bank (2010).

APPENDIX B

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE EAST ASIA AND PACIFIC (EAP) REGION

B LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)

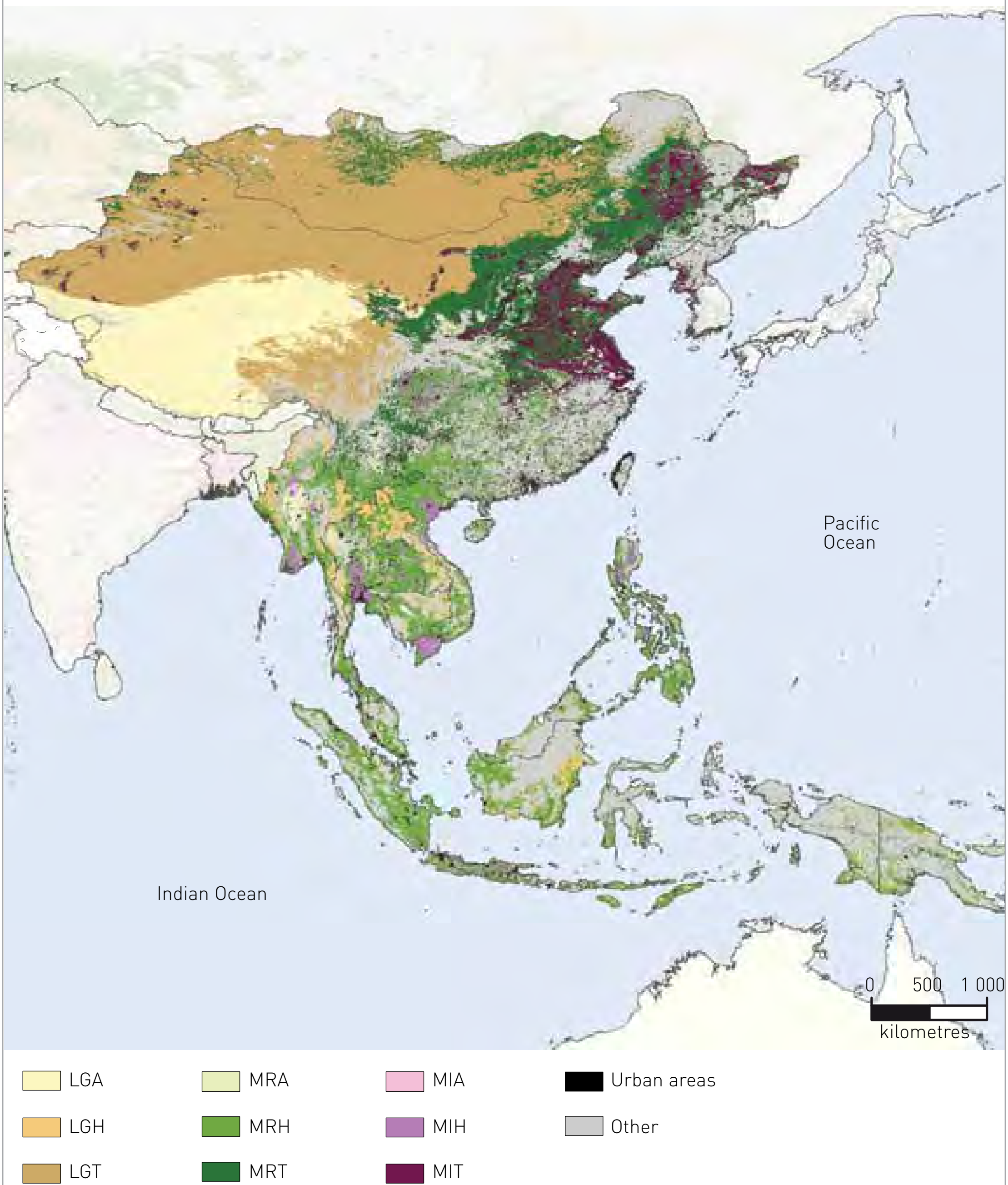


TABLE B RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Cambodia											
National rural poverty	692	59 518	0	62	2 015 500	0	0	106 162	0	121 355	**2 303 289**
Internat. poverty rate $1.25	503	46 695	0	48	1 498 380	0	0	78 863	0	88 967	**1 713 456**
Internat. poverty rate $2.00	1 127	92 596	0	103	3 356 090	0	0	176 605	0	197 632	**3 824 153**
China											
National rural poverty	12 893	213	266 109	135 882	1 633 650	2 813 520	9 869	289 433	864 714	1 319 040	**7 345 323**
Internat. poverty rate $1.25	295 915	424	2 632 770	818 225	10 277 700	17 554 300	56 081	1 702 660	5 418 340	8 005 690	**46 762 105**
Internat. poverty rate $2.00	685 734	813	5 754 820	1 878 610	23 465 700	40 177 900	126 956	3 882 650	12 303 600	18 199 900	**106 476 683**
Democratic People's Republic of Korea											
National rural poverty	896	0	108	688	0	67 537	451	0	73 856	147 237	**290 773**
Internat. poverty rate $1.25	0	0	0	0	0	9	0	0	0	19	**28**
Internat. poverty rate $2.00	0	0	0	0	0	19	0	0	0	44	**63**
Indonesia											
National rural poverty	2 738	86 482	1 740	34 736	8 915 510	22 685	585	1 476 360	21 742	1 333 390	**12 096 968**
Internat. poverty rate $1.25	2 960	93 714	1 879	37 611	9 652 970	242 184	648	1 599 170	23 551	1 460 530	**13 115 217**
Internat. poverty rate $2.00	7 361	239 397	4 885	94 705	24 273 300	609 486	1 636	4 009 110	59 067	3 683 960	**32 982 907**
Lao People's Democratic Republic											
National rural poverty	205	310 381	8 844	38	616 925	3 000	0	26 618	0	90 986	**1 056 997**
Internat. poverty rate $1.25	205	329 801	9 474	46	660 858	3 417	0	29 117	0	97 607	**1 130 525**
Internat. poverty rate $2.00	331	560 565	16 498	69	1 158 150	5 831	0	50 363	0	154 507	**1 946 314**
Malaysia											
National rural poverty	459	22 097	92	1 308	421 564	279	36	26 991	0	94 616	**567 442**
Internat. poverty rate $1.25	69	794	1	165	59 843	24	5	3 193	0	3 744	**67 838**
Internat. poverty rate $2.00	248	12 352	55	661	217 771	145	19	13 875	0	42 637	**287 763**
Mongolia											
National rural poverty	0	0	477 089	0	0	130 952	0	0	4	3 391	**611 436**
Internat. poverty rate $1.25	0	0	16 394	0	0	7 055	0	0	2	1 675	**25 126**
Internat. poverty rate $2.00	0	0	9 448	0	0	4 426	0	0	2	1 619	**15 495**

(Continued)

TABLE B RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Myanmar											
National rural poverty	7 798	190 245	22 270	1 106 720	2 343 750	45 923	121 395	368 949	799	468 638	**4 676 487**
Internat. poverty rate $1.25	0	48	13	0	89	25	0	2	0	49	**226**
Internat. poverty rate $2.00	2	112	25	0	208	59	0	9	0	109	**524**
Papua New Guinea											
National rural poverty	88	92 619	4 751	139	257 143	110 553	0	0	0	490 002	**955 295**
Internat. poverty rate $1.25	74	76 273	4 048	117	212 625	94 159	0	0	0	422 663	**809 959**
Internat. poverty rate $2.00	119	118 175	6 226	177	333 910	153 422	0	0	0	643 464	**1 255 493**
Philippines											
National rural poverty	2 057	3 066	38	26 201	6 627 550	52 648	3 088	1 014 110	368	794 393	**8 523 519**
Internat. poverty rate $1.25	1 263	1 894	28	16 056	4 061 530	32 202	1 889	621 130	226	489 077	**5 225 295**
Internat. poverty rate $2.00	2 507	3 916	51	32 045	8 097 070	64 329	3 761	1 237 210	449	970 110	**10 411 448**
Thailand											
National rural poverty	9 977	34 338	93	148 342	2 453 610	680	15 208	316 555	0	192 340	**3 171 143**
Internat. poverty rate $1.25	110	65	3	23 299	365 658	109	2 870	61 442	0	18 568	**472 124**
Internat. poverty rate $2.00	8 994	32 862	83	126 056	2 060 890	578	12 859	269 451	0	161 581	**2 673 354**
Timor-Leste											
National rural poverty	1 713	14 072	297	3 062	159 615	13 170	541	2 496	11	7 790	**202 767**
Internat. poverty rate $1.25	2 289	17 621	369	4 072	211 630	17 439	720	3 420	14	10 675	**268 249**
Internat. poverty rate $2.00	3 350	27 319	565	5 983	310 032	25 375	1 069	5 212	21	16 008	**394 934**
Viet Nam											
National rural poverty	2 500	269 019	15 644	18 991	5 363 000	82 222	3 903	2 930 350	139	538 861	**9 224 629**
Internat. poverty rate $1.25	248	30 188	1 918	1 918	509 674	7 996	379	286 052	18	54 936	**893 327**
Internat. poverty rate $2.00	3 290	360 429	21 005	25 311	7 088 350	108 917	5 158	3 876 860	182	708 641	**12 198 143**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

APPENDIX C

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE EASTERN EUROPE AND CENTRAL ASIA (EECA) REGION

C LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)

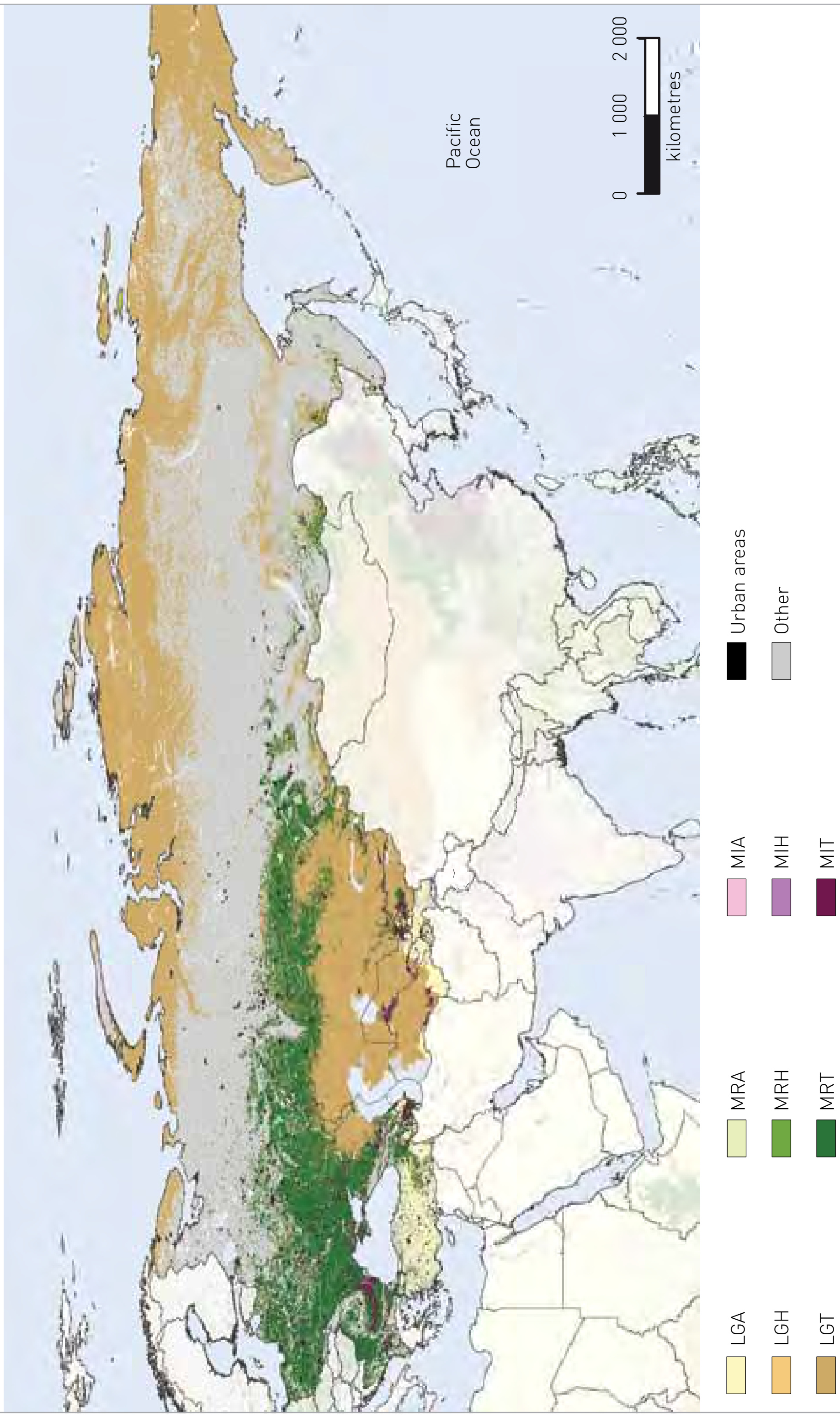


TABLE C RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Albania											
National rural poverty	2 928	0	510	63 766	21 161	34 090	9 913	18 616	2 140	14 976	**168 100**
Internat. poverty rate $1.25	178	0	0	6 854	1 941	5 208	406	1 759	41	652	**17 039**
Internat. poverty rate $2.00	1 114	0	91	22 190	6 896	12 195	3 820	6 279	891	5 254	**58 730**
Armenia											
National rural poverty	33 907	0	41 412	95 108	0	77 188	9 202	0	28 134	5 994	**290 945**
Internat. poverty rate $1.25	1 418	0	3 451	9 247	0	7 229	168	0	1 683	23	**23 219**
Internat. poverty rate $2.00	14 124	0	18 086	38 493	0	32 333	3 437	0	11 458	2 018	**119 949**
Azerbaijan											
National rural poverty	21 915	0	9 218	330 976	0	344 899	8 480	0	132 047	30 480	**878 015**
Internat. poverty rate $1.25	1 156	0	760	21 117	0	22 453	30	0	2 030	374	**47 920**
Internat. poverty rate $2.00	1 148	0	752	21 184	0	22 470	32	0	2 031	373	**47 990**
Belarus											
National rural poverty	0	0	11 155	0	0	190 490	0	0	248	15 029	**216 922**
Internat. poverty rate $1.25	0	0	0	0	0	673	0	0	7	128	**808**
Internat. poverty rate $2.00	0	0	0	0	0	673	0	0	7	128	**808**
Bosnia and Herzegovina											
National rural poverty	10	12	0	30 683	2 808	111 248	93	129	0	31 534	**176 517**
Internat. poverty rate $1.25	0	0	0	6 559	693	16 544	0	0	0	24	**23 820**
Internat. poverty rate $2.00	0	0	0	6 559	693	16 535	0	0	0	24	**23 811**
Bulgaria											
National rural poverty	1 207	0	2 622	9 809	0	84 902	428	0	12 489	22 958	**134 415**
Internat. poverty rate $1.25	0	0	0	543	0	2 134	0	0	0	0	**2 677**
Internat. poverty rate $2.00	0	0	0	681	0	5 353	0	0	5	15	**6 054**
Georgia											
National rural poverty	12 494	0	23 560	103 093	78 835	201 591	5 419	2 165	10 568	90 671	**528 396**
Internat. poverty rate $1.25	3 841	0	6 545	25 979	19 627	49 448	1 836	536	3 174	22 638	**133 624**
Internat. poverty rate $2.00	8 148	0	14 800	59 212	44 681	112 780	3 196	1 275	6 342	54 496	**304 930**

(Continued)

TABLE C RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Kazakhstan											
National rural poverty	0	0	201 846	1	0	155 506	283	0	9 369	2 956	**369 961**
Internat. poverty rate $1.25	0	0	7 408	0	0	4 176	113	0	2 014	602	**14 313**
Internat. poverty rate $2.00	0	0	3 986	0	0	1 985	163	0	1 357	558	**8 049**
Kyrgyzstan											
National rural poverty	61 302	0	962 117	1 911	0	191 168	103	0	37 706	24 137	**1 278 444**
Internat. poverty rate $1.25	30 401	0	416 692	870	0	82 214	61	0	16 496	7 747	**554 481**
Internat. poverty rate $2.00	30 988	0	550 483	1 045	0	103 645	69	0	20 343	9 355	**715 928**
Latvia											
National rural poverty	5	0	6 731	727	0	36 811	0	0	0	4 224	**48 498**
Internat. poverty rate $1.25	0	0	17	102	0	1 313	0	0	0	381	**1 813**
Internat. poverty rate $2.00	0	0	17	102	0	1 313	0	0	0	381	**1 813**
Lithuania											
National rural poverty	0	0	23	0	0	183	0	0	0	2	**208**
Internat. poverty rate $1.25	0	0	34	0	0	949	0	0	0	22	**1 005**
Internat. poverty rate $2.00	0	0	34	0	0	949	0	0	0	22	**1 005**
Moldova, Republic of											
National rural poverty	0	0	0	0	0	718 136	0	0	26 527	16 882	**761 545**
Internat. poverty rate $1.25	0	0	0	0	0	85 527	0	0	4 241	2 431	**92 199**
Internat. poverty rate $2.00	0	0	0	0	0	125 922	0	0	4 632	2 895	**133 449**
Poland											
National rural poverty	0	0	0	0	0	151	0	0	0	42	**193**
Internat. poverty rate $1.25	64	0	0	27	0	171 057	0	0	32	4 108	**175 288**
Internat. poverty rate $2.00	64	0	0	27	0	171 057	0	0	32	4 108	**175 288**
Romania											
National rural poverty	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Internat. poverty rate $1.25	0	0	0	0	0	68 026	0	0	1 873	4 181	**74 080**
Internat. poverty rate $2.00	0	0	0	0	0	68 036	0	0	1 873	4 181	**74 090**

n.a. = not available.

(Continued)

TABLE C RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Russian Federation											
National rural poverty	387	0	504	324	0	1 516	0	0	0	234	**2 965**
Internat. poverty rate $1.25	177	0	5 016	818	44	46 107	0	0	802	16 450	**69 414**
Internat. poverty rate $2.00	195	0	5 057	855	44	46 157	0	0	802	16 489	**69 599**
Tajikistan											
National rural poverty	624 666	0	164 859	582 199	0	215 688	85 979	0	14 559	33 434	**1 721 384**
Internat. poverty rate $1.25	254 897	0	65 483	227 714	0	84 816	34 314	0	5 837	11 631	**684 692**
Internat. poverty rate $2.00	585 030	0	154 291	535 855	0	198 702	80 282	0	13 584	32 623	**1 600 367**
The former Yugoslav Republic of Macedonia											
National rural poverty	2 246	0	5 817	29 378	0	40 610	603	0	3 534	14 591	**96 779**
Internat. poverty rate $1.25	135	0	448	2 443	0	3 626	7	0	131	638	**7 428**
Internat. poverty rate $2.00	564	0	1 358	7 649	0	9 815	122	0	812	2 307	**22 627**
Turkey											
National rural poverty	702 090	804	110 961	2 845 760	41 016	416 921	135 107	1 411	13 695	328 968	**4 596 733**
Internat. poverty rate $1.25	35 727	72	6 111	306 495	4 126	39 749	232	12	0	1 315	**393 839**
Internat. poverty rate $2.00	207 821	186	34 082	681 856	9 618	97 411	40 441	360	4 861	96 021	**1 172 657**
Turkmenistan											
National rural poverty	214 112	0	518 410	7 587	0	3 882	3 109	0	21 322	2 321	**770 743**
Internat. poverty rate $1.25	176 163	0	405 987	6 354	0	2 865	2 573	0	11 966	1 551	**607 459**
Internat. poverty rate $2.00	279 079	0	797 498	8 619	0	5 319	4 559	0	27 814	2 622	**1 125 510**
Ukraine											
National rural poverty	375	0	17 717	237	0	1 955 860	7	0	63 659	178 550	**2 216 405**
Internat. poverty rate $1.25	12	0	19	7	0	52 957	0	0	129	199	**53 323**
Internat. poverty rate $2.00	12	0	19	7	0	52 991	0	0	129	199	**53 357**
Uzbekistan											
National rural poverty	596 157	0	1 065 250	276 490	0	118 205	185 832	0	455 097	9 428	**2 706 459**
Internat. poverty rate $1.25	881 972	0	1 532 550	413 323	0	179 467	279 377	0	682 820	11 345	**3 980 854**
Internat. poverty rate $2.00	1 468 760	0	2 554 750	682 639	0	295 302	462 664	0	1 128 970	15 952	**6 609 037**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

APPENDIX D

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE LATIN AMERICA AND CARIBBEAN (LAC) REGION

D LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)

TABLE D RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Argentina											
National rural poverty	277 033	77 202	6 175	76 745	250 332	1 953	2 956	1 414	16	46 588	**740 414**
Internat. poverty rate $1.25	5 297	405	90	4 611	7 426	65	125	34	0	1 727	**19 780**
Internat. poverty rate $2.00	11 601	895	240	8 876	17 794	324	341	90	2	3 483	**43 646**
Belize											
National rural poverty	20	1 288	0	0	7 919	6	0	1	0	22 606	**31 840**
Internat. poverty rate $1.25	10	480	0	0	3 852	0	0	0	0	479	**4 821**
Internat. poverty rate $2.00	18	886	0	0	7 111	0	0	0	0	884	**8 900**
Bolivia											
National rural poverty	285 259	60 712	440 059	35 364	81 827	134 839	94	0	3 735	177 810	**1 219 699**
Internat. poverty rate $1.25	37 250	3 116	107 392	2 884	13 959	23 520	29	0	829	9 329	**198 308**
Internat. poverty rate $2.00	75 619	8 983	171 418	5 984	25 586	45 824	30	0	1 140	43 193	**377 777**
Brazil											
National rural poverty	390 647	655 907	25 956	745 869	4 069 320	107 213	1 983	59 809	1 683	390 569	**6 448 956**
Internat. poverty rate $1.25	10 445	45 060	1 416	58 841	444 370	11 983	96	5 533	88	21 624	**599 456**
Internat. poverty rate $2.00	71 361	157 402	6 193	182 677	1 161 700	33 285	421	17 089	516	81 487	**1 712 131**
Chile											
National rural poverty	34 298	8 666	1 712	38 866	23 049	6 958	9 458	1 543	571	6 479	**131 600**
Internat. poverty rate $1.25	63	0	8	3 553	4	770	416	0	49	73	**4 936**
Internat. poverty rate $2.00	72	0	9	4 430	18	934	439	0	59	86	**6 047**
Colombia											
National rural poverty	59 479	206 566	96 207	22 914	1 942 370	1 141 420	93	29 237	9 760	456 701	**3 964 747**
Internat. poverty rate $1.25	16 543	51 426	28 982	6 477	504 787	292 672	20	7 245	2 429	116 285	**1 026 866**
Internat. poverty rate $2.00	30 180	90 296	45 592	10 080	872 393	511 933	55	13 990	4 610	223 530	**1 802 659**
Costa Rica											
National rural poverty	11	209	18	402	52 849	4 104	3	5 189	2	95 111	**157 898**
Internat. poverty rate $1.25	1	0	0	35	5 312	441	0	163	0	1 452	**7 404**
Internat. poverty rate $2.00	2	32	2	74	9 036	589	0	741	0	11 156	**21 632**

(Continued)

TABLE D RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Dominican Republic											
National rural poverty	496	2 380	0	22 145	571 755	33 315	5 122	13 086	154	178 645	**827 098**
Internat. poverty rate $1.25	46	393	0	1 743	44 904	2 569	659	1 351	14	17 555	**69 234**
Internat. poverty rate $2.00	115	789	0	4 770	132 669	7 706	1 184	2 985	42	43 284	**193 544**
Ecuador											
National rural poverty	50 941	21 178	48 999	271 413	409 036	304 769	71 331	46 312	52 354	122 494	**1 398 827**
Internat. poverty rate $1.25	4 621	1 797	4 124	22 525	34 358	25 551	4 871	2 822	3 492	5 198	**109 359**
Internat. poverty rate $2.00	12 623	5 129	13 038	54 385	84 661	62 336	15 884	11 023	12 051	20 071	**291 201**
El Salvador											
National rural poverty	0	20	6	1 748	243 172	7 893	33	4 794	11	95 849	**353 526**
Internat. poverty rate $1.25	0	6	3	324	43 226	1 434	8	923	3	17 750	**63 677**
Internat. poverty rate $2.00	0	10	3	549	88 445	2 790	9	1 759	5	35 266	**128 836**
Guatemala											
National rural poverty	0	215	0	219 512	932 713	588 752	6 741	36 996	263	631 588	**2 416 780**
Internat. poverty rate $1.25	0	43	0	38 378	164 858	104 755	1 288	6 674	52	110 202	**426 250**
Internat. poverty rate $2.00	0	86	0	73 947	312 591	198 219	2 260	12 484	88	217 505	**817 180**
Guyana											
National rural poverty	1	3 521	0	0	8 262	0	0	6 176	0	78 270	**96 230**
Internat. poverty rate $1.25	0	405	0	0	1 148	0	0	906	0	3 826	**6 285**
Internat. poverty rate $2.00	0	1 790	0	0	3 389	0	0	1 917	0	9 690	**16 786**
Haiti											
National rural poverty	2 199	0	0	60 740	1 391 480	89 696	5 990	20 666	0	198 007	**1 768 778**
Internat. poverty rate $1.25	1 827	0	0	50 645	1 156 890	74 565	4 906	17 156	0	164 253	**1 470 242**
Internat. poverty rate $2.00	2 397	0	0	66 587	1 519 310	98 098	6 533	22 587	0	216 831	**1 932 343**
Honduras											
National rural poverty	2 558	8 011	423	30 414	724 326	113 661	364	5 911	88	303 125	**1 188 881**
Internat. poverty rate $1.25	751	2 515	120	9 502	227 031	35 454	116	1 858	27	94 773	**372 147**
Internat. poverty rate $2.00	1 094	3 494	178	12 786	305 796	47 982	160	2 461	38	129 569	**503 558**

(Continued)

TABLE D RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Jamaica											
National rural poverty	29	2 702	0	76	127 569	545	0	380	0	29 758	**161 059**
Internat. poverty rate $1.25	2	186	0	4	9 211	37	0	42	0	2 737	**12 219**
Internat. poverty rate $2.00	7	651	0	18	29 990	124	0	87	0	7 133	**38 010**
Mexico											
National rural poverty	474 264	3 735	70 045	562 371	596 395	479 643	40 586	8 943	12 150	832 569	**3 080 701**
Internat. poverty rate $1.25	9 189	0	13	34 571	44 670	37 860	1 188	499	600	28 502	**157 092**
Internat. poverty rate $2.00	67 196	552	25 201	171 230	178 324	141 823	13 266	2 510	3 859	219 190	**823 151**
Nicaragua											
National rural poverty	1 546	4 029	0	68 944	502 251	24 128	339	2 012	0	169 540	**772 789**
Internat. poverty rate $1.25	378	826	0	16 550	119 693	5 935	92	566	0	42 465	**186 505**
Internat. poverty rate $2.00	778	1 812	0	34 593	248 964	12 227	186	1 023	0	90 894	**390 477**
Panama											
National rural poverty	151	2 385	37	278	166 674	1 567	0	4 321	64	69 837	**245 314**
Internat. poverty rate $1.25	20	343	0	44	25 254	206	0	708	15	6 770	**33 360**
Internat. poverty rate $2.00	47	562	0	74	45 257	517	0	1 463	21	18 029	**65 970**
Paraguay											
National rural poverty	504	47 354	0	4 980	262 254	0	0	267	0	69 240	**384 599**
Internat. poverty rate $1.25	0	14 273	0	8	92 021	0	0	141	0	15 640	**122 083**
Internat. poverty rate $2.00	0	21 016	0	8	133 432	0	0	168	0	30 428	**185 052**
Peru											
National rural poverty	842 762	10 132	275 775	155 494	123 762	802 208	53 186	3 320	38 399	313 476	**2 618 514**
Internat. poverty rate $1.25	83 225	1 067	19 011	18 723	14 850	101 035	5 920	373	4 025	20 729	**268 958**
Internat. poverty rate $2.00	196 637	2 509	73 178	37 803	29 149	197 196	13 183	841	10 232	60 435	**621 163**

(Continued)

TABLE D RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Suriname											
National rural poverty	2	1 030	0	2	4 088	0	1	248	0	14 046	**19 417**
Internat. poverty rate $1.25	1	228	0	1	1 325	0	0	3	0	2 490	**4 048**
Internat. poverty rate $2.00	2	408	0	1	2 170	0	1	240	0	7 815	**10 637**
Uruguay											
National rural poverty	0	15 602	0	0	31 211	0	0	255	0	1 575	**48 643**
Internat. poverty rate $1.25	0	489	0	0	729	0	0	12	0	27	**1 257**
Internat. poverty rate $2.00	0	944	0	0	1 493	0	0	19	0	88	**2 544**
Venezuela											
National rural poverty	34 569	80 144	4 712	59 712	234 931	15 702	693	2 729	101	62 255	**495 548**
Internat. poverty rate $1.25	16 464	28 588	1 753	23 215	76 397	5 805	231	363	43	18 518	**171 377**
Internat. poverty rate $2.00	5 051	13 502	1 312	11 793	45 950	3 938	33	50	10	4 943	**86 582**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

APPENDIX E

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE MIDDLE EAST AND NORTH AFRICA (MENA) REGION

E LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)

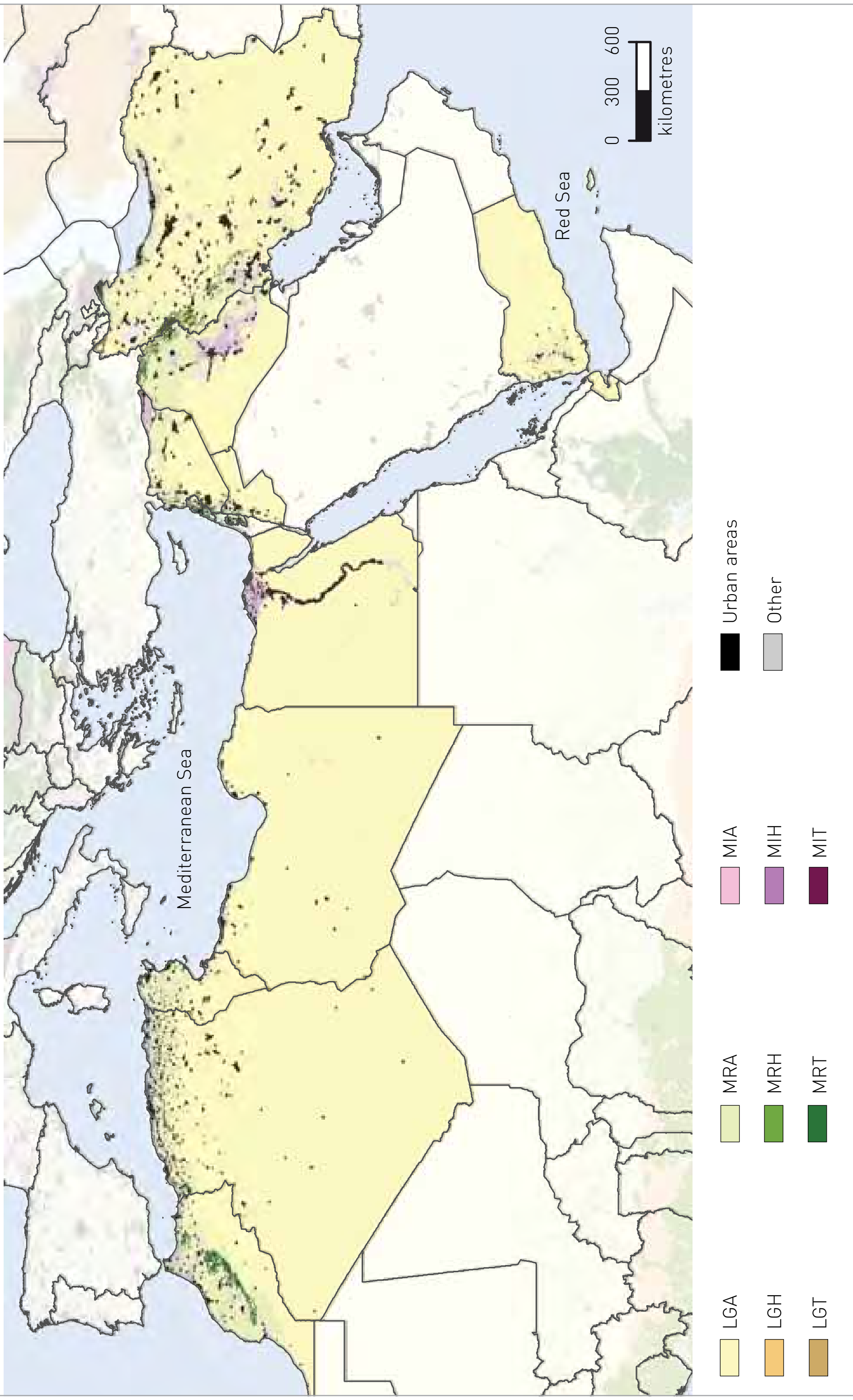


TABLE E RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Algeria											
National rural poverty	842 380	0	167	1 115 390	9 268	56 284	27 961	2 842	438	109 928	**2 164 658**
Internat. poverty rate $1.25	168 045	0	55	249 092	2 303	12 347	7 774	685	118	27 378	**467 797**
Internat. poverty rate $2.00	521 471	0	112	849 793	7 024	41 503	20 696	2 160	320	82 672	**1 525 751**
Djibouti											
National rural poverty	94 270	0	0	988	0	0	0	0	0	941	**96 199**
Internat. poverty rate $1.25	29 224	0	0	378	0	0	0	0	0	59	**29 661**
Internat. poverty rate $2.00	62 005	0	0	676	0	0	0	0	0	896	**63 577**
Egypt											
National rural poverty	1 999 510	0	0	492 613	0	0	1 831 460	0	0	26 809	**4 350 392**
Internat. poverty rate $1.25	366 436	0	0	99 451	0	0	366 532	0	0	6 205	**838 624**
Internat. poverty rate $2.00	1 636 280	0	0	390 349	0	0	1 448 220	0	0	23 572	**3 498 421**
Iran (Islamic Republic of)											
National rural poverty	3 873 160	0	35 473	888 123	13 728	88 793	88 531	3 773	3 174	65 374	**5 060 129**
Internat. poverty rate $1.25	2 707 380	0	24 688	591 481	9 070	60 957	66 492	2 528	2 745	46 284	**3 511 625**
Internat. poverty rate $2.00	1 031 660	0	11 564	237 671	3 582	21 639	23 978	919	1 109	17 781	**1 349 903**
Iraq											
National rural poverty	287 991	0	4 117	1 146 120	0	133 703	240 325	0	2 079	1 829	**1 816 164**
Internat. poverty rate $1.25	41	0	8	82	0	45	0	0	0	0	**176**
Internat. poverty rate $2.00	17	0	3	29	0	19	0	0	0	0	**68**
Jordan											
National rural poverty	79 739	0	243	90 564	0	6 160	6 279	0	19	86	**183 090**
Internat. poverty rate $1.25	2 009	0	0	9 499	0	620	641	0	0	10	**12 779**
Internat. poverty rate $2.00	12 804	0	81	18 489	0	1 143	1 283	0	4	15	**33 819**
Morocco											
National rural poverty	444 079	149	1 641	1 541 870	9 598	159 312	62 851	1 056	192	86 619	**2 307 367**
Internat. poverty rate $1.25	14 279	8	26	179 068	766	18 939	7 658	200	14	7 929	**228 887**
Internat. poverty rate $2.00	199 447	90	825	768 322	4 678	79 879	34 984	629	94	44 899	**1 133 847**

(Continued)

TABLE E RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

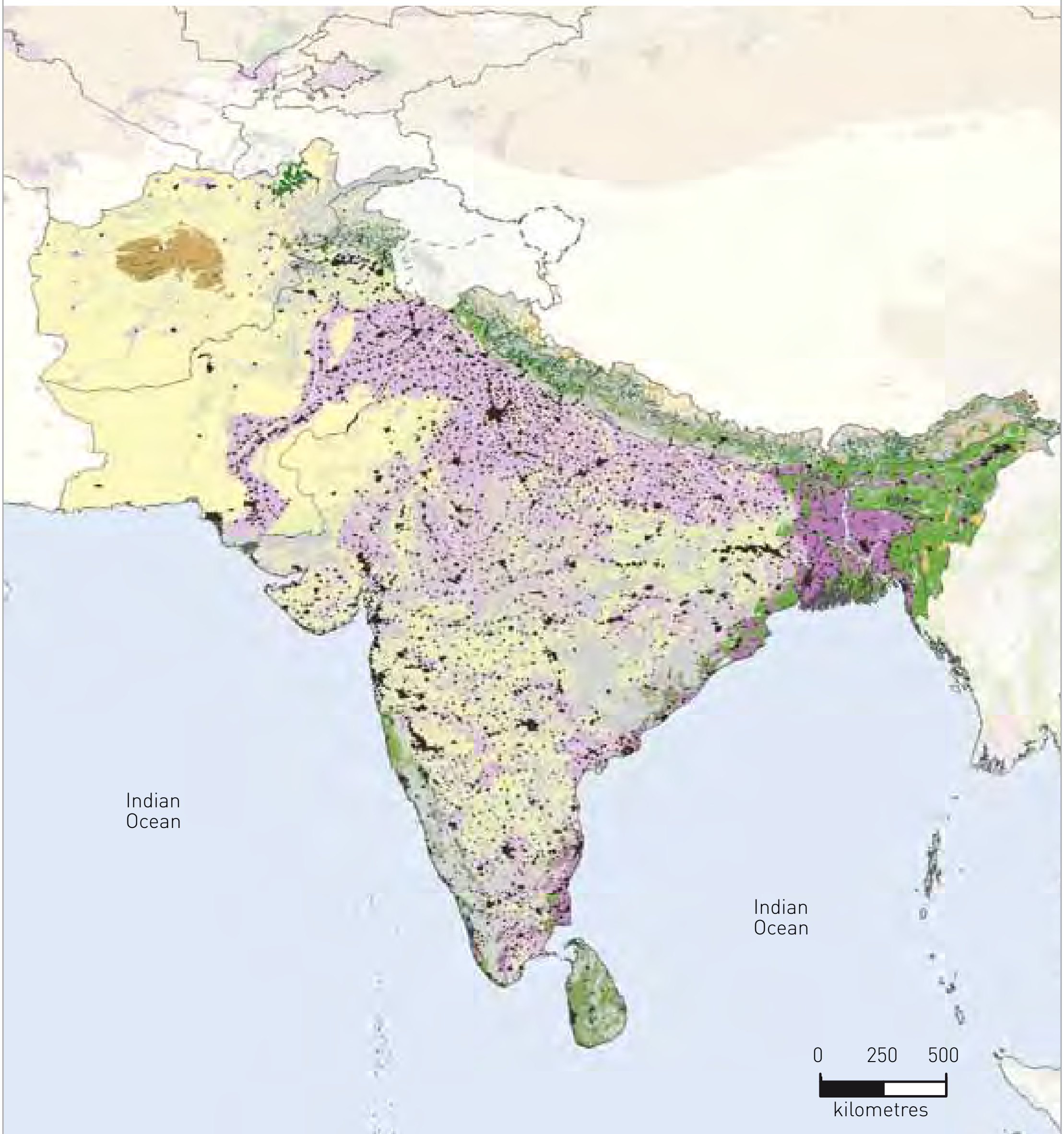
Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Syrian Arab Republic											
National rural poverty	837 026	0	4 271	921 511	1 440	19 884	127 810	1 600	178	6 438	**1 920 158**
Internat. poverty rate $1.25	16	0	0	18	0	0	0	0	0	0	**34**
Internat. poverty rate $2.00	24	0	0	39	0	0	0	0	0	0	**63**
Tunisia											
National rural poverty	18 765	0	0	247 467	248	154	8 695	13	2	13 597	**288 941**
Internat. poverty rate $1.25	7 411	0	0	64 671	53	68	1 362	3	0	3 080	**76 648**
Internat. poverty rate $2.00	17 683	0	0	224 829	248	148	8 202	13	2	13 276	**264 401**
Yemen											
National rural poverty	3 408 550	0	0	1 752 230	0	35 438	62 073	0	388	5 356	**5 264 035**
Internat. poverty rate $1.25	1 338 010	0	0	684 413	0	13 752	24 367	0	150	2 237	**2 062 929**
Internat. poverty rate $2.00	3 520 680	0	0	1 813 470	0	36 741	64 160	0	401	5 574	**5 441 026**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

APPENDIX F

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE SOUTH ASIA (SA) REGION

F LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)



LGA
LGH
LGT
MRA
MRH
MRT
MIA
MIH
MIT
Urban areas
Other

TABLE F RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

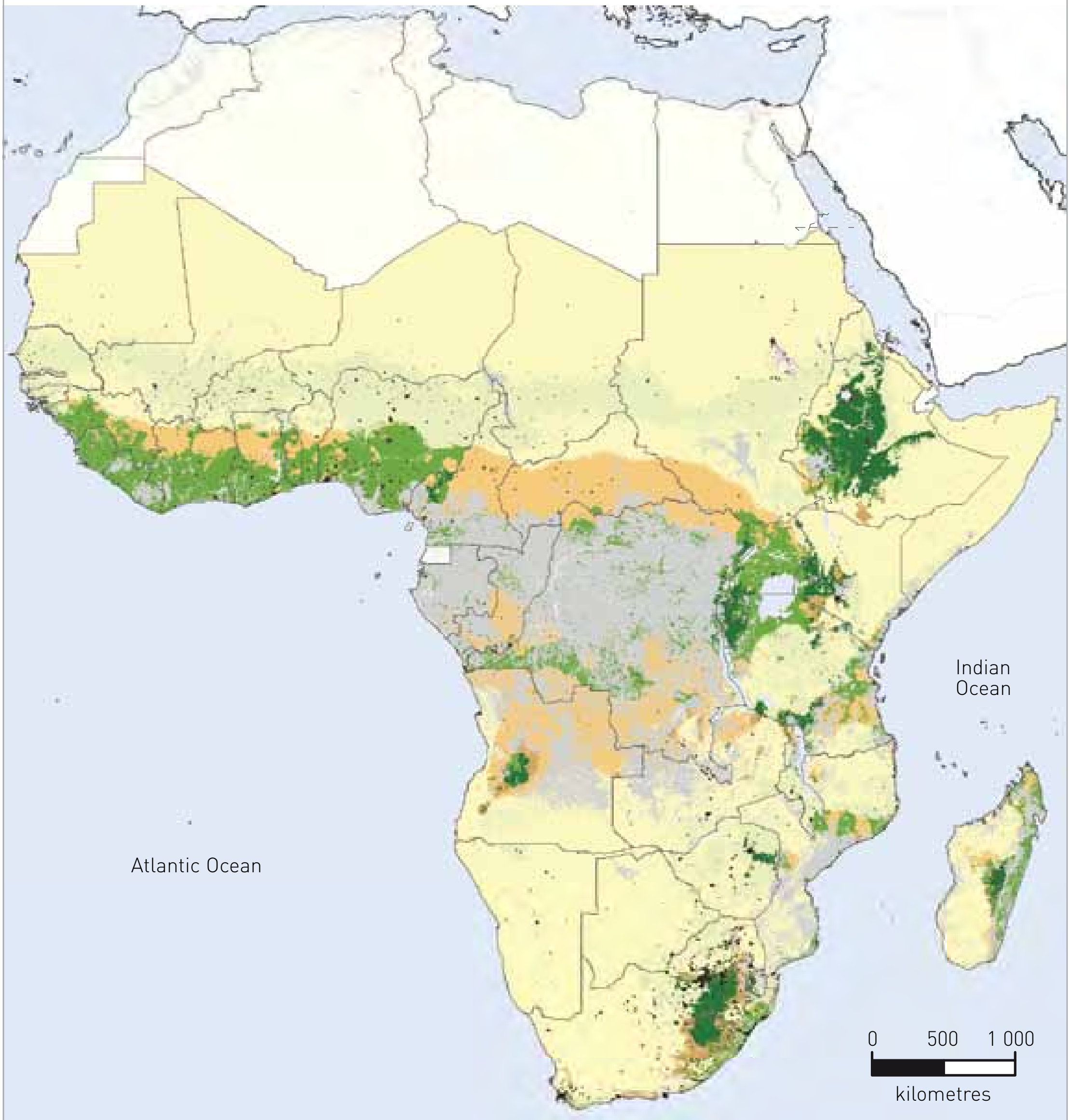
Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Afghanistan											
National rural poverty	3 326 830	0	386 318	1 686 040	0	252 100	300 758	0	14 525	258 043	**6 224 614**
Internat. poverty rate $1.25	481	0	0	144	0	95	1	0	0	218	**939**
Internat. poverty rate $2.00	1 132	0	0	385	0	247	2	0	0	567	**2 333**
Bangladesh											
National rural poverty	17 096	168	0	180 391	7 158 170	0	44 168	9 379 650	0	256 846	**17 036 489**
Internat. poverty rate $1.25	20 402	193	0	209 545	8 165 970	0	50 429	10 639 800	0	297 253	**19 383 592**
Internat. poverty rate $2.00	33 412	311	0	343 172	13 378 300	0	82 552	17 424 200	0	486 857	**31 748 804**
Bhutan											
National rural poverty	3 392	14	747	130	20 753	26 839	0	1 135	496	17 896	**71 402**
Internat. poverty rate $1.25	2 281	13	675	59	16 440	20 705	0	973	424	15 385	**56 955**
Internat. poverty rate $2.00	4 907	16	922	202	32 208	38 845	0	1 738	860	31 619	**111 317**
India											
National rural poverty	1 126 520	23 187	18 682	48 403 100	13 804 400	763 399	27 555 500	4 495 260	13 157	10 632 300	**106 835 505**
Internat. poverty rate $1.25	1 544 400	30 769	25 122	64 589 400	18 409 200	1 019 620	36 772 200	5 995 340	17 596	14 183 300	**142 586 947**
Internat. poverty rate $2.00	2 773 990	55 366	44 749	117 310 000	33 417 400	1 850 880	66 767 000	10 883 700	32 077	25 748 300	**258 883 462**
Nepal											
National rural poverty	63 883	36	19 886	241 639	896 470	322 943	382 680	263 025	22 685	906 625	**3 119 872**
Internat. poverty rate $1.25	97 806	49	31 593	386 606	1 428 590	512 388	611 848	421 650	36 178	1 453 080	**4 979 788**
Internat. poverty rate $2.00	136 513	75	44 747	546 024	2 012 180	722 527	858 905	591 685	50 889	2 040 810	**7 004 355**
Pakistan											
National rural poverty	5 183 770	0	0	4 514 120	57 521	545 250	5 612 130	6 751	12 521	1 227 370	**17 159 433**
Internat. poverty rate $1.25	3 283 390	0	0	2 838 690	36 184	341 145	3 541 930	4 265	7 886	773 046	**10 826 536**
Internat. poverty rate $2.00	8 699 240	0	0	7 602 320	96 653	915 186	9 426 130	11 401	21 036	2 076 800	**28 848 766**
Sri Lanka											
National rural poverty	458	0	0	3 115	527 781	18 182	48	57 738	346	124 974	**732 642**
Internat. poverty rate $1.25	704	0	0	4 977	829 558	28 452	76	90 105	554	192 439	**1 146 865**
Internat. poverty rate $2.00	2 006	0	0	14 040	2 351 560	81 017	216	255 414	1 576	546 647	**3 252 476**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

APPENDIX G

LIVESTOCK PRODUCTION SYSTEMS AND ESTIMATED NUMBERS OF RURAL POOR LIVESTOCK KEEPERS IN THE SUB-SAHARAN AFRICA (SSA) REGION

G LIVESTOCK PRODUCTION SYSTEMS (VERSION 5)



LGA	MRA	MIA	Urban areas
LGH	MRH	MIH	Other
LGT	MRT	MIT	

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011)

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Angola											
National rural poverty	371 476	1 087 110	130 379	24 281	180 321	367 981	39	0	0	363 910	**2 525 497**
Internat. poverty rate $1.25	367 221	1 073 310	130 330	24 158	165 510	325 161	36	0	0	363 718	**2 449 444**
Internat. poverty rate $2.00	708 750	1 341 570	172 975	31 568	207 675	422 253	46	0	0	479 712	**3 364 549**
Benin											
National rural poverty	186 263	74 173	0	340 522	1 031 660	0	138	2 969	0	9 373	**1 645 098**
Internat. poverty rate $1.25	190 279	77 314	0	348 881	1 069 440	0	141	3 058	0	9 610	**1 698 723**
Internat. poverty rate $2.00	317 195	122 725	0	548 840	1 696 100	0	226	4 897	0	15 320	**2 705 303**
Botswana											
National rural poverty	185 877	0	0	103 295	0	0	21	0	0	49	**289 242**
Internat. poverty rate $1.25	70 809	0	0	43 348	0	0	3	0	0	29	**114 189**
Internat. poverty rate $2.00	179 420	0	0	90 562	0	0	5	0	0	40	**270 027**
Burkina Faso											
National rural poverty	418 480	23 148	0	3 909 660	5 947	0	1 682	0	0	2 611	**4 361 528**
Internat. poverty rate $1.25	442 349	24 093	0	4 138 610	6 370	0	1 813	0	0	2 683	**4 615 918**
Internat. poverty rate $2.00	644 164	35 643	0	5 947 570	8 929	0	2 578	0	0	3 917	**6 642 801**
Burundi											
National rural poverty	0	0	0	0	717 872	2 220 890	0	25 625	14 528	78 986	**3 057 901**
Internat. poverty rate $1.25	0	0	0	0	904 384	2 796 090	0	32 315	18 308	99 814	**3 850 911**
Internat. poverty rate $2.00	0	0	0	0	1 039 560	3 213 060	0	37 073	21 029	114 684	**4 425 406**
Cameroon											
National rural poverty	67 786	474 695	18 261	909 970	457 228	304 857	1 206	857	300	430 007	**2 665 167**
Internat. poverty rate $1.25	36 723	283 471	10 648	531 327	264 260	179 231	720	509	180	197 898	**1 504 967**
Internat. poverty rate $2.00	70 431	478 389	18 467	960 022	482 900	320 165	1 389	900	317	444 348	**2 777 328**
Cape Verde											
National rural poverty	4 955	0	0	60 249	0	5 139	1 243	0	18	62	**71 666**
Internat. poverty rate $1.25	2 022	0	0	20 978	0	1 758	408	0	6	24	**25 196**
Internat. poverty rate $2.00	3 907	0	0	41 151	0	3 582	849	0	12	42	**49 543**

(Continued)

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Central African Republic											
National rural poverty	86 825	843 655	0	4 800	51 900	0	0	0	0	72 526	**1 059 706**
Internat. poverty rate $1.25	90 193	927 698	0	5 069	56 149	0	0	0	0	83 382	**1 162 491**
Internat. poverty rate $2.00	114 084	1 127 120	0	6 639	74 524	0	0	0	0	105 959	**1 428 326**
Chad											
National rural poverty	1 110 390	1 787	0	1 672 450	0	0	1 245	0	0	23 381	**2 809 253**
Internat. poverty rate $1.25	1 404 260	2 033	0	2 015 480	0	0	1 452	0	0	28 709	**3 451 934**
Internat. poverty rate $2.00	1 973 220	2 790	0	2 796 390	0	0	2 248	0	0	37 026	**4 811 674**
Comoros											
National rural poverty	30	0	0	0	53 097	5 412	0	71	0	39 738	**98 348**
Internat. poverty rate $1.25	24	0	0	0	41 531	4 218	0	56	0	30 948	**76 777**
Internat. poverty rate $2.00	33	0	0	0	58 717	6 001	0	79	0	43 779	**108 609**
Congo											
National rural poverty	10	173 790	0	0	54 850	0	0	0	0	101 389	**330 039**
Internat. poverty rate $1.25	10	183 435	0	0	60 501	0	0	0	0	103 440	**347 386**
Internat. poverty rate $2.00	13	251 964	0	0	80 917	0	0	0	0	150 830	**483 724**
Cote d'Ivoire											
National rural poverty	60 261	449 567	0	52 329	3 252 610	156	187	9 554	0	163 607	**3 988 271**
Internat. poverty rate $1.25	24 524	194 342	0	18 999	1 302 400	61	76	3 749	0	67 129	**1 611 280**
Internat. poverty rate $2.00	46 104	374 987	0	40 220	2 609 620	130	136	7 619	0	129 681	**3 208 497**
Democratic Republic of the Congo											
National rural poverty	151 956	2 138 470	28 735	22 514	5 451 680	1 196 810	0	1 660	0	5 201 920	**14 193 745**
Internat. poverty rate $1.25	117 954	1 650 540	21 563	17 748	4 284 240	936 342	0	1 291	0	3 786 790	**10 816 468**
Internat. poverty rate $2.00	159 099	2 228 770	29 868	23 557	5 768 140	1 256 590	0	1 700	0	5 473 760	**14 941 484**
Eritrea											
National rural poverty	406 079	0	245	798 225	0	295 770	2 071	0	1 589	6 567	**1 510 546**
Internat. poverty rate $1.25	151	0	0	716	0	51	0	0	0	4	**922**
Internat. poverty rate $2.00	310	0	0	1 405	0	100	0	0	0	7	**1 822**

(Continued)

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Ethiopia											
National rural poverty	1 687 690	45 209	38 900	4 217 470	1 408 250	13 204 400	44 670	1 404	102 934	256 080	**21 007 007**
Internat. poverty rate $1.25	1 564 880	41 520	35 354	3 666 430	1 225 760	11 461 000	38 575	1 217	89 037	226 180	**18 349 953**
Internat. poverty rate $2.00	2 985 580	76 108	75 596	7 274 720	2 430 990	22 773 400	76 823	2 435	176 037	442 765	**36 314 454**
Gabon											
National rural poverty	271	3 532	0	0	8 119	0	0	0	0	16 016	**27 938**
Internat. poverty rate $1.25	15	43	0	0	302	0	0	0	0	476	**836**
Internat. poverty rate $2.00	99	1 106	0	0	2 437	0	0	0	0	8 763	**12 405**
Gambia											
National rural poverty	5 965	0	0	264 052	0	0	408	0	0	9 771	**280 196**
Internat. poverty rate $1.25	631	0	0	20 466	0	0	47	0	0	833	**21 977**
Internat. poverty rate $2.00	5 319	0	0	238 227	0	0	360	0	0	8 855	**252 761**
Ghana											
National rural poverty	71 121	238 893	0	411 937	2 152 940	0	498	450	0	92 392	**2 968 231**
Internat. poverty rate $1.25	47 434	203 128	0	313 174	1 652 100	0	399	344	0	70 956	**2 287 535**
Internat. poverty rate $2.00	90 700	327 066	0	560 994	2 952 320	0	695	636	0	127 635	**4 060 046**
Guinea-Bissau											
National rural poverty	305 870	158 491	0	188 766	1 045 400	1 274	1 561	2 049	0	36 884	**1 740 295**
Internat. poverty rate $1.25	67 705	621	0	213 086	10 190	0	2 626	0	0	31 816	**326 044**
Internat. poverty rate $2.00	106 512	892	0	341 387	16 644	0	4 308	0	0	50 761	**520 504**
Guinea											
National rural poverty	90 317	768	0	286 697	14 373	0	3 556	0	0	42 706	**438 417**
Internat. poverty rate $1.25	535 771	271 033	0	347 973	1 845 870	2 304	2 656	3 752	0	66 029	**3 075 388**
Internat. poverty rate $2.00	647 861	329 662	0	431 746	2 298 830	2 845	3 402	4 618	0	81 875	**3 800 839**
Kenya											
National rural poverty	801 555	25 213	92 208	1 584 660	1 748 920	3 870 240	29 631	26 878	24 078	786 881	**8 990 264**
Internat. poverty rate $1.25	347 255	10 930	38 843	626 525	694 167	1 535 980	11 827	10 682	9 580	313 888	**3 599 677**
Internat. poverty rate $2.00	714 746	20 944	76 340	1 273 040	1 405 130	3 108 190	23 772	21 574	19 345	632 705	**7 295 786**

(Continued)

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Lesotho											
National rural poverty	0	0	21 018	863	0	537 835	100	0	559	375	**560 750**
Internat. poverty rate $1.25	0	0	15 873	681	0	425 879	80	0	457	305	**443 275**
Internat. poverty rate $2.00	0	0	25 914	985	0	613 892	119	0	659	442	**642 011**
Liberia											
National rural poverty	1	62	0	104	421 684	1	0	2	0	153 197	**575 051**
Internat. poverty rate $1.25	2	91	0	143	592 831	1	0	4	0	225 082	**818 154**
Internat. poverty rate $2.00	2	97	0	162	669 032	1	0	4	0	250 119	**919 417**
Madagascar											
National rural poverty	861 529	146 772	16 642	720 596	1 364 480	685 539	23 519	17 334	8 499	454 691	**4 299 601**
Internat. poverty rate $1.25	1 109 540	187 603	23 196	914 916	1 728 110	870 379	30 251	22 423	10 921	585 738	**5 483 077**
Internat. poverty rate $2.00	1 390 410	240 914	28 861	1 202 570	2 282 640	1 148 550	39 899	29 282	14 368	769 280	**7 146 774**
Malawi											
National rural poverty	20 059	10 767	2 975	3 229 040	901 373	84 599	919	4 333	0	165 001	**4 419 066**
Internat. poverty rate $1.25	26 013	14 075	3 916	4 266 170	1 191 030	111 764	1 209	5 732	0	217 336	**5 837 245**
Internat. poverty rate $2.00	31 484	16 755	4 779	5 219 780	1 457 230	136 744	1 485	7 003	0	265 678	**7 140 938**
Mali											
National rural poverty	1 264 700	30	0	3 134 430	271	0	19 404	0	0	18 711	**4 437 546**
Internat. poverty rate $1.25	891 884	21	0	2 122 140	182	0	12 923	0	0	12 536	**3 039 686**
Internat. poverty rate $2.00	1 266 670	33	0	3 195 970	274	0	19 505	0	0	18 928	**4 501 380**
Mauritania											
National rural poverty	864 392	0	0	96 801	0	0	1 226	0	0	1 904	**964 323**
Internat. poverty rate $1.25	242 707	0	0	31 453	0	0	500	0	0	739	**275 399**
Internat. poverty rate $2.00	560 612	0	0	62 168	0	0	740	0	0	1 133	**624 653**
Mozambique											
National rural poverty	1 028 160	229 669	3 363	1 756 500	866 986	9 370	7 427	1 616	0	615 277	**4 518 368**
Internat. poverty rate $1.25	1 379 650	316 383	5 244	2 372 940	1 170 420	12 824	10 239	2 171	0	837 445	**6 107 316**
Internat. poverty rate $2.00	1 603 450	374 063	6 099	2 853 310	1 422 680	15 420	12 066	2 656	0	1 014 640	**7 304 384**

(Continued)

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Namibia											
National rural poverty	443 940	0	48	213 446	0	0	25	0	0	8 879	**666 338**
Internat. poverty rate $1.25	437 262	0	48	176 861	0	0	21	0	0	7 505	**621 697**
Internat. poverty rate $2.00	497 511	0	48	225 726	0	0	29	0	0	9 353	**732 667**
Niger											
National rural poverty	1 992 330	0	0	4 034 440	0	0	16 034	0	0	5 266	**6 048 070**
Internat. poverty rate $1.25	1 992 590	0	0	4 037 430	0	0	16 017	0	0	5 293	**6 051 330**
Internat. poverty rate $2.00	2 546 770	0	0	5 249 430	0	0	20 875	0	0	6 873	**7 823 948**
Nigeria											
National rural poverty	119 097	376 933	608	8 686 050	8 238 150	28 979	50 459	11 862	0	609 174	**18 121 312**
Internat. poverty rate $1.25	224 462	668 355	916	15 373 800	14 585 600	49 763	89 908	20 838	0	1 073 130	**32 086 772**
Internat. poverty rate $2.00	283 461	853 508	1 214	20 019 400	19 030 600	66 046	117 280	27 372	0	1 396 480	**41 795 361**
Rwanda											
National rural poverty	0	0	0	0	677 240	2 294 160	0	8 089	19 171	95 057	**3 093 717**
Internat. poverty rate $1.25	0	0	0	0	830 054	2 811 510	0	9 927	23 509	116 642	**3 791 642**
Internat. poverty rate $2.00	0	0	0	0	979 472	3 314 900	0	11 673	27 708	137 125	**4 470 878**
Senegal											
National rural poverty	179 579	0	0	1 746 170	0	0	6 186	0	0	22 941	**1 954 876**
Internat. poverty rate $1.25	155 447	0	0	1 431 930	0	0	5 414	0	0	19 000	**1 611 791**
Internat. poverty rate $2.00	256 404	0	0	2 605 980	0	0	9 607	0	0	33 655	**2 905 646**
Sierra Leone											
National rural poverty	596	41 576	11	852	1 668 910	439	9	12 968	0	64 603	**1 789 964**
Internat. poverty rate $1.25	396	27 976	8	555	1 113 180	308	6	8 745	0	43 713	**1 194 887**
Internat. poverty rate $2.00	573	39 905	11	790	1 588 780	439	9	12 516	0	62 419	**1 705 442**
South Africa											
National rural poverty	396 804	44 990	156 601	2 733 670	1 536 560	1 112 580	26 917	5 466	4 073	252 168	**6 269 829**
Internat. poverty rate $1.25	150 803	20 251	72 658	1 222 180	684 260	510 477	11 734	2 465	1 774	111 309	**2 787 911**
Internat. poverty rate $2.00	205 586	29 163	96 528	1 964 810	1 119 600	807 819	19 495	4 013	2 929	183 196	**4 433 139**

(Continued)

TABLE G RURAL POOR LIVESTOCK KEEPERS ESTIMATED BY COUNTRY AND LIVESTOCK PRODUCTION SYSTEM (VERSION 5, NOT DISTINGUISHING HYPER-ARID AREAS). POVERTY RATES ARE FROM WORLD BANK (2011) *(Continued)*

Country	LGA	LGH	LGT	MRA	MRH	MRT	MIA	MIH	MIT	Other	Total
Sudan											
National rural poverty	6 241 150	202 535	25	4 011 420	137 362	6 978	157 053	0	18	106 781	**10 863 322**
Internat. poverty rate $1.25	212	176	4	294	308	0	0	0	0	5	**999**
Internat. poverty rate $2.00	355	227	7	428	440	0	0	0	0	15	**1 472**
Swaziland											
National rural poverty	0	0	0	102 521	84 438	80 666	512	101	40	77 443	**345 721**
Internat. poverty rate $1.25	0	0	0	87 064	71 416	68 163	457	83	32	66 833	**294 048**
Internat. poverty rate $2.00	0	0	0	112 606	91 079	86 948	583	110	44	87 266	**378 636**
Togo											
National rural poverty	0	140 998	0	171 703	518 230	0	24	537	0	4 575	**836 067**
Internat. poverty rate $1.25	0	174 180	0	203 382	611 897	0	36	620	0	5 447	**995 562**
Internat. poverty rate $2.00	0	305 817	0	362 907	1 099 670	0	60	1 117	0	9 894	**1 779 465**
Uganda											
National rural poverty	9 518	73 090	2 561	35 344	4 903 910	1 130 550	0	2 010	957	196 213	**6 354 153**
Internat. poverty rate $1.25	13 336	104 534	3 572	50 344	7 380 830	1 699 330	0	3 022	1 435	295 121	**9 551 524**
Internat. poverty rate $2.00	18 960	156 687	4 997	75 410	10 834 800	2 493 210	0	4 431	2 110	432 498	**14 023 103**
United Republic of Tanzania											
National rural poverty	295 924	159 941	42 842	3 062 750	2 647 450	753 579	19 352	2 774	1 588	690 731	**7 676 931**
Internat. poverty rate $1.25	635 170	357 790	99 717	6 650 600	5 830 820	1 663 540	42 235	5 981	3 488	1 516 030	**16 805 371**
Internat. poverty rate $2.00	721 078	413 274	114 126	7 320 710	6 407 590	1 824 340	46 205	6 562	3 810	1 664 990	**18 522 685**
Zambia											
National rural poverty	2 220 880	290 087	87 542	1 208 690	38 222	7 480	6 688	28	0	338 064	**4 197 681**
Internat. poverty rate $1.25	1 933 660	239 249	69 083	978 535	31 167	5 775	5 560	21	0	274 537	**3 537 587**
Internat. poverty rate $2.00	2 391 270	303 782	89 864	1 235 830	39 629	7 685	6 853	28	0	339 016	**4 413 957**
Zimbabwe											
National rural poverty	630 076	11	10 251	1 596 730	6 201	137 140	8 257	0	710	84 882	**2 474 258**
Internat. poverty rate $1.25	118	0	0	99	0	12	0	0	0	145	**374**
Internat. poverty rate $2.00	142	0	0	125	0	15	0	0	0	175	**457**

Developing regions are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

Informed livestock sector policy development and priority setting is heavily dependent on a good understanding of livestock production systems. In a collaborative effort between the Food and Agriculture Organization and the International Livestock Research Institute, stock has been taken of where we have come from in agricultural systems classification and mapping; the current state of the art; and the directions in which research and data collection efforts need to take in the future.

The book also addresses issues relating to the intensity and scale of production, moving from what is done to how it is done. The intensification of production is an area of particular importance, for it is in the intensive systems that changes are occurring most rapidly and where most information is needed on the implications that intensification of production may have for livelihoods, poverty alleviation, animal diseases, public health and environmental outcomes.

A series of case studies is provided, linking livestock production systems to rural livelihoods and poverty and examples of the application of livestock production system maps are drawn from livestock production, now and in the future; livestock's impact on the global environment; animal and public health; and livestock and livelihoods.

This book provides a formal reference to Version 5 of the global livestock production systems map, and to revised estimates of the numbers of rural poor livestock keepers, by country and livestock production system. These maps and data are freely available for download via FAO's web pages: http://www.fao.org/AG/againfo/resources/en/glw/home.html. It is hoped that this publication will stimulate further work in this field and encourage the use of livestock production systems information and maps in research and analysis.

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