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Global Mapping of Agricultural Production Systems

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A Living from Livestock

PPLPI Meeting Report

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1. OVERVIEW

1.1 Introduction

Many organizations are involved in assembling and disseminating global spatial data sets that can be used for a wide variety of purposes. Currently, one of the biggest gaps in these data sets is a spatial agricultural systems classification, that provides adequate detail on crops and livestock, and in particular that manages to break down the “mixed systems” category into more useful components.

Global data sets are becoming increasingly important for priority setting and targeting by organizations with a global mandate for agriculture and agricultural research for development in developing countries, such as FAO, the international centres of the Consultative Group on International Agricultural Research (CGIAR) system, and regional and subregional research organisations. The world within which agricultural research for development is practised is extremely dynamic, and given recent shifts of focus of the CGIAR towards poverty alleviation, priority setting and targeting are not one-off events, but have to be continually refined and updated. Recent evidence suggests that there can be considerable heterogeneity in the determinants of rural poverty, one implication of this being that poverty alleviation efforts will have to be targeted at much smaller intervention (or recommendation) domains than have perhaps been considered in the past.

This meeting was designed to fill a key gap in available spatial databases by bringing a group of people together to brainstorm on the difficult problems involved, and identify a way forward, in developing a dynamic global agricultural production systems classification that can be mapped, ground-truthed and refined through time. The work built on considerable efforts that have been made in the past, and will be based on “case study” systems classifications developed for a diverse range of countries, from which general lessons can be learnt for applying to the global scale. The outputs from this meeting will find immediate application in the work of FAO and the CGIAR centres, in targeting technology and policy interventions that are effective in promoting sustainable livelihoods of the poor in developing countries. The meeting was funded by FAO’s Pro-Poor Livestock Policy Initiative.

1.2 Workshop Objectives

1. To review and summarize existing global agricultural production system classifications.
2. Based on existing classifications and five country case studies, to develop a common classification framework that can a) be mapped using existing global data sets, b) meet various operational requirements (e.g. stratification for livestock production modelling), and c) be of operational use at national level.
3. Begin to develop a detailed plan of work for completing a global systems classification.

1.3 Background

In September 2004 a “global spatial data and information user workshop”, focusing on data development, dissemination and use, was held at the Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA. The workshop was co-organized by the Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University, the United Nations Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), the World

Health Organization (WHO), and the Consultative Group on International Agricultural Research (CGIAR). The meeting covered a wide range of topics, including standardization/harmonization of spatial data and information, integration of biophysical and socioeconomic data, identification of users' needs for online data services, and education and capacity building in how to use such services. In addition to these a stock-take was made of global data sets, under the following three broad themes: environment; food and agriculture; and population, poverty and health.

The principal organizer of the workshop reported here (Robinson) was charged with exploring gaps in food and agriculture datasets. In consultation with other participants it was concluded that the most significant gaps were in our understanding of the distribution of agricultural production systems, and a particular need was identified to disentangle the "mixed farming system" categories. To address this issue would clearly require building on existing work to define a generally applicable production system classification, and to identify (and fill) gaps in global coverage of the input data.

It was recommended at the meeting that FAO and the CGIAR should champion efforts to resolve this shortfall, and it was acknowledged that on-going activities should be promoted in terms of collating input data. The workshop reported here was organised in direct response to that recommendation, building on the immediate requirements of FAO's Pro-Poor Livestock Policy Initiative for digital maps of agricultural production systems in its five focus countries.

There have been many farming systems classifications proposed over the last 40 years. With the advent of GIS and current availability of global spatial data sets, the prospects are very good of being able to use relatively high-resolution raster data on livestock, crops, land cover and land use to develop a mapable systems classification that can be useful for a wide variety of potential users.

There are various features that a global farming systems classification should have:

- It has to be feasible using available or easily-derived global data sets, ideally at a resolution of 30 arc-seconds (about 1km at the equator).
- A statistical approach to systems classification should be avoided as far as possible, to render the classification scheme interpretable and repeatable, given updates of information, additional data layers and adjustments to classification criteria.
- The classification scheme should be hierarchical, so that it depends on the scale at which one is operating, but higher-resolution system types are nested within the same coherent framework that operates independently of scale.
- The scheme needs to account adequately for livestock systems and deal with issues of convergence versus independence of livestock-cropping systems – in other words, the fact that 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 have an emphasis on the poor, in terms of being able to identify relatively small populations of poor crop farmers and livestock keepers, 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 development of production systems.

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. Ruthenberg (1980), for example, distinguishes among collection, cultivation, and grassland utilisation (at the global level collection probably does not need to be dealt with, because of its economic insignificance). For cultivation, the classification is based on the type of rotation (natural fallow, ley system, field system, system with perennial crops) associated with 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 gown per year). For grassland utilisation, there is a continuum from total nomadism, through transhumance, to settled animal husbandry.

Another example is that of Grigg (1972), who starts from a consideration of work done in the 1930s on distinguishing characteristics of agriculture (Whittlesey, 1936). The Dixon and Gulliver (2001) approach comes up with a classification based broadly on rainfed/irrigated, agroecology, and location (urban/coastal), although this does not involve livestock in any detail. Seré and Steinfeld (1996) dealt with livestock systems based on agroecology and the distinction between mixed and pastoral, irrigated and rainfed, and urban/landless. This has been mapped (Kruska *et al.*, 2003), but no distinction is possible within the 'mixed system' category.

It should be noted that such classification schemes are very different from the approach of agro-ecological zonation. These are now becoming very sophisticated (for example, see Fisher *et al.*, 2002), and manage to avoid entirely the problem of farming system definition. However, such analyses have little to say as to the future and potential impacts of change on sustainable livelihoods at the household level.

As far as we are aware, no global classification system deals with small ruminants, monogastric species (pigs and poultry), bees, rabbits, etc, but the impacts of such livestock species on poverty alleviation and household food security may be profound in particular situations. How these should be dealt with in a global scheme is not yet clear.

During the workshop we hoped to consider the following:

- How to develop a classification scheme that deals with agricultural production systems and the livestock components in detail.
- What are the critical data layers that can be used for the work? These would include layers such as livestock, population, climate and cropping, and a comprehensive inventory has just been completed by FAO.
- How can the classification be validated? This may go beyond changing thresholds and re-running the classification fairly quickly, to use of other standard data sets that could be used, such as the World Bank Living Standards Measurement Survey (LSMS) data, which sometimes contain information on farming and livestock.

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2. REVIEW OF EXISTING GLOBAL AGRICULTURAL SYSTEMS CLASSIFICATIONS

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2.1 Overview

There have been many farming systems classifications proposed over the last 40 years. With the advent of GIS and global data sets, the benefits of being able to slice relatively high-resolution raster data (livestock densities, crop land, numbers of poor people, etc) in various ways are considerable. Ruthenberg (1980), for example, distinguishes between collection, cultivation, and grassland utilisation (collection probably does not need to be dealt with, because of its economic insignificance). For cultivation, he ends up with a classification based on the type of rotation (natural fallow, ley system, field system, system with perennial crops) associated with 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 2 years of cropping and 18 of fallow; R=300 for a system where 3 crops are gown per year). For grassland utilisation, Ruthenberg talks about the continuum from total nomadism through to stationary animal husbandry via transhumance.

Grigg (1972) starts from a consideration of work done in the 1930s on distinguishing characteristics of agriculture, but rapidly backs away from this to arrive at a rather motley collection of systems. The Dixon/FAO approach (Dixon *et al.*, 2001) arrives at a classification based broadly on rainfed/irrigated, agroecology, and location (urban/coastal) though this does not involve livestock in any detail. Seré and Steinfeld (1996) deal with livestock systems based on agroecology and the distinction between mixed and pastoral, irrigated and rainfed, and urban/landless.

Note that this is all very different from the approach of agroecological zonation. These are now becoming very sophisticated (see Fisher *et al.* (2002), for example). On the one hand, analyses based on AEZs avoid entirely the problem of farming system definition. But on the other, such analyses have very little to say as to the future and potential impacts of change on sustainable livelihoods at the household (the system of major interest) level.

There is no generic system that is truly comprehensive and can serve all purposes. The poverty focus, while making a lot of sense from the poverty alleviation angle, will probably cause many problems in mapping, either because appropriate global data sets do not exist or because of problems in trying to represent essentially non-spatial factors in spatial terms.

Pragmatically, we can attempt to develop some system as a refinement or development of existing classifications (see Table 2.1), at the same time as we are assembling global data sets that can be used in the mapping work. It seems that one practicable option might be to modify and extend S&S to incorporate something much more comprehensive on the cropping side.

We seem to be caught between the following: we can map broad systems and zones based on available data sets, but we are quite a way from making these relevant to livelihood options (issues related to crop distribution, livestock distribution, heterogeneity of systems, etc).

During the meeting, it would be good to develop some clarity on the following issues:

1. We need to be clear about what the purposes of the classification system will be. Might the classification hierarchy be collapsible in terms of the cropping side and

the livestock side, depending on requirements? In terms of uses, certainly summarizing livestock, population and poverty data by farming systems would be a major use.

2. Can we identify critical data layers for the work? We should use standard and evolving datasets wherever possible. We should also try and avoid using different datasets that measure similar variables.
3. Is it best to modify or expand an existing classification system?
4. And how do we go about calibrating and validating the classification?

Table 2.1: *A comparison of some existing farming system classifications. In the columns showing how crops and livestock are dealt with, numbers indicate (very broadly) the stages in the classification.*

Classification	How are crops dealt with?	How are livestock dealt with?	How many categories?	Pros, cons, and can it be mapped?
Ruthenberg (after FAO etc.)	1. Degree of cultivation (R) 2. Forest, bush, savanna, grass 3. Crop type 4. Irrigated vs rainfed	1. Degree of movement/ permanence	8 major	Possibly overly broad categories, and incomplete?
Grigg (after Whittlesey etc.)	1. Crop type 2. Commercialisation 3. Location/agro-ecology	1. Degree of movement/ permanence	9 major	The system is incomplete and somewhat selective
Dixon/FAO	1. Crop type 2. Commercialisation 3. Location/agro-ecology	1. 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 & Steinfeld	1. Are there crops or not? 2. Rainfed vs irrigated 3. Agro-ecology	1. Landless or rangeland based 2. Agroecology	11 major	Livestock based, so no categorisation of crop systems Can be mapped as is

2.2 Discussion

The discussion focused on several issues. One issue was the nature of the mixed systems. The point was made that crops are rather easier to deal with than livestock (mobility etc). In addition, we tend to map what we are able to, given what we have. The CGIAR focus is often on mixed, integrated systems, rather than the large systems. For example, rabbits, ducks, bees etc – these are very important in some livelihood systems, but they are very hard to show up on maps. This is a major challenge.

Another issue related to the use of such a classification. There was a feeling that we need to concentrate on agricultural systems rather than land-use systems, but it needs to be a broad-based classification system, that would allow different perspectives. Clarity is definitely needed on the purposes of such maps, otherwise they may be seen as rather supply-driven. The question was raised, are we after a map *per se*, or is it rather a framework or a tool that is needed, that can be used for a wide variety of different purposes? But the level of detail is key: for example, we may be interested in land degradation, which is heavily related to land management – this may entail a different level of detail from a production orientation (for instance).

There was also discussion about the limits to what is realistically possible. Can a systems' classification be made scale-independent? FAO's LCCS system of land cover was cited as an example of a hierarchical system built around key functional elements. It was pointed out that when we talk of 'global data', we can mean either global data sets, or (more interestingly) data that are important everywhere – but it is probably not meaningful to talk of a "one size fits all" classification system. In fact we need both global maps, and that these maps be more detailed. In addition, the point was made that the drivers of change in agricultural systems will often not be able to be represented spatially (and are thus outside the scope of our spatial data sets), which makes representing the dynamics of systems challenging.

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3. A DYNAMIC LIVESTOCK PRODUCTION SYSTEM CLASSIFICATION SCHEME

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3.1 Introduction

Seré and Steinfeld (1996) developed a global livestock production system classification scheme. In it, livestock systems fall into four categories: landless systems, livestock only/rangeland-based systems (areas with minimal cropping), mixed rainfed systems (mostly rainfed cropping combined with livestock) and mixed irrigated systems (a significant proportion of cropping uses irrigation and is interspersed with livestock). A method has been devised for mapping the classification, based on agro-climatology, land cover, and human population density (Kruska *et al.*, 2003). The classification system can be run in response to different scenarios of climate and population change, to give very broad-brush indications of possible changes in livestock system distribution in the future.

3.2 Model Structure and Data

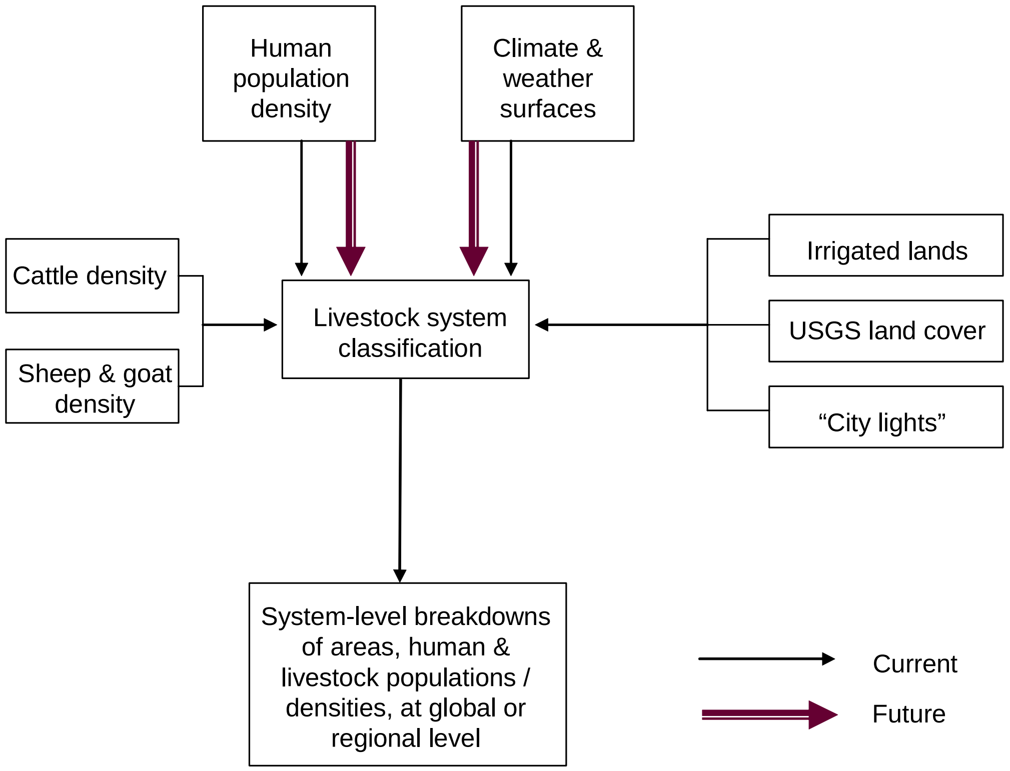
The livestock production system proposed by Seré and Steinfeld (1996) is made up of the following types:

- Landless monogastric systems, in which the value of production of the pig/poultry enterprises is higher than that of the ruminant enterprises.
- Landless ruminant systems, in which the value of production of the ruminant enterprises is higher than that of the pig/poultry enterprises.
- Grassland-based systems, in which more than 10 percent of the dry matter fed to animals is farm produced and in which annual average stocking rates are less than 10 temperate livestock units per hectare of agricultural land.
- Rainfed mixed farming systems, in which more than 90 percent of the value of non-livestock farm production comes from rainfed land use, including the following classes.
- Irrigated mixed farming systems, in which more than 10 percent of the value of non-livestock farm production comes from irrigated land use.

The grassland-based and mixed systems are further categorized on the basis of climate: arid –semiarid (with a length of growing period < 180 days), humid-subhumid (LGP > 180 days), and tropical highlands/temperate regions. This gives 11 categories in all. This system has been mapped using the methods of Kruska *et al.* (2003) (Figure 3.1), and is now regularly updated with new datasets (Kruska, 2006). For land-use/cover, we use version 3 of the Global Land Cover (GLC) 2000 data layer (JRL, 2005). For Africa, this included irrigated areas, so this is used instead of the irrigated areas database of Döll and Siebert (2000), which is used for Asia and Latin America. For human population, we use new 1km data (GRUMP, 2005). For length of growing period, we use a layer developed from the WorldCLIM 1km data for 2000 (Hijmans *et al.*, 2004), together with a new "highlands" layer for the same year based on the same dataset (Jones and Thornton, 2005). Cropland and rangeland are now defined from GLC 2000, and rock and sand areas are now included as part of rangelands.

The original LGP breakdown into arid-semiarid, humid-subhumid and highland-temperate areas has now been expanded to include hyper-arid regions, defined by FAO as areas with zero growing days. This was done because livestock are often found in some of these regions in wetter years when the LGP is greater than zero. Areas in GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2 as well as a LGP greater than 60 (which can allow cropping) are now included in the mixed system categories. The landless systems still present a problem, and are not included in version 3 of the classification. Urban areas have been left as defined by GLC 2000. To look at possible changes in the future, we use the GRUMP population data and project human population out to 2030 and 2050 by pro-rata allocation of appropriate population figures (e.g., the UN medium-variant population data for each year by country, or the Millennium Ecosystem Assessment country-level population projections). LGP changes to 2030 and 2050 are projected using downscaled outputs of coarse-gridded GCM outputs, using methods outlined in Jones and Thornton (2003).

Figure 3.1: *Mapping the Seré and Steinfeld (1996) livestock production system classification.*



3.3 Application

The mapped Seré and Steinfeld (1996) classification was originally developed for a global livestock and poverty mapping study designed to assist in targeting research and development activities concerning livestock (Thornton *et al.*, 2000; 2003). Estimates of the numbers of poor livestock keepers by production system and region were derived and mapped. This information was used in the study of Perry *et al.* (2002), which was carried out to identify priority research opportunities that can 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). The methods have recently been used in work to assess the spatial distribution of methane emissions from African domestic ruminants to 2030 (Herrero *et al.*, 2006), and in a study to map climate vulnerability and poverty in sub-Saharan Africa in relation to projected climate change (Thornton *et al.*, 2006).

3.4 Uncertainty

Uncertainties in the scheme are outlined in Table 3.1.

Table 3.1: *Major uncertainties in the mapped Seré and Steinfeld (1996) classification.*

Model Structure	• Based on thresholds associated with human population density and length of growing period • Also based on land-cover information that is known to be currently weak with respect to cropland identification • The global classification is quite coarse, and no differentiation is made of the mixed systems
Parameters	**Inputs:** • Land cover, length of growing period, human population density, irrigated areas, urban areas • Observed or modelled livestock densities **Outputs:** • Areas associated with grassland-based systems and mixed crop-livestock systems (rainfed and irrigated), broken down by AEZ (which can then be combined with other national or sub-national information, such as poverty rates)
Driving force	• Even at the broad-brush level, population change and climate change will not be the only drivers of land-use change in livestock-based systems, globally
Initial condition	• Some validation of the systems layers has been carried out for current conditions, but more is needed
Model operation	• Assembling the input data and running the classification is not an automated procedure. It requires separate sets of FORTRAN programmes for estimating changing agro-climatological conditions; and various sets of ArcInfo scripts for spatially allocating population data and rerunning the classification

3.5 Future Classification Modifications

We are currently exploring ways to further delineate the mixed crop-livestock systems based on IFPRI's global spatial allocation of crop data (You and Wood, 2004). Preliminary attempts have involved mapping major crop types or certain combinations such as “dominant cereal” of yields or distribution information within mixed systems. Although such attempts have added value to the classification, the number of crops and/or combinations that might be required by users are too numerous to be practical.

Instead, we have decided to keep the systems map dynamic by making future versions of the livestock mixed systems areas identical to IFPRI's extent of cropped areas. Thus if the two databases are harmonized, it should be very easy for users to map or obtain the necessary summary crop statistics within any or all of the livestock mixed systems as needed. In other words, the databases together can be used to drive end users' needs.

The livestock systems also need to be harmonized with FAO's Gridded Livestock of the World database (Robinson *et al.* 2007; FAO (2007). In this case, the areas defined as having livestock must be identical. For example, the livestock-only areas and mixed systems must only be in areas defined by FAO as having certain species of livestock (the ‘ruminant’ or ‘monogastric’ masks are binary layers that delineate areas as being suitable or not). Again, the end user can decide how to use the livestock density information in conjunction with the livestock systems map in terms of further defining livestock-only systems or mixed systems, or simply by reporting livestock numbers by species within existing systems.

Finally, where needed, other farming system information can be combined when necessary with the ILRI livestock systems layers. An example would be that used in vulnerability mapping for Africa where some of the FAO-World Bank farming system categories for Africa (Dixon and Gulliver, 2001) were included on the same map as the livestock systems as ‘non livestock’ categories (forest crops, coastal artisan fishing etc.).

3.6 Discussion

A few questions of clarity were addressed. The human population projections were done on the basis of the rates of change for the years 1990-2000, and then numbers were adjusted pro rata out to 2030 so that projections matched the national estimates. The Seré and Steinfeld classification has not been mapped yet for the developed world - this needs to be done.

The importance was highlighted of breaking down the mixed systems, to assess the availability (and possible limits to) feed resources.

It was also noted that this livestock production system mapping work has fed into several priority setting activities, including work at ILRI in 2000, and more recently work carried out for the sub-Saharan Africa Challenge Programme.

The point was made that the issue of irrigation is a complex one: it can bring about enormous changes to farming systems, and a yes/no approach may actually skate over a lot of this complexity, in terms of what could be done in the future, if there were irrigation infrastructure in particular places. There is on-going work at IWMI and elsewhere on trying to map the irrigation characteristics of specific locations (e.g. canals, supplemental, etc), but there is a lot more work to do. This was felt to be especially important, as globally, the loss of functional irrigation capacity per year is more than the gains.

There was some discussion of the need to include other key livelihood options in the mixed systems (such as aquaculture). It was noted that we may need to experiment more with changing population thresholds for some systems, such as the coastal zones, where these are often particularly high. Gap analysis (in data availability) was felt to be important. Even if there is good information, there are still benefits to mapping, to be able to understand better the spatial characteristics of systems, for example.

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4. FAO'S GLOBAL LIVESTOCK INFORMATION SYSTEM

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4.1 Introduction

One of the major limitations in livestock sector planning, policy development and analysis is the paucity of reliable and accessible information on the distribution, abundance and use of livestock. With the objective of redressing this shortfall, the United Nations Food and Agriculture Organisation's Livestock Production and Health Division (FAO-AGA) has developed a global livestock information system in which geo-referenced livestock data are collated, standardised and made freely available through FAO's website. Where gaps exist in the available data, or where spatial detail is insufficient, livestock numbers have been predicted from empirical relationships between livestock densities and environmental, demographic and climatic variables in similar agro-ecological zones. This approach enables coarse resolution livestock statistics, for example at provincial administrative level, to be disaggregated into modelled raster data, with a spatial resolution, presently, of about 5km. This methodology for modelling livestock distributions has been summarised in a short paper (Robinson *et al.*, 2007) and is written up in detail, with examples of applications in FAO (2007).

4.2 Methods and Results

Available national agricultural statistics on livestock populations are collected and converted to densities that are adjusted to account for the area of land deemed suitable for livestock production based on environmental, land-cover and land-use criteria. For example, livestock are excluded from areas where satellite-derived vegetation indices indicate there to be insufficient grazing; where other features of land-cover, such as elevation and slope would preclude livestock development; and where prevailing land-use would not permit livestock to occur, such as in urban and protected areas. This data archive provides the training data that are used to establish statistical relationships between livestock densities and a series of predictor variables. This modelling approach has the major advantages both of predicting livestock densities in areas with no livestock data and disaggregating livestock density data that were available originally only at a coarse spatial resolution. Since the predictors of animal density are unlikely to be consistent from region to region, or across different agro-ecological zones, models are developed separately for different geographical regions and for different ecological zones (defined empirically by cluster analysis of remotely sensed climatic variables).

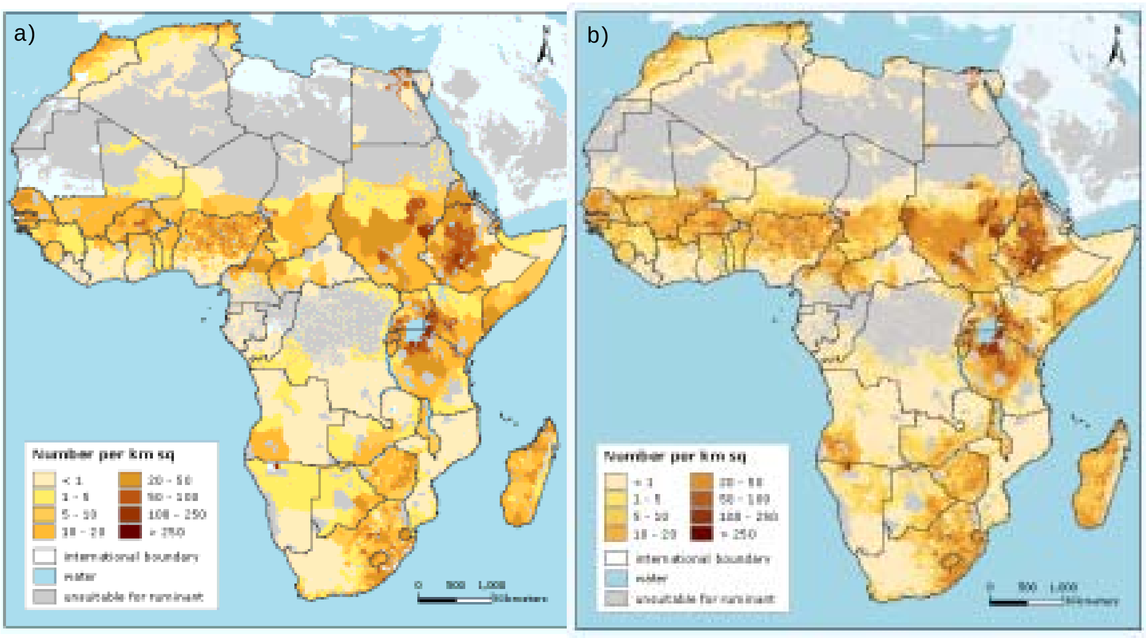
4.3 Worked Example – Cattle in Africa

Cattle densities are derived from various national census reports, livestock surveys and data archives from 1992 to 2003. In Africa, for example (Figure 4.1a), most known cattle population data come from fairly large administrative units; usually administrate level 1 (province) or level 2 (district).

Values are extracted for approximately 19,000 sample points regularly spaced over the land mass of Africa. A series of stepwise multiple regression analyses is performed between cattle densities and a range of predictor variables, including satellite derived measures of rainfall, temperature, vapour pressure deficit and vegetation cover;

elevation; potential evapo-transpiration; length of growing period; tsetse fly distributions; and human population density. The derived equations are then applied to the predictor variables to generate a map of predicted cattle density at a spatial resolution of three minutes of arc (approximately 5km at the equator). To avoid spurious predictions, the predicted total numbers for each administrative unit are then adjusted to equal those reported for that administrative unit. A further product is generated, adjusting the predicted national totals to match FAO's official national statistics for the year 2000, providing a time-standardised dataset.

Figure 4.1: *Gridded Livestock of the World products for Africa: a) observed cattle density, and b) predicted cattle density.*



The predicted cattle distribution in Africa (Figure 4.1b) mirrors the observed distribution (Figure 4.1a) very well and highlights major foci, such as the east and southern African highlands, Tanzania, semi-arid and dry sub-humid West Africa and minor foci, such as the Gezira irrigation scheme in Sudan, the inland delta of the river Niger in Mali, and southeastern Zambia.

Overall, human population density is a major determinant for all species distributions, being the primary predictor in 30% of regression equations used. It features particularly prominently in the case of monogastric species (pigs and chickens). The variables describing climatic seasonality are important predictors for all livestock species; length of growing period is important for ruminant species; elevation is important for cattle, as is the number of tsetse species; a factor peculiar to Africa.

Thus, for cattle, buffalo, sheep, goats, pigs and poultry and chickens, three global products (divided into 8 regional tiles) have been generated: (a) the reported densities, adjusted for land-suitability; (b) the modelled densities (adjusted to match the original reported totals, at the administrative level by which they were reported); and (c) the modelled distributions corrected so that national totals match those provided by FAOSTAT data for the year 2000.

4.4 Data Dissemination

The methodology described above relates specifically to the Gridded Livestock of the World (GLW)[1], and is explained in detail in a forthcoming publication (see website). These data layers are made freely available using FAO's GeoNetwork data repository[2], which provides a common portal for spatial data available from FAO. The underlying database of livestock statistics is also used to provide statistical input for a number of other information products. One of these is GLiPHA[3], the Global Livestock Production and Health Atlas, a user-friendly, highly interactive electronic atlas. The atlas provides a scaleable overview of spatial and temporal variation of quantitative animal production and health information through the combination of maps, tables and charts. Thematic layers include data on: the biophysical environment, socio-economics, livestock population and production, animal health and trade. Data are provided through country projects, usually at the provincial (level 1) administrative level, and a global project. The global project contains national data: livestock statistics are extracted from FAOSTAT[4], and disease information is derived primarily from the Office International des Epizooties (OIE) HANDISTATUS II database[5]. GLiPHA can be accessed interactively from its website or can be downloaded to a personal computer.

A further route for data dissemination is through the standard reports produced by FAO's Animal Production and Health Division (AGA). The national Livestock Sector Briefs and the regional Livestock Sector Reviews draw upon the livestock database for their statistical charts and tables. These reports are available from the AGA website[6].

4.5 Applications

The spatial nature of these livestock data allows a wide array of applications. Livestock distribution data provide the units to which production parameters (calving rates, milk yields *etc*.) may be applied for estimating livestock production; they can be used to evaluate impacts, both of and on livestock, by applying any number of different rates; they provide the denominator in prevalence and incidence estimates for epidemiological applications; and they provide the host distributions for disease transmission models. Many applications to which the data have already been put are described in some detail in a forthcoming publication, FAO's Gridded Livestock of the World, 2007. What follows is a summary.

Estimates of livestock biomass can be produced. Composite measures of livestock, such as 'tropical livestock units', combine population densities with the average weights of individuals of each species. A related application is to assess whether livestock populations in given areas exceed defined thresholds, such as the carrying capacity of the land (though the concept of carrying capacity for livestock is somewhat contentious, particularly in pastoral areas). This can be extended, through herd models, to projections of future livestock populations and estimates of production (for example, milk, meat and draft power). Production estimates can then be combined with consumption estimates (derived by multiplying average consumption rates with human population data), to derive production-consumption

[1] http://www.fao.org/ag/againfo/resources/en/glw/default.html

[2] http://www.fao.org/geonetwork

[3] http://www.fao.org/ag/aga/glipha/index.jsp

[4] http://faostat.fao.org

[5] http://www.oie.int/hs2

[6] http://www.fao.org/ag/againfo/resources/en/pubs_sap.html

balances and thus to infer where livestock and livestock products may be moving, an important consideration both in relation to trade and to disease transmission.

By appropriately adjusting the parameters in herd models, the impact of interventions (removing tsetse or controlling brucellosis, for example) can be estimated. By linking these estimates to current price data, they can be presented as cash figures as an input, for example, to benefit-cost estimates for livestock disease interventions. As well as estimating the impact of disease, a prerequisite for disease risk mapping is sound knowledge of the distributions of susceptible species and disease vectors.

Further applications of livestock distribution data include estimating the environmental impact of livestock. Environmental impacts may take a number of forms, such as overgrazing by ruminants and equines in densely populated mixed farming areas of Africa, nutrient overloading from industrial pig production in Southeast Asia, or forest encroachment for beef production at the fringes of the Latin American rainforests.

These data are intended for use not only by planners, but also by a much wider range of analysts and research professionals. What makes the data so valuable is that they are regularly updated and can be accessed directly via the FAO website in a number of different formats: graphics and tables (planning type applications) and detailed GIS layers (analytical applications).

It is through quantitative applications, such as those described above, that the impacts of technical interventions can be estimated and assessed. Also, by incorporating these data into appropriate decision support methodologies, the impacts of livestock-sector development policies can be evaluated so that informed recommendations for policy adjustments can be made. These new global datasets are an invaluable contribution to the rapidly expanding field of livestock geography, enabling us to explore the complex interrelationships among people, livestock and the environment in which they coexist.

4.6 Discussion

The questions was asked, what was the manpower needed for the Gridded Livestock of the World data set? The answer was, considerable. It was noted that the data years are different in this data set. No time cut-offs were used; the data used were as detailed as could be obtained, whatever the age.

This modelling is still based on the notion of "suitability". In a dynamic situation, the environmental predictors for non-ruminants may not be so good. It was acknowledged that more work needs to be done on suitability, as the clusters may go awry in the developed world, for example.

It was noted that one problem with maps in general is that they appear to portray 'accurate' information: what is really required is an error map. Perhaps we need to improve accuracy rather than resolution. Work is in progress to use higher-resolution input data, but the data layers have not really been validated or ground-truthed in any systematic way.

There was some discussion on the fact that in some parts of the world, the classical determinants of livestock distribution are becoming less important. In Vietnam, for example, pigs were associated with people 10 years ago, but nowadays, this is much less so. If the predictors in the model are static, how do we deal with system dynamics? It seems that one would either have to develop new regression models, or define new variables for the models. It is certainly the case that we are seeing the separation of land from production of livestock over time in many places.

There was also discussion of the point that such maps seem to need intelligent users, to understand the limits to what they can be used for – but of course, users may not always have adequate insight into such things. The need for local knowledge to validate these maps was noted.

4.7 References

FAO (2007) *Gridded Livestock of the World, 2007*, by G.R.W. Wint T.P. Robinson. Rome: Food and Agriculture Organization of the United Nations, Animal Production and Health Division.

Robinson, T.P., Franceschini, G, and Wint, G.R.W. (2007). FAO's Gridded Livestock of the World. *Veterinaria Italiana* **43,** (*page numbers forthcoming*).

5. *AGRO*-MAPS: A GLOBAL SPATIAL DATABASE OF SUB-NATIONAL AGRICULTURAL LAND-USE STATISTICS

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5.1 Background

Agricultural land-use information is a crucial input in developing strategies and plans to tackle issues of interest to FAO Member States, including: Food security & poverty; Land degradation; Climate change; Policy formulation; Land use planning; and Investments in sustainable agriculture.

Despite its importance, there is generally little consistent information of wide-area coverage on agricultural land use and its spatial variations *within* countries. The shortcomings of existing datasets and a growing requirement for more precise geographic targeting of interventions led FAO[7], IFPRI[8] (the International Food Policy Institute), SAGE[9] (The Center for Sustainability and the Global Environment) and CIAT[10] (The International Center for Tropical Agriculture), with some funding support from the Millennium Ecosystem Assessment, to develop jointly the Agro-MAPS (Mapping of Agricultural Production Systems) database. This database contains statistics on primary food crops, aggregated by sub-national administrative districts, on crop production, area harvested and crop yields. These selected statistics represent a limited, yet very important component of agricultural land use. The Agro-MAPS database now permits, for the first time, regional to global overviews of crop production statistics and their spatial variation on a sub national level

5.2 Available Data

The data in Agro-MAPS were obtained mainly from published reports on national agricultural censuses, usually carried out every 5 to 10 years, or from annual estimates reported in published sources. The data were pre processed in order to ensure overall consistency and enhance accuracy of the final integrated database. This included (i) replacement of non-standard crop names and statistic descriptions with standardized FAO unique identifier codes[11] (ii) conversion when necessary, of data on 'production', 'area harvested' and 'yield' to standardized reporting units (i.e. metric tons, hectare and metric tons per hectare, respectively). (iii) Adjustments to the reported year in order to facilitate subsequent comparisons between sub-national and national aggregated FAOSTAT statistics (iv) differentiation between 'not reported' and true 'zero' values, where possible. These instances are adequately commented, including citation of original sources, to facilitate eventual re-interpretation by end users.

The data are aggregated at the first and second levels of administrative subdivision below the national level. The statistical tables include unique identifier codes (NUTS[12]

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[7] http://www.fao.org/
[8] http://www.ifpri.org/
[9] http://www.sage.wisc.edu/
[10] http://www.ciat.cgiar.org/access/index.htm
[11] http://apps.fao.org/page/collections?subset=agriculture
[12] http://ec.europa.eu/comm/eurostat/ramon/nuts/splash_regions.html

for European countries, and SALB[13] for most other countries) for the administrative districts in each country. This allows ready visualization of the tabular data as maps. Emphasis has been placed on compiling recent data, however, data covering multiple years are also available for many countries. Data for a total of 134 countries (130 countries at admin1 level and 59 countries at admin2 level), from six geographic regions (Africa, Asia, Near East in Asia, Latin America and the Caribbean, North America and Oceania) and representing approximately 92 percent of the world's land surface, are currently (*June 2006*) available in Agro-MAPS.

Owing to its importance in characterizing agricultural production systems, information on major crop combinations will soon be added to the Agro-MAPS database.

5.3 Access to Agro-MAPS Data

Users can interactively browse the database and download statistical data in a variety of output formats (csv, dbf, xml) as well as the related shapefiles (excluding the shapefiles for Europe) from the Agro-MAPS web site[14]. Users can create, for a selected country or region, thematic maps showing the spatial distribution of crop production, area harvested and yields, by year (or for the latest year for which data are available). Data distributions can be examined and display legends subsequently modified dynamically. A CD-ROM version of Agro-MAPS with the same functionality as the web site, but with an important set of supplementary data for the USA, can be ordered from the Sales and Marketing Group, Food and Agricultural Organization of the United Nations, Viale delle Terme di Caracalla, 00100, Rome, Italy. E-mail: publications-sales@fao.org Fax: (+39) 06 57053360.

5.4 Discussion

It was noted that Africa has 57 countries (Admin level 0) and 5,690 units at Admin level 2. In terms of maintenance of the system with up-to-date statistics, there are only limited resources for this work, so it will have to be done on a targeted basis.

Agro-MAPS has similar functionality to KIMS/KIDS, in that it uses the standard FAO platform, but there are some additions, such as crop combinations. There were no plans to link this with the new country and sub-country FAOSTAT system in the future. The comment was made that there seems to be a need to coordinate efforts more within FAO.

[13] http://www3.who.int/whosis/gis/salb/salb_home.htm

[14] http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp

6. GENERATING GLOBAL CROP DISTRIBUTION MAPS: FROM CENSUS TO GRID

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6.1 Overview

As fundamental parameters for agriculture policy research, agricultural production statistics by geopolitical units such as country or sub-national entities have been used in many econometric analyses. However, collecting sub-national data is quite difficult in particular for developing countries. Even with great effort and only on regional scales, enormous data gaps exist and are unlikely to be filled. On the other hand, the spatial scale of even the subnational unit is relatively large for detailed spatial analysis. In order to evaluate food security, technology potential and the environmental impacts of production in a strategic and regional context, it is critical to have reliable information on the spatial distribution and coincidence of people, agricultural production, and environmental services. This paper proposed a spatial allocation model for generating highly disaggregated, crop-specific production data by a triangulation of any and all relevant background and partial information. This includes national or sub-national crop production statistics, satellite data on land cover, maps of irrigated areas, biophysical crop suitability assessments, population density, secondary data on irrigation and rainfed production systems, cropping intensity, and crop prices. This information is compiled and integrated to generate 'prior' estimates of the spatial distribution of individual crops. Priors are then submitted to an optimization model that uses cross-entropy principles and area and production accounting constraints to simultaneously allocate crops into the individual pixels of a GIS database. The result for each pixel (notionally of any size, but typically from 25 to 100 sq km) is the area and production of each crop produced, split by the shares grown under irrigated, high-input rainfed, and low-input rainfed conditions (each with distinct yield levels).

Following the testing in Latin America and sub-Saharan Africa, the spatial allocation model is applied to generate a global, detailed picture of crop production for 20 major crops (wheat, rice, maize, barley, millet, sorghum, potato, sweet potato, cassava and yams, plantain and banana, soybean, dry beans, other pulse, sugar cane, sugar beets, coffee, cotton, other fibres, groundnuts, and other oil crops). The detailed spatial datasets represent a truly unique and extremely rich platform for exploring the social, economic and environmental consequences of agricultural production in a strategic policy context.

6.2 Discussion

A question was asked about the determination of the input levels. The input levels are irrigated, subsistence, high-input rainfed, and low-input rainfed. Data were collected on area and yield by input levels, mostly on a country level but on a sub-national level for large countries. Pixel-level allocations are made by input levels following a similar process as that used for allocating the different crops. In many situations, the low-input rainfed class is the same as the subsistence class.

The work does not yet consider mixed cropping. It is assumed that only one crop is grown in any plot in a given year. One pixel could be allocated multiple crops but they are planted in different plots within the pixel. We do consider multiple cropping of the same crop, such as double- or triple-cropping of irrigated rice. In short, the basic method can be described as "prior allocation plus cross-entropy minimization subject to various area constraints". The prior allocation is based on gross revenue, and in essence, suitability plays an important role.

7. CONTEMPORARY GLOBAL LAND-COVER (GLC) DATA SETS

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7.1 Contemporary Global Land-Cover (GLC) Data Sets

7.1.1 What do Global Land-Cover Datasets Contain and Why?

A quick survey[15] of current GLC products shows that a typical map will have 26 classes of forest and 1 class of agriculture. This is only slightly facetious. For example, the GLC 2000 dataset legend contains 10 classes of forest, 5 classes of herbaceous cover or shrub land, 1 class of agriculture, 2 mosaic classes of cropland/shrub land and cropland/forest and urban, water and various barren area classes.

There are several reasons for the under-representation of agriculture[16] and the focus on forest land cover types. Firstly, if we look at remote sensing in general, land cover mapping is a long way down the list of priorities behind climate and atmospheric modelling. It has been argued that the atmospheric and oceanographic communities have a much stronger lobby and a more focused approach, and therefore a greater influence and involvement in the development and planning of satellite and sensor requirements. Perhaps this is due to the strong emphasis on the chemistry and physics of natural phenomenon which leads to a much clearer identification of the needs of the sensor. It has been suggested that the land cover 'group' is not so strong or focussed. Secondly that within this group there are many different research themes and needs, and it is the forestry and desertification themes which are much stronger and more visible to the remote sensing and satellite development community than the agricultural themes.

7.2 What is Available Now and What Can We Expect in the Future?

7.2.1 GLC2000

In contrast to former global mapping initiatives the GLC2000 project is a bottom up approach to global mapping. In this project more than 30 research teams were involved, contributing to 19 regional windows. Each defined region was mapped by local experts, which guaranteed an accurate classification, based on local knowledge.

GLC2000 is a core dataset for the Millennium Ecosystems Assessment. This means in particular that the GLC2000 dataset is a main input dataset to define the boundaries between ecosystems such as forest, grassland, and cultivated systems.

The GLC2000 project uses the FAO Land Cover Classification System (LCCS). This is a hierarchical classification, which allowed each regional partner to describe the land cover classes at the thematic detail best suited to the land cover in their region of expertise, whilst following a standardised classification approach. LCCS allows the regionally defined legends to be translated into more generalised global land cover classes for the GLC2000 global product. These global classes describe the type of vegetation and the density of the cover, independent of geo-climatic zone, such as temperate or tropical forests. The mosaicing of 21 regional products, and the

[15] Made on the back of a beer mat at around 11pm in the Siam City Hotel bar on April 3rd 2006.

[16] And other key land cover types such as urban.

translation to a standardised global legend, made it possible to create a consistent global land cover classification based on regional expert knowledge.

GLC2000 was primarily based on the "VEGA 2000" data set. This is essentially composed of 14 months of daily 1km resolution satellite data acquired over the whole globe by the VEGETATION instrument on-board the SPOT 4 satellite and delivered as multi-channel daily mosaics. The period covered was 1 November 1999 to 31 December 2000. As stated above, there is little or no separation of different agricultural land covers in the GLC2000 legend.

7.2.2 GLOBCOVER

The GLOBCOVER project was launched in 2004 as an initiative of ESA which is now evolving to an international collaboration between ESA, FAO, UNEP, JRC, IGBP and GOFC-GOLD. Its objective is to produce a global land-cover map for the year 2005, using, as the main source of data the fine resolution (300 m) mode data from MERIS sensor on-board ENVISAT satellite that has been acquired throughout 2005. This new product is intended to update and to complement the other existing comparable global products, such as the global land cover map for the year 2000 (GLC2000).

The key idea of the analysis is to combine the high spatial consistency of class delineation obtained from multi spectral composites with the good land cover discrimination provided by temporal profile analysis. The classification process will focus on regionally tuned approaches (including involving regional experts) using the FAO Land Cover Classification System (LCCS). We can expect the agricultural classes to similar to GLC2000.

The GLOBCOVER products will be provided in two stages: Version 1 in January 2007 and Version 2 in 2008. The reference date for GLOBCOVER is 2005.

7.2.3 MODIS 32 Day composites

One of the products generated from MODerate resolution Imaging Spectroradiometer (MODIS) is a set of 32-day composites, each with 7 channels and a resolution of 500m. There are 11 composites for each Julian year. This product is not a usable land cover map, but the time series of composites has enough spectral and temporal information to enable skilled users to generate land cover maps for their area of study.

Currently, 16 day composites at 250m resolution are under consideration by GLCF.

7.2.4 MODIS Continuous fields

This is another global MODIS product that consists of three 500m resolution images that estimate the percentage of each pixel that is tree covered, herbaceous covered or barren. Hence, for any one pixel the sum of these three images is 100. The reference date is 2001.

7.3 Options for Agricultural Production Systems Mapping

It is unlikely that there will be any one RS/GIS image product that will meet the requirements of the Global Agricultural Productions Systems (GAPS) mapping community. Therefore there are several different modelling and data collection approaches that could be followed in order to create a useful product.

1. **Accumulation and assessment of global or near global datasets** that are of relevance to the agricultural productions systems mapping.

2. **Rules based re-classification** using relevant ancillary data (length of growing season, population density, terrain, land cover etc.) to classify pixels into different farming systems (see Kruska in this report for a good example).
3. **Similarity and distance based analysis** using the same data as in point 2. This involves the identification of 'exemplar' productions systems and their characteristics (i.e. average rainfall, average elevation, average population density, average length of growing season), and then computing a pixel by pixel similarity index across the study area to locate areas with similar characteristics. Typically this kind of index uses Mahalanobian distances which can then be scaled to a 0-1 range (1 being identical) using a chi-square test.
4. **Re-interpretation of the underlying data used in GLC maps**, like the 14 month VEGA time series from GLC 2000. The multi-temporal data behind GLC2000 could be used to extract different agricultural classifications from the time series.
5. **New object orientated classification methods** (such as those used in Ecognition software) could be tested to see if they are better suited to identifying areas subject to different agricultural land use. This may be especially if the Ag. Productions Systems tend to create heterogeneous land use patterns that are not easily classified with pixel based methods.

7.4 Discussion

Questions were asked about ideal resolutions for remote sensing imagery for classifying agricultural land. It was pointed out that resolution per se may not help that much in difficult situations, such as heavily mixed systems or rotations; things are far more complex.

It was noted that crop land is greatly underestimated in GLC 2000 (see the slide comparing GLC2000 with MODIS and GLOBCOVER). The differences are hard to believe. Such comparisons have not yet been done for large areas or countries, unfortunately. But is there a right and a wrong? This is sort-of science, but there is a lot of art to interpretation. One needs local knowledge, this really is key. The point was made that a lot of local and/or prior knowledge must have been used for the 10 tree classes – why couldn't such knowledge have been used for the one agricultural class?

It was not known if there are any links from GLOBCOVER to FAO, or if there are any other US initiatives that may provide useful information in the future.

7.5 Useful Links

GLC2000
http://www-gvm.jrc.it/glc2000/

GLOBCOVER
http://www.gofc-gold.uni-jena.de/sites/globcover.html

GLCF: MODIS 32 day composites
http://glcf.umiacs.umd.edu/data/modis/500m32day.shtml

GLCF: MODIS continuous fields
http://glcf.umiacs.umd.edu/data/modis/vcf/

GLCF: AVHRR Global Land Cover Classification
http://glcf.umiacs.umd.edu/data/landcover/

USGS: GLCC
http://edcsns17.cr.usgs.gov/glcc/

Land Cover and Land Cover Dynamics at Boston University
http://www-modis.bu.edu/landcover/

LGRSS Global Land Cover Project
http://www.geog.umd.edu/landcover/global-cover.html

SAGE
http://www.sage.wisc.edu/

GLCN
http://www.glcn.org/

Mahalanobis Distances ArcView Extension[17]
http://www.jennessent.com/arcview/mahalanobis_description.htm

[17] The author has written an AML version of this extension, which gives more flexibility by allowing more than 8 input layers and multiple exemplar locations.

8. RECENT WORK ON POPULATION AND POVERTY MAPPING DATASETS AT CIESIN

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8.1 Population

8.1.1 Gridded Population of the World

The first version of the Gridded Population of the World (GPW1) was released in 1995 and contained population estimates for 1994, based on input data for 19,000 sub-national administrative units. GPW version 2 was released in 2000 and included estimates for 1990 and 1995, based on input data for 127,000 sub-national administrative units. The final, or 'production,' version of GPW3 was completed in December 2005 and included population estimates for 1990, 1995, and 2000. GPW3 also included future estimates for 2005, 2010 and 2015. The total number of administrative units was greatly increased for version two and again for version three; the input data for GPW3 included nearly 400,000 sub-national administrative units. Output grids for GPW2 and GPW3 have a resolution of 2.5 arc minutes.

GPW relies on 'raw' population data and uses no modelling. Rather, populations are allocated proportionally within the boundaries of each sub-national administrative unit. Grid cells located on the boundaries of multiple administrative units are assigned an average value based on neighbouring cells. GPW, with its emphasis on raw data, is therefore only as good as its input population and boundary data, which can vary widely in both resolution and timeliness. GPW relies on hundreds of data suppliers and uses data that are available either from national statistical offices, development agencies and in some instances non-governmental organizations which are available for free or for purchase. The various versions of GPW have been a collaboration between CIESIN and other institutions (see http://sedac.ciesin.columbia.edu/gpw for more details; and Deichmann *et al.* 2001).

The GPW approach contrasts with that used in the LandScan database, which is produced by the Oak Ridge National Laboratory and has a resolution of 30 arc seconds. LandScan uses input data, some of which is not publicly available, to generate estimates of ambient populations, relying on 'black box' modelling techniques. 'Best available census counts are distributed to cells based on probability coefficients, which in turn are based on road proximity, slope, land cover and night-time lights' (see http://www.ornl.gov/sci/landscan/landscanCommon/landscan_doc.html), but as of LandScan2003 the night-time lights were no longer used. Best available census counts refer to much spatially coarser inputs than are available in GPW3 but that have been temporally adjusted by the US Census Bureau's International Program Center to the year in question. Ambient population indicates a population distribution averaged across time of day, season of the year, and so forth.

8.1.2 Gridded Rural Urban Mapping Project

CIESIN's Gridded Rural Urban Mapping Project (GRUMP) was intended to improve population surfaces by accounting for urban areas explicitly, not just as an input into a population surface. GRUMP models urban areas using GPW administrative boundaries and populations, as well NOAA night-time lights satellite data for a 1994/95 city-light composite, and settlement points data collected from a variety of sources (Balk *et al.*, 2005). GRUMP was released in alpha version in 2004, with a resolution of 30 arc seconds. The beta version is scheduled for release in 2006.

The UN Population Division estimates (WUP, 2003) that in world at present slightly less than half of the global population is urban. Some insights from GRUMP (McGranahan *et al.*, 2005) include:

- Somewhat less than 3% of global land-area is urban.
- Two-thirds of coastal dwellers, and more than 50% of island and inland water dwellers are urban.
- More than 10% of coastal land is urban.
- Population densities in coastal areas are high for both urban and rural areas.

There are, however, a number of known limitations to the GRUMP methodology. Night-time lights show a 'blooming' effect, making urban extents in well-lit areas larger than their extents would be judged to be from other sources. Additionally, night-time lights are an inconsistent indicator of global populations, because some countries have disproportionately more lights than others. The lights data are also static: current data are from 1994/95. New methods may therefore be necessary to use lights data for other time periods, because it is unclear whether changes in lights data will reflect changes in extents or simply new sources of wealth/light. There are also difficulties with the settlement points which are used to estimate urban populations: not only are many points missing, but about half of the lights globally cannot be matched to settlements. The sources of these 'unallocated' lights are likely to be industrial areas, anomalies or smaller cities not reported in the tabular sources.

D. Balk at CIESIN is currently working with S. V. Nghiem, E. Rodriguez, and G. Neumann at JPL on other ways to use remote sensing data to estimate urban areas. Specifically they are exploring the use of QuikSCAT/SeaWinds Scatterometer (radar) data to model urban extents through the detection of buildings, and have analyzed results for Dallas and Fort Worth as well as Bogotá, Colombia. These initial findings indicate that the scatterometer data do not display the blooming effect that characterizes the night-time lights and are therefore closer to the expected footprints of urban areas.

8.2 Poverty Mapping Datasets

8.2.1 Global Poverty Mapping

CIESIN is concluding a two-year contract with the World Bank's Japan's Policy and Human Resource Development (PHRD) Fund to develop both global and small area poverty mapping datasets (see: http://sedac.ciesin.org/povmap). In addition to global sub-national datasets for infant mortality rates and child malnutrition, a number of global datasets for biophysical parameters related to poverty have been assembled. These parameters include drought frequency, water runoff per capita, GAEZ growing season, slope greater than 15%, terrestrial biomes, distance to coast, elevation, access, and soil fertility constraints.

8.2.2 Small Area Estimates

The small area estimation technique for poverty mapping was developed at the World Bank in the late 1990s (Hentschel *et al.*, 1998; Hentschel *et al.*, 2000; Elbers *et al.*, 2003). The SAE technique uses econometric methods to integrate household surveys with census data. It thus combines the detailed information on welfare and living standards collected for a representative sample population with the greater coverage of the census, which typically does not include data on income or expenditure. CIESIN has collected data produced using the small area poverty estimation technique for the following 19 countries: Albania Bangladesh, Bolivia, Bulgaria, Cambodia, China (Yunnan province), Ecuador, Guatemala, Kenya, Indonesia, Madagascar, Malawi, Morocco, Mozambique, Nicaragua, South Africa, Uganda, Viet Nam, the West Bank and Gaza.

A total of 29,629 tabular units of poverty and inequality data, at various geographic scales and spatial coverage were collected for the above countries. Of these, the tabular data for all but South Africa and Nicaragua are freely available for download at http://www.ciesin.columbia.edu. Spatial data (administrative boundaries) are also available for download for all but China (Yunnan province) and South Africa. Since the majority of the data was separated from the associated geographies, a great deal of effort was required to find the relevant geographical data and re-link these to poverty attributes.

Findings from the small area poverty mapping project include the following (Muñiz *et al.*, forthcoming):

- Characteristics of sub-national poverty *distribution* vary across countries.
- Definitions of poverty and scale of analysis affect distribution.
- Although poverty and inequality rates vary across sub-national administrative areas, they cluster in geographic space.

8.3 Conclusions and Areas for Further Research

There is a great deal of interest in developing new methodologies for accurately mapping urban and rural settlements, particularly those that exploit the new data streams offered by the field of remote sensing. In the area of poverty mapping, the production and availability of small area estimation data for all countries would be a valuable addition to existing datasets. Additionally, because estimates of poverty cannot be equated across countries without a means for equating poverty lines, this would seem to be a promising area for further research, one that is complicated by the fact that some countries calculate poverty rates differently for urban and rural areas.

8.4 Discussion

There have been impressive developments in these databases in recent times, but it was noted that we are a long way from having global poverty maps based on small-area estimation. And there are still problems with cross-country comparisons, even though country poverty lines are often based on a “basic needs” basket.

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9. ACCESSIBILITY FOR MAPPING AGRICULTURAL PRODUCTION SYSTEMS

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9.1 What is Accessibility and How Can It Be Measured?

Over the last ten years there has been a growing awareness that rural accessibility concerns more than just roads, (Barwell, 1996). Reports and surveys carried out in developing regions paint a picture of rural isolation and unproductive use of limited resources, in which the farmer largely inhabits a walking world. In his introduction to Transport and the Village, Cleaver states that:

> It is clear that the extremely poor state of off the road transport system in Africa acts as a powerful brake on agricultural productivity and growth. Improved accessibility will reduce the economic costs of moving goods from local markets and ease the barriers to social facilities. This will contribute to economic growth and enhance social well-being.

But before national governments can provide environments conducive to the development of local infrastructure, there is a need for a model that can incorporate the local environmental factors that define rural inaccessibility. Also any model should be flexible enough not only to quantify time and cost of travel but also infrastructure improvement (or degradation) scenarios to be created and evaluated. Clearly there are different levels of infrastructure availability, transport availability, and many different environmental effects, and economic considerations. For example it would be impossible to apply the same model of rural accessibility to sub-Saharan West Africa and Central American Hillsides, but any model should be capable of incorporating all of these factors in a way that is not only sensible and geographically sensitive but also educational and explanatory.

Accessibility has been defined as the ability for interaction or contact with sites of economic or social opportunity (Deichmann, 1997). Goodall (1987) defines accessibility as the ease with which a location may be reached from other locations. More contentious statements include that the concept of accessibility can be used in rural development policy as an indicator of rural deprivation and as a variable for location analysis (Geertman, 1995), and that “Access is a precondition for the satisfaction of almost any economic need, and certainly for all physical needs, hence accessibility provides a central integrating concept with which to grasp the complex interactions between the subsistence, economic and social needs of any population” (Dixon-Fyle, 1998).

Access can be measured to any target of interest. Examples include a town or market, a health facility or education facility, a seed bank or distribution centre. The next section describes a common method for measuring access.

9.1.1 Measuring Accessibility

Vector models of accessibility require that the transport network data are complete and continuous and that the ‘targets’ are linked to the vectors. Preparing this data can be very demanding, especially when relying on data sources such as DCW which are incomplete and have many inconsistencies. Raster modelling of accessibility is generally easier (although more time consuming) than vector modelling, but requires that the data are rasterised to a common spatial framework.

The bare minimum requirements for raster based accessibility modelling using a *costdistance*[18] function are 1) a transport network, 2) a background layer, and 3) a set of target points. The transport network can be a combination of roads, rivers and rails, the background layer is simply a polygon layer that defines the area of analysis, and the targets are a set of points (or polygons in the case of urban areas) that represent the locations for which we want to calculate access to. All the input layers are converted to raster[19] and are re-classed as follows:

Transport: Assuming the raster pixels are 1000m x 1000m, the cells in the transport raster are re-classed based on the number of minutes required to cross 1000m of each type of transport medium (1min for traversing a good quality road pixel at 60km/hr, 6min for traversing a river pixel at 10km/hr, etc.).

Background: Assuming foot based travel where there is no transport network, so taking a speed of 4km/hr, the time to cross 1000m is 15min.

Targets: each target is given a unique ID.

Then the transport layer and background layer are merged into one layer which is called the *cost* or *friction* raster since each pixel represents the cost (in time) to traverse each pixel. This friction raster and target raster are input to the *costdistance* function and the results are a travel time raster[20] and a catchment raster representing the catchment zones around each target. It is then possible to use the layers to determine the location and number of people with particular levels of access to the targets. Other socio-economic information on the population can be used to assess inequality amongst other things.

The method can be run for different modes of transport by changing the assumed speed over each transport network medium. It can also be run for different seasons if heavy rainfall has an impact on travel times. For example, after Hurricane Mitch, CIAT collected information on road and bridge damage to determine the loss of accessibility in different parts of Honduras and to estimate the number of affected people, and to suggest priorities for road-reconstruction.

Other data layers can be used as input, to increase the degree of realism in the access model. If international borders feature in the study area, then a high travel time can be assigned to transport network pixels which cross the border (60, 90 or 120 minutes, for example). Land cover classes can be included to reduce the travel speed over truly inaccessible land cover types (swamps for example). Elevation is another factor which can be used as a mask to make all areas over a certain elevation (5,000, for example) as inaccessible. Finally, Slope can be used a multiplying factor such that travel time across all pixels (except rivers/lakes) increases as slope increases.

Unless the model is calibrated by determining the real speeds and travel times between various locations on the travel network then care should be taken when interpreting the results. If the model is not calibrated, then the access raster can only give a relative measure of access, in the sense that if pixel A has an access time of 1.5 hours and pixel B 2 hours, then we are simply saying that pixel A has greater access than B, but we should not quote the exact travel time.

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[18] In ESRI products the function is called **COSTDISTANCE**; IDRISI includes the **COSTPUSH** and **COSTGROW** functions which also allow anisotropic cost (i.e. cost depends on direction of travel, which is useful for dealing with slopes).

[19] The input raster data should be projected into an equal are projection before running the *costdistance* function

[20] In this example, the output travel time will be in minutes and is based on pixels measured in metres, and so the result should be divided by 60 to convert to time in hours, and again by 1000 to relate the distances to km rather than metres.

9.2 How Is It Useful for Mapping Agricultural Production Systems?

As mentioned in the first section, access can be measured to many types of targets. If markets are chosen, then there is an obvious analogy to the Von Thünen land model where we can investigate the relationship between the cost or economic distance from a market and the land use patterns around the market. The Von Thünen model is an excellent illustration of the balance between land cost and transportation costs. As one gets closer to a city, the price of land increases. The farmers of the isolated state balance the cost of transportation, land, and profit and produce the most cost-effective product for market.

This information could be used to make simple models of land use allocation based on the Von Thünen assumptions of land use vs. distance to market, whereby areas closer to market are typically dedicated to dairy and intensive agriculture, further out we have forest resources, followed by field crops, grains and finally livestock.

9.3 Summary

1. **The accessibility map (and its derivatives) is focused on a resource or market, commonly referred to as a target.** Although administrative units are also based around a population centre, there are no consistent guidelines or rules that describe their creation from region to region, and they may or may not have any relation to resource or market catchments. The access surface and the catchment area around each target depends on the road network, which in turn reflects the attractivity of certain zones, e.g. large cities.
2. **It is defined by local physical, agricultural and economic factors relating to accessibility.**
3. **The map is dynamic in that it is will adapt with time as the underlying factors influencing it change.** Road networks are expanded in some places and become degraded in others.
4. **Accessibility is important at local, regional and national levels and is an inherently scaleable concept.** Catchments for local products can be generated, as can catchments for processing plants for large scale agricultural production, and finally for commodities such as exported crops as related to access to ports and major cities.
5. **Accessibility can be applied to a range of issues, and access to agricultural markets is but one application.** For example health care provision via mid wives, rural health care centres of general hospitals can be assessed, and compared to infant mortality rates. Access to education can be determined as well as its effect as a constraint on local development. Gender issues could be addressed by focusing on infrastructure and facility siting improvements to minimise the load-carrying work and effort where women bear the larger part of the transport burden.
6. **Consistent and intuitive results at multiple scales.** The relationship between land use/cover and accessibility is stronger and more consistent across scale than Euclidean distance measures. Can this be expanded to look at types of agricultural land use?
7. **Combines many important thematic data.** Biophysical (land cover and terrain), social (population and infrastructure) and economic (market forces, supply and demand) factors.
8. **Temporal aspect.** The above factors change naturally with time, both on the long term and the short term and the units adapt with them. Therefore it is a

unique spatial unit particularly well suited to development planning, monitoring and modelling.

9.4 Discussion

Accessibility appears to be more a function of time rather than distance, in general. The point was made that there are also issues of value and perishability of products, which could be used to refine these analyses - this could provide a useful predictive tool. Travel time has been calibrated for some of the areas.

A recent CSI meeting identified a better roads network as the "number 1 desired global data set". There appears to be no work being done on modelling of future road networks; current road networks are presenting enough of a problem. Other possible refinements were mentioned, such as urban gridlock and dealing with export crops. Such issues can be dealt with, provided the information exists.

9.5 Useful Links

9.5.1 Background

Measuring accessibility in GIS
http://www.geovista.psu.edu/sites/geocomp99/Gc99/010/gc_010.htm

9.5.2 Software

Accessibility Analyst
http://www.ciat.cgiar.org/access/index.htm

AccessMod
http://www.who.int/kms/initiatives/accessmod/en/index.html

9.5.3 Data

State of the art in global road databases
http://www.ciesin.org/pdf/globalroads.pdf

Urban areas and urban locations
http://sedac.ciesin.columbia.edu/gpw

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10. AGRICULTURAL / LIVESTOCK PRODUCTION SYSTEMS IN UGANDA

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10.1 Introduction

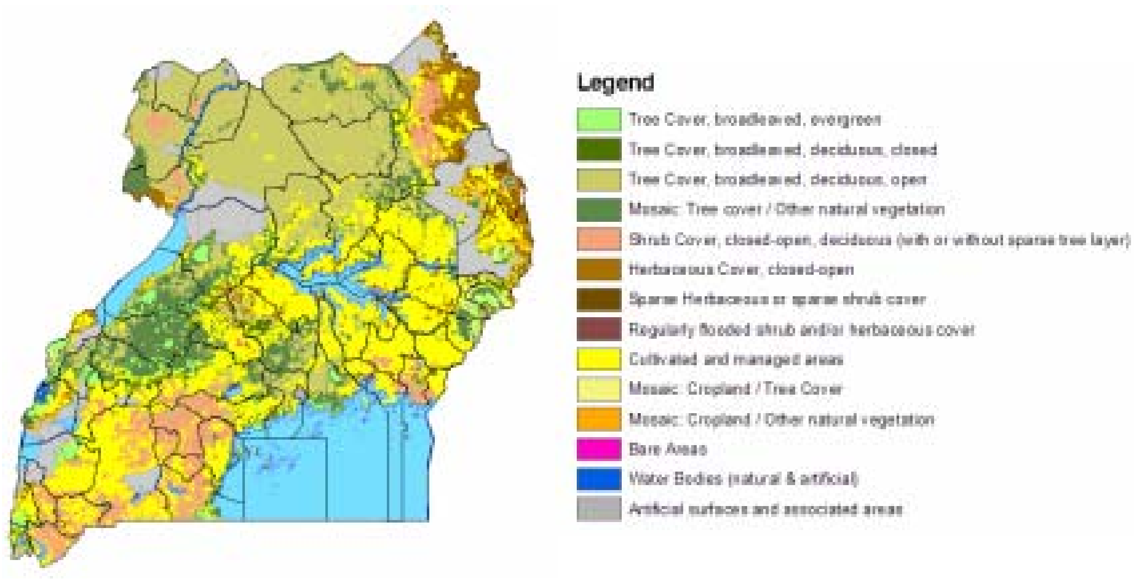
An important objective in digital mapping of agricultural production systems, in this case with a special emphasis on livestock, is to produce a classification that is relevant at the local (say national) level and at the same time sufficiently generic to be applicable at a global scale. For a classification scheme to be practical at national level requires both that the spatial resolution is sufficiently high and that the contents are detailed enough to be relevant to national studies and applications. To be globally applicable it should be based (at least to some extent) on data that are available for the entire globe. National datasets vary, however, in detail. It is therefore proposed that a hierarchical approach to production system mapping should be adopted whereby global coverage is provided by combining the most appropriate global datasets in a way that then allows more detail to be added for different regions or countries as these details are available and required. In this Uganda case study existing systems are briefly reviewed, and a framework for producing global but locally-relevant systems is proposed.

10.2 Land Cover

Land cover describes broadly the nature of the earth's surface in terms of water, natural vegetation, cultivation, artificial surfaces etc. Land cover is determined by hydrology, climate substrate type and anthropogenic intervention and is obviously closely linked to land use, the more specific application to which the land is put, and thus to agricultural production systems. A number of global land cover datasets exist; the most widely used being the Landscan[21] and GLC 2000[22] (Figure 10.1) datasets, but these vary considerably in their definition of agricultural land cover classes.

[21] http://www.ornl.gov/sci/gist/projects/LandScan
[22] http://www-gvm.jrc.it/glc2000/

Figure 10.1: *GLC 2000 land cover data for Uganda.*



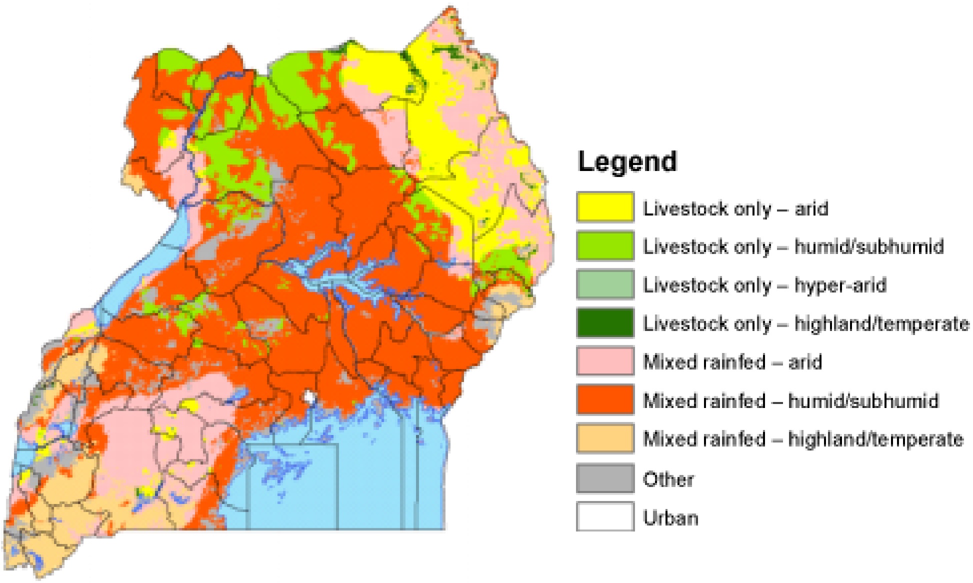
The Landscan data distinguishes two agricultural land cover classes: (i) dry cropland and pasture, and (ii) cropland/woodland, whilst the GLC 2000 distinguishes three: (i) cultivated and managed areas, (ii) mosaic cropland / tree cover, and (iii) mosaic cropland / other natural vegetation. The overall extent of agricultural land is not consistent between the two datasets. A third, regional land cover dataset is provided by the Africover data (Di Gregorio and Jansen, 1998), which for Uganda distinguishes eighteen agricultural land use classes, together covering a considerably larger area than either global dataset. Whist the Africover data are probably the most appropriate for mapping production systems in Uganda and other countries where is has been done, its restricted coverage makes it inappropriate for global mapping. The Landscan data are less widely used, making the GLC 2000 data, shown in Figure 10.1, the most applicable. There are clearly limitations, however, in the level of detail provided by GLC 2000, which will need to be addressed in the longer term.

10.3 Global Production Systems Datasets

Seven broad farming systems mapped in a global study by the World Bank and FAO combined current state-of-knowledge assessments of natural resources, prevailing farming activities and livelihood strategies to define them (Dixon *et al*., 2001). This approach led to a classification based broadly on agro-ecology, presence or absence of irrigation and location (urban/coastal), but did not incorporate livestock in any detail. Whist the original classification is far too crude to be of use at a national level, e.g. Uganda is divided into only three zones: (i) highland perennial. (ii) maize mixed, and (iii) pastoral, attempts have been made to implement the classification system using more detailed data (see the case study for Senegal by George and Franceschini in this report).

Seré and Steinfeld (1996) developed a classification of livestock systems based on agro-ecology and the distinction between mixed and pastoral, irrigated and rainfed, and urban/landless areas. Emerging from this is one of the more widely used classifications developed and mapped by the International Livestock Research Institute (ILRI) (Thornton *et al*., 2002); described in detail by Kruska in this report, and shown for Uganda in Figure 10.2. Whilst Thornton's classification tends to amalgamate similar systems and fails to capture important differences in use and livestock husbandry practices within categories (e.g. grassland-based grazing combines pastoralists and ranchers, which are clearly not equivalent), it is undoubtedly the most appropriate classification system available, and work is underway to increase the level of detail.

Figure 10.2: *ILRI's livestock production system classification (Thornton et al., 2002) with some classes further divided to give more detail (Kruska, 2006).*



10.4 National Agricultural Systems Classifications

In addition to these more widespread systems, national classification systems have also been developed. For example (NEMA, 1996)[23] distinguishes five systems: (i) northern and eastern cereal-cotton-cattle, (ii) intensive banana-coffee, (iii) western banana-coffee-cattle, (iv) West Nile cereal-cassava-tobacco, and (v) Kigezi afro-montane. Musiitwa and Komutunga (2001) developed a classification also with five classes, but with little overlap with the former: (i) long-rain unimodal systems (Northern and West Nile systems), (ii) transitional zone (Teso, Lango and banana-cotton-finger millet systems), (iii) banana and coffee system, (iv) montane systems (Elgon, Kabale-Kisoro and Ruwenzori), and (v) pastoral systems (Karamoja and the South-Western pastoral systems). Closely related are national estimates of agroecological zones. For example Wortmann and Eledu (1999) distinguish 33 agroecological zones, each of which they describe in detail (including landscape, soils, land use climate and cropping systems). Whilst relevant locally, all of these classifications have two problems. Firstly, they are not based on a classification scheme, as such, and are therefore merely descriptive. Secondly, they are very specific to Uganda so would have little applicability elsewhere.

[23] http://easd.org.za/Soe/Uganda/augindx.htm

10.5 Data Driven Approaches

Relatively simple statistical classifications of cattle and human population levels, cultivation intensity and elevation have also been investigated (Wint *et al.*, 1997). 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, they are sensitive both to geographical region and value range and cannot be replicated systematically in time and space.

Figure 10.3: *Data driven systems mapping approach using crop and livestock data (UBOS, 2004). In this example, for simplicity human population data were excluded since they were closely related to crop data. The legend shows first the level of cropping (H = high; M = medium; and L = low) and then the level of livestock.*

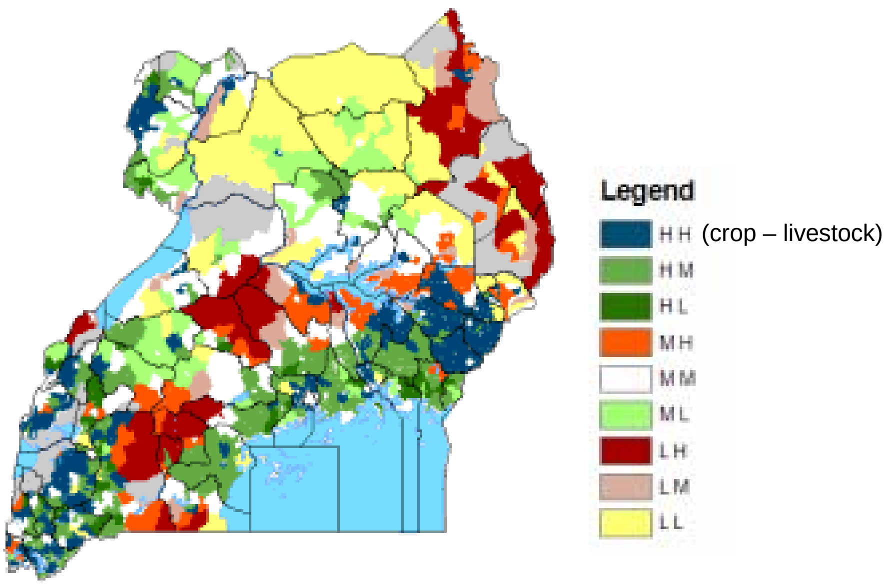


Figure 10.3 shows a simple example developed for Uganda using census data from 2002. The predominantly livestock (pastoral) areas can be seen in magenta and orange; greens show those areas dominated by crop farming and blue, areas where both crops and livestock occur in large numbers.

10.6 Conclusion

A hierarchical approach to production system mapping (Figure 10.4) should, at the first level be based on globally available datasets that can be used to provide broad systems characteristics, in the ways done by Thornton *et al*. (2002) and Kruska (2006). Essentially these should include the best available estimates of length of growing period, human population density and land-cover. This first level can then be moderated by information on irrigation, which will over-ride factors such as length of growing period by allowing cultivation in areas otherwise unsuitable, or more commonly allow for multiple cropping. This is the only level at which the data would be globally consistent. A second level should include more specific data on particular crop and livestock combinations and on other livelihood options (such as aquaculture). Whilst it should be possible to obtain global coverage at this level, there will be differences in the level of detail from country to country. A third level would vary considerably in detail from country to country and would be dependent on data such as market-orientation, management practices, cultural practices and so-on.

The first challenge in developing such a system is to identify globally-consistent high quality datasets to map the first level. We can then start to think about how best to incorporate crop, livestock and other data to disentangle the 'mixed' and 'other' production systems.

Figure 10.4: *Schematic hierarchical agricultural production systems classification scheme.*

Level 1	Length of growing period Population Land cover Irrigation
Level 2	Modelled crops (yield, genotype) Modelled livestock (off-take, breed) Aquaculture, fishing, forest crops
Level 3	Market-orientation (accessibility) Industrialisation, management practices Disease (of crops and livestock) Legislation Cultural practices

10.7 Discussion

There was some discussion on the complexity of a multi-level system description, compared with the recent IFPRI ASARECA domain identification work. What are the benefits of extra complexity, and who are the potential users? Sophisticated targeting should be possible with such a scheme.

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11. MAPPING THE AGRICULTURAL PRODUCTION SYSTEMS OF SENEGAL USING THE F-CAM APPROACH

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11.1 Summary

The paper outlines a draft methodological **f**ramework for the **c**haracterization **a**nd **m**apping (F-CAM) of agricultural production systems (defined as areas of similar 'natural resources base', 'agricultural land uses' and 'socioeconomic context') that are that are useful for planning a wide range of land-management interventions. Using established definitions of land use, land utilization types and regional farming systems as a starting point, relevant data sets are suitably compiled and analyzed by a combination of expert knowledge and spatial modelling, to form composite spatial units defining agricultural production systems. Preliminary results from a case study at national scale (for Senegal) are presented.

11.2 Characterisation and Mapping of Agricultural Production Systems

Suggestions of relevant parameters for mapping agricultural production systems are provided from studies on land evaluation for agriculture - for which land utilization types are defined (FAO, 1996) - and from studies on the mapping of farming systems at regional to global scales (e.g. Dixon *et al.*, 2001).

1. natural resources base
2. dominant livelihood sources (land-use purpose and management)
    - land-use purpose
        - products & services
        - processing & off-farm income
    - land-use management
        - market orientation
        - capital intensity
        - labour intensity
        - power source
        - technology use (management)
3. socio economic factors
    - farm size & scale/ land tenure
    - income level
    - infrastructure
    - population density

Since a major reason for mapping agricultural production systems is to support decision making in relation to land management interventions, we reason that 'core' 'characterization' parameters should include

- current land use purposes (i.e. the targeted agricultural goods and services – crops, livestock, aquaculture, forestry, etc.) and the associated management.
- the range of potential land uses given the existing resource base, and
- the prevailing socioeconomic conditions which exert the strongest influences on the choice of acceptable land-use and land-management options.

These considerations constitute the basis for the mapping of agricultural production systems, - areas of similar resource base, similar land use purpose and management, as well as similar socio-economic setting. The parameters selected for the compilation of spatial data characterising each of these 3 components for the Senegal case study are described below, followed by a general description of the methodology for spatial data integration and querying.

11.3 Areas of Similar Resources Base

Land cover information was extracted from the Global Land Cover 2000 (GLC2000) dataset (Joint Research Centre, 2006) that was interpreted from 1km SPOT imagery using the LCCS classification scheme (FAO, 2005). Multiple LCCS classes were regrouped into 6 major classes (trees, regularly flooded vegetation, herbaceous and sparse shrub, shrub, cultivated areas, mixed cropland) in order to highlight zones of different intensities of cultivation.

An input 'interpolated' image layer showing the length of growing period (i.e. the number of days where rain exceeds more than half evapotranspiration) was created using NewLocClim software and its associated database of agro-climatic observations covering the period 1961-1990. The selected output data classes were as follows: arid (0-29 days); dry semi-arid (30-119 days); moist semi-arid (120-179 days); moist sub-humid (180-269 days); humid (> 270 days)

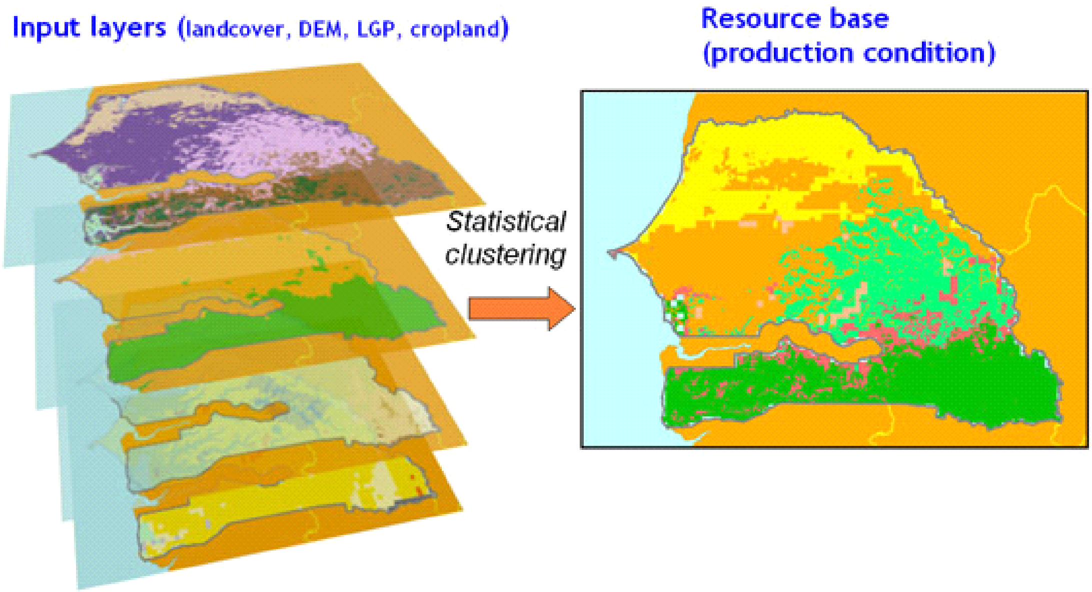
A digital elevation model for Senegal was extracted from a composite dataset processed by the Global Land Cover Network (GLCN, 2006) using SRTM data (3 arcseconds ~90m) (USGS, 2006-a) and GTOPO30 data (30 arc-seconds ~1km) (USGS-b, 2006). This data was classified into the following 6 classes: <36; 37-110; 111-200; 201-260; 261-350; >351 metres.

A soils map of Senegal was reclassified using expert knowledge into a limited number of output suitability classes (very suitable, suitable, not suitable) indicating relative level of inherent agronomic constraint of the dominant soils.

The reclassified maps of land cover, LGP, soils and elevation were spatially overlaid to yield a raster map consisting of various combinations of the input layers some of which were not significantly different from each other. Cluster analysis, allowed the identification of a smaller number (13) of significantly different output classes for the resource-base units (Figure 11.1).

The 13 resources-base units reflect the biophysical factors which together exert a strong (but not the only) influence on land-use options. Actual land uses within any given resources-base unit may reasonably be expected to be similar. These units have therefore been used to spatially re-allocate 'low resolution' aggregated census statistics on actual land-uses and management.

Figure 11.1: *Creation of resources-base units.*



11.4 Land-use Purpose and Management

The crop statistics for the most recently available detailed agricultural census (1998/99) were selected and used to prepare a map showing the spatial distribution of different crop-group combinations (aggregated by administrative department) (from Agro-MAPS) (George *et al*., 2003). In practice, each crop was assigned to a major FAO crop 'commodity' group. The relative contribution made by each crop group to the total harvested area for each administrative unit was then calculated. In a final step, the most significant crop groups, which accounted for more than 70 percent of the total harvested area, were used to define a unique label for each administrative unit.

The available 'map' on irrigation (from AQUASTAT), depict the percentage of areas that are 'equipped' for irrigation as a raster image.

Statistics on livestock numbers (cattle, sheep, goats, pigs, horses, donkeys, camels, poultry) in each of the 33 administrative departments (from the 2004 livestock census) were converted to standardized Tropical Livestock Units (TLU) and used to create a map showing the spatial distribution of TLU/per rural capita.

A map of areas where coastal fishing is a major source of livelihood was added by delimiting corridors alongside coastal areas in those administrative districts where a high percentage of household involvement in fishing activities was reported in the agricultural census.

11.5 Socio-economic Conditions

Data on rural population density were extracted from FAO's Poverty Mapping Urban Rural Database that was derived from LANDSCAN.

The 'average size of area cultivated by household' (from the 1998/99 agricultural census) was used as a proxy for land availability.

Data on the road/rail network were used as input to cost-distance modelling to create a raster data layer showing relative access to markets.

11.6 Spatial Analysis

The spatial allocation (through expert knowledge) of attributes of 'land-use purpose and management' to the resources-base units allows their 'conversion' into agricultural production systems (i.e. areas of similar resources and actual land uses). These systems may be further characterised (i.e. sub classified) on the basis of socio-economic criteria, in order to support a wider range of decision making.

Following simple spatial overlay of the data sets described earlier, each output pixel was associated with a number of attributes:

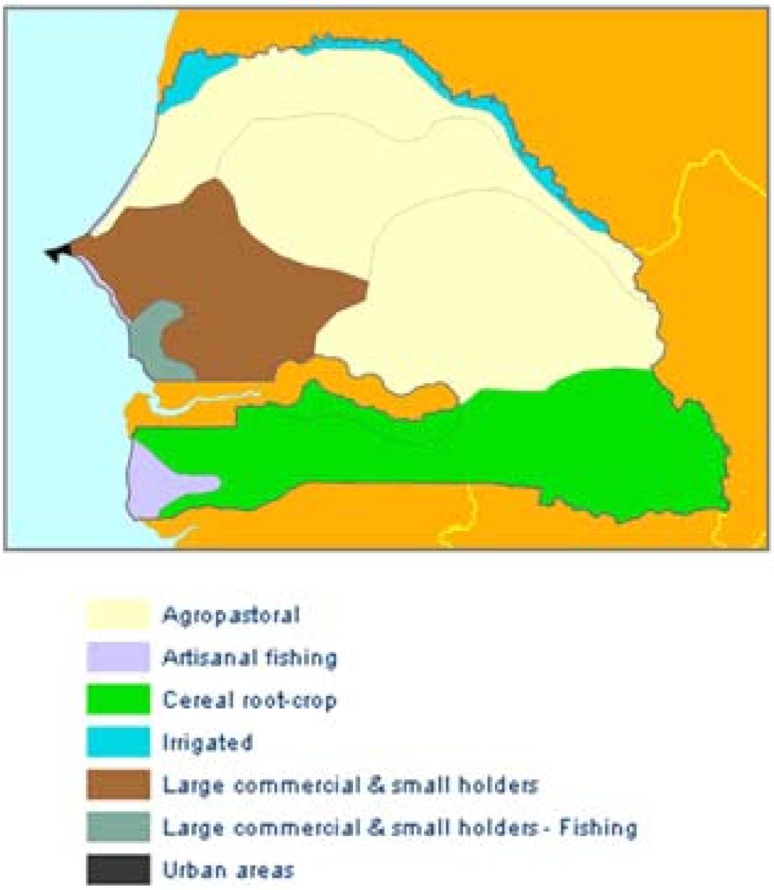
Major theme	Corresponding attributes
Resources base	land cover; LGP; soils suitability; elevation
Crops & management	major crop (group) combinations; irrigation
Livestock & management	TLU per capita;
Fishing	% households involved in fishing
Socio-economic conditions	rural population density; land availability (average size of cultivated area; cultivated land per capita); infrastructure/market access;

This per-pixel characterization allows subsequent classification and analysis to support a variety of decision making needs. As an example, each output pixel was reclassified into a regional farming system class (Figure 11.2) (using a decision tree classifier based on a typology of farming systems for sub Saharan Africa derived from Dixon et al (2001). Details of the reclassification are provided in George and Franceschini (2005).

11.7 Concluding Remarks

The study demonstrates the potential to develop country-wide maps of agricultural production systems at a district level using data that are readily-accessible from a variety of sources. Specific information providing insights on agricultural land management is, however, limited. The spatial resolution (level of aggregation) of the input data maps could exert a strong influence on the appearance and as well as validity of output map classes. Hence, the finest resolution data available should be used whenever feasible. The methodological framework is scale independent, structured and therefore potentially replicable. Field testing by national experts to establish the validity of results and limitations of the methodological approach is planned.

Figure 11.2: *Map of farming systems derived by spatial query of the database on agricultural production systems.*



11.8 Discussion

It was pointed out that the F-CAM methodology, owing to its structured approach to data selection and subsequent querying, easily facilitates subsequent updating of agricultural production maps when new input datasets become available. The time required for analysis is largely dependent on the availability of relevant datasets.

11.9 References

Dixon, J. and Gulliver, A. (with Gibbon, D.) (2001) *Farming Systems and Poverty. Improving Farmers' Livelihoods in a Changing World*. Rome and Washington DC: FAO and The World Bank. pp 412.

FAO (1996) *Agro-ecological zoning guidelines*. Rome: FAO Soils Bulletin 73.

FAO (2005) *Land Cover Classification System (LCCS): Classification concepts and user manual. Software version 2* (revised by A. Di Gregorio). pp 190.

George, H. and Franceschini, G. (2005) f-CAM – A framework for the characterisation and mapping of agricultural land use at sub national scales using pre-existing data sets. Unpublished report on CD-ROM.

George, H., Nachtergaele, F.O. and Koohafkan, P. (2003) Agro-MAPS: A global spatial database of sub-national agricultural land-use statistics. Proceedings of Africa-GIS 2003, Dakar, Senegal. pp 16. URL: http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp (last accessed 27 March 2006).

12. THE PERU CASE STUDY

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12.1 Overview

Very little progress has been made in the Peru case study, in terms of assembling crop and livestock data and doing some characterisation of farming systems. This work is dependent on other PPLPI activities in the country, and later on during 2006 could be linked to a case study that applies the decision/discussion support tool EXTRAPOLATE to look at the pro-poor policy implications of changes in the policy environment surrounding the production of camelid fibre.

In the meantime, and to illustrate one aspect of the use of a systems classification, Figure 12.1 shows the Seré and Steinfeld (1996) classification for Peru as mapped using the methods of Kruska *et al.* (2003) with new datasets. The classification is mapped using various data sets:

- Land-use/cover: we use version 3 of the Global Land Cover (GLC) 2000 data layer (JRL, 2005). For Africa, this included irrigated areas, so this is used instead of the irrigated areas database of Döll and Siebert (2000), which is used for Asia and Latin America.
- For human population, we use new 1km data (GRUMP, 2005).
- For length of growing period, we use a layer developed from the WorldCLIM 1km data for 2000 (Hijmans *et al.*, 2004), together with a new "highlands" layer for the same year based on the same dataset, using similar methods as those outlined above (Jones and Thornton, 2005).
- Cropland and rangeland are now defined from GLC 2000, and rock and sand areas are now included as part of rangelands.

The original LGP breakdown into arid-semiarid, humid-subhumid and highland-temperate areas has now been expanded to include hyper-arid regions, defined by FAO as areas with zero growing days. This was done because livestock are often found in some of these regions in wetter years when the LGP is greater than zero. Areas in GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2 as well as a LGP greater than 60 (which can allow cropping) are now included in the mixed system categories. The landless systems still present a problem, and are not included in version 3 of the classification. Urban areas have been left as defined by GLC 2000.

To look at possible changes to 2030, we used the GRUMP population data and projected human population out to 2030 by pro-rata allocation of the UN medium-variant population figures for that year by country. LGP changes to 2030 were projected using downscaled outputs of the Hadley CM3 model for the B2 SRES scenario (for details of the methods, see Jones and Thornton, 2003). Figure 12.2 shows a re-run of the classification for 2030 using these projected LGP and human population data. A quick comparison with Figure 12.1 shows that projected increases in population density and changes in climate will result in more areas being classified as mixed systems in the highland areas in 2030 than is the case now. This is one example of the use of a systems classification, allowing users to assess in a general way some of the impacts of changes in global drivers in the coming decades on farming systems and livelihoods.

12.2 Discussion

This raises the issue of how to include other livelihood options, such as income contributions etc. There are also issues of food security; enterprise outputs may serve all sorts of purposes, but how these can be incorporated into this kind of framework, is a difficult question.

12.3 References

Döll, P. and Siebert, S. (2000) A digital global map of irrigated areas. *ICID Journal* **49,** 55-66.

GRUMP (2005) Global Urban-Rural Mapping Project (GRUMP). Dataset available at http://beta.sedac.ciesin.columbia.edu/gpw

Hijmans, R.J., Cameron, S. and Parra, J, (2004) WorldClim climate surfaces. Online at http://biogeo.berkeley.edu/worldclim/worldclim.htm

Jones, P.G. and Thornton, P.K. (2003) The potential impacts of climate change in tropical agriculture: the case of maize in Africa and Latin America in 2055. *Global Environmental Change* **13,** 51-59.

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JRL (2005) GLC 2000 (Global Land Cover) data layer, Joint Research Laboratory, Ispra, Italy. Online at http://www.gvm.sai.jrc.it/glc2000/defaultGLC2000.htm

Kruska, R.L. (2006) Seré and Steinfeld version 3. Digital data set, ILRI, Nairobi, Kenya.

Kruska, R. L., Reid, R. S., Thornton, P, K., Henninger, N. and Kristjanson, P. M. (2003).) Mapping livestock-orientated agricultural production systems for the developing world. *Agricultural Systems* **77,** 39-63.

Seré, C. and Steinfeld, H. (1996) *World livestock production systems: current status, issues and trends*. Rome: FAO Animal Production and Health Paper 127.

13. TOWARDS A GLOBAL AGRICULTURAL PRODUCTION SYSTEMS CLASSIFICATION: VIETNAM CASE STUDY

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Food and Agriculture Organisation (Consultant)

13.1 Overview of Vietnam's Agro-ecological and Socio-economic Geography

Vietnam is typically divided a number of agro-ecological regions, the most important of which are:

1. The poor mountainous upland areas of the northern part of the country, with a very low population density, an under-developed market infrastructure, and very little commercially-oriented agriculture. Agriculture in the region is largely based on upland rainfed mixed cropping systems dominated by rice and corn, most households also raise some cattle, pigs and local chickens.
2. The densely populated river plains in the vicinity of major urban areas, with a comparatively low poverty rate, and well developed markets. The agricultural system is dominated by irrigated intensive paddy rice cultivation, in the Mekong River delta often mixed with aquaculture systems. Livestock production is an important commercial activity, with industrial pig production, a broiler industry, and a dairy industry.
3. The central coastal lowlands with a moderate population density, and moderate poverty rates, where markets are under-developed in the northern part, and somewhat better developed in the southern part. The fishing industry is important particularly in the southern part. Irrigated and rainfed rice cultivation dominates, though industrial crops such as peanuts, coffee and rubber are increasingly grown, too. Dairy and beef cattle production is limited, though buffalo production is relatively well-developed, and small holdings of goats and sheep are common in the dry areas of the southern part.
4. The Central Highlands and their southern foothills have a low population density, and poverty rates are high in its mountainous parts and relatively low in the plains. The area is well-known for industrial tree crop production, particularly rubber, coffee and cashew nut, as well as for commercial horticultural production. Beef, as well as dairy production is relatively well developed. Forestry is important, though in many parts deforestation is a serious problem.

13.2 Examples of Existing Agricultural Production Systems Classifications

13.2.1 Dixon *et al.* (2001)

According top Dixon's classification, all lowlands and lower uplands fall into the category 'lowland rice', and most of the higher uplands into 'upland intensive mixed', as well as some parts of the latter into 'highland extensive mixed'. The 'sparse (forest)' class mainly covers the industrial rubber production areas, though some small parts of the mountainous North Central Coast, which indeed saw some major hardly reversible environmental damage during the years of war, made it into that class, too.

13.2.2 Thornton *et al.* (2002)

Most lowland areas of Vietnam fall into the ‘mixed irrigated’ class of the respective agro-ecological zone, with some coastal areas falling into the ‘mixed rainfed’ class. Most up- and highlands fall into the ‘mixed rainfed’ class of the respective agro-ecological zone, with some upland plains and valleys falling into the ‘mixed irrigated’ class.

13.3 Towards a Classification System: Observations Based on a Country Case Study of Vietnam

Figure 13.1: *Schema of a possible classification scheme for Vietnam.*

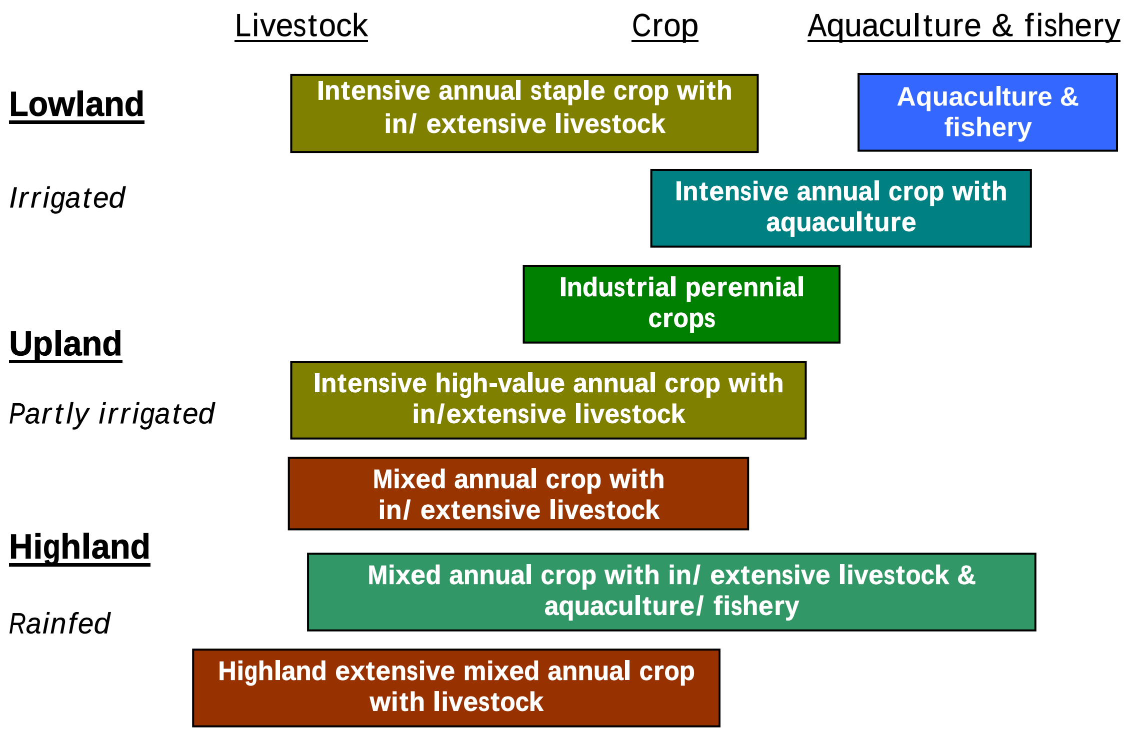

Figure 13.1 shows a schema of a possible classification system for Vietnam. Further possible further brake-downs include: (i) forestry use component; (ii) sloping versus flat land agriculture; (iii) according to dominant main livestock species; (iv) ‘traditional’ versus industrial livestock production; (v) staple versus horticultural annual crops; and (vi) subsistence versus market oriented production.

The important challenge that remains is that the classification scheme should potentially be compatible with a global classification system.

13.4 Discussion

This presentation was a graphic illustration of the fact that high-incidence-of-poverty areas are not necessarily the areas where the largest numbers of poor people are actually located. This work was felt to be a very valuable data source for validation of crop distribution models (such as the work by You *et al.* presented in this report).

The classification system has not yet been mapped; it is quite *ad hoc*, but it would be interesting to do this. The presently best available source of information for such applications is the 2002 Agricultural Census. However, there is not so much information on annual crops in that census, but more on cash crops and perennials from about 10,000 communes.

13.5 References

Dixon, J. and Gulliver, A. (with Gibbon, D.) (2001) *Farming Systems and Poverty. Improving Farmers' Livelihoods in a Changing World*. Rome and Washington DC: FAO and The World Bank. pp 412.

Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., Odero, A. and Ndegwa, T. (2002) *Mapping poverty and livestock in the developing world.* 124 pp. Nairobi: International Livestock Research Institute.

14. REQUIREMENTS OF GLOBAL LIVESTOCK PRODUCTION SYSTEM MAPS

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14.1 Overview

There are various features that a global, map-able farming systems classification might have:

1. It should be doable using available or easily-derived global data sets, ideally at similar resolutions.
2. It may be best to avoid a statistical/empirical approach as far as possible, because the system has to be interpretable and repeatable, given updates of information, additional data layers and adjustments to classification criteria.
3. It should be hierarchical -- it should make sense at whatever resolution the underlying data are at. So the system for the globe should be applicable to Kenya, and derived in the same way. It may even be a nested system -- i.e. the classification system depends on the scale at which one is operating, but higher-resolution system types are nested within the same coherent framework that operates independently of scale.
4. The classification should be dynamic, in the sense that we need to be able to predict something about the likely developments of farming systems in the future, and how they might evolve, in response to drivers such as population pressure, changes in demand for livestock and crop products, and climate change.
5. The classification should have an emphasis on the poor, in terms of being able to identify relatively small populations of poor croppers and livestock keepers.

From these general considerations, the presentation then went on to outline a recent study of vulnerability to climate change in sub-Saharan Africa commissioned by DFID and carried out at ILRI (Thornton *et al.*, 2006). This study broke down projected changes in length of growing period to 2050 on a country-by-system basis, for which we used the Seré and Steinfeld (1996) system linked to parts of the Dixon *et al.* (2001) classification. For the areas characterized as “other” in the Seré and Steinfeld scheme, we overlaid the cropping/livelihood systems found in the Dixon map, and these included forest-based systems, perennial highland systems, root-based systems, and coastal artisanal fishing systems, for example. If we had had a more comprehensive (and better tested) farming system classification scheme available for Africa, the results of the study could probably have been linked more directly to household livelihood strategies. This would ultimately result in improved broad-brush targetting of hotspots characterized by high potential levels of climate change impact and high levels of current vulnerability to change, so that appropriate adaptation options could be better linked to the households and communities that could most benefit from them.

14.2 Discussion

The vulnerability mapping work was based on the sustainable livelihoods approach for two reasons: the less important reason was that DFID was the donor for this work, and in the past DFID has been a staunch advocate of the approach. The more important reason was that the sustainable livelihoods approach provides a useful framework for helping to focus the work on people and poverty. Given the diversity of approaches to the notions of vulnerability and vulnerability assessment, this framework helped to focus our choices of indicator.

14.3 References

Dixon, J. and Gulliver, A. (with Gibbon, D.) (2001) *Farming Systems and Poverty. Improving Farmers' Livelihoods in a Changing World*. Rome and Washington DC: FAO and The World Bank. pp 412.

Seré, C. and Steinfeld, H. (1996) *World livestock production systems: current status, issues and trends*. Rome: FAO Animal Production and Health Paper 127.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N. and Omolo, A., with contributions from Orindi, V., Adwerah, A., Otiende, B., Bhadwal, S., Anantram, K., Nair, S. and Kumar, V. (2006) *Mapping climate vulnerability and poverty in Africa*. Report to the Department for International Development, ILRI, Nairobi, Kenya, 10 March 2006, pp 159. Online at http://www.dfid.gov.uk/research/mapping-climate.pdf

15. SPATIAL LIVESTOCK PRODUCTION MODELLING

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15.1 Introduction

Livestock distribution maps are extremely useful in drawing policy makers' attention to areas of high density of particular livestock species that are therefore surmised to be at risk of environmental degradation or and / or constitute areas of high animal and possibly human health risks and thus require attention. Livestock distribution maps however do not provide information on the dynamics of livestock populations, which are important determinants for the above risks, and therefore spatial livestock production modelling represents the next logical step to improve collective capacity for *ex-ante* and *ex-post* assessment of the impact of different livestock sector development interventions.

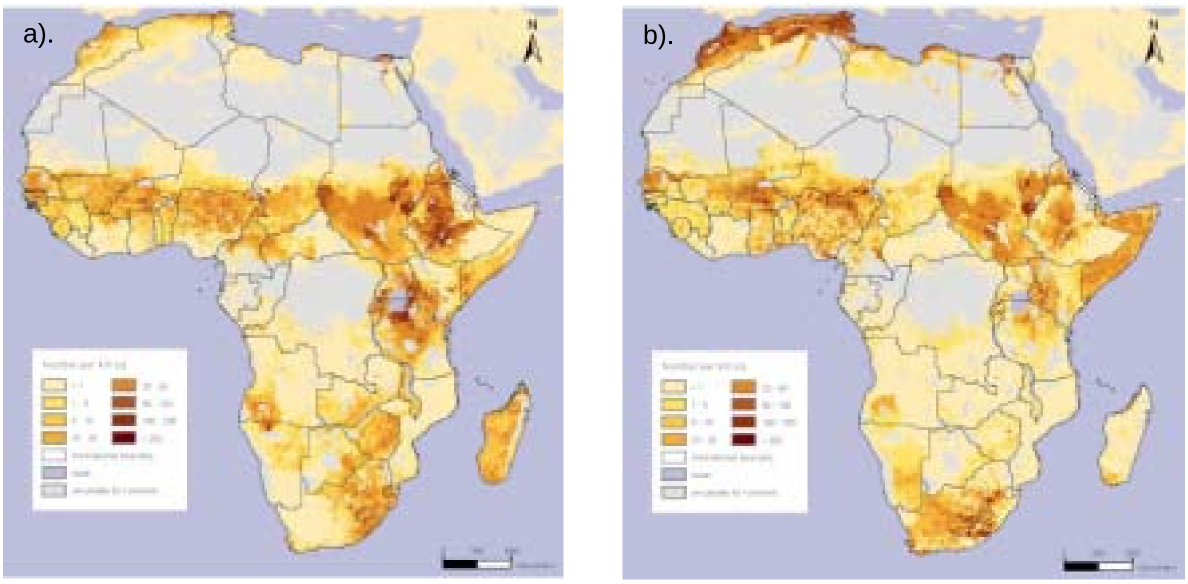
Spatial livestock production modelling as described in this paper builds on but goes beyond the mapping of livestock populations and biomass with the aim of spatially capturing the contribution of livestock to human food supply (meat, milk and eggs), their demands on natural resources through feed intake and production of waste and offering the potential for evaluating simple 'what-if' scenarios.

15.2 Materials and Methods

For any chosen geographic area and species, spatial livestock production modelling requires livestock density maps, livestock production systems maps and estimates of 'average output' per animal of the selected species.

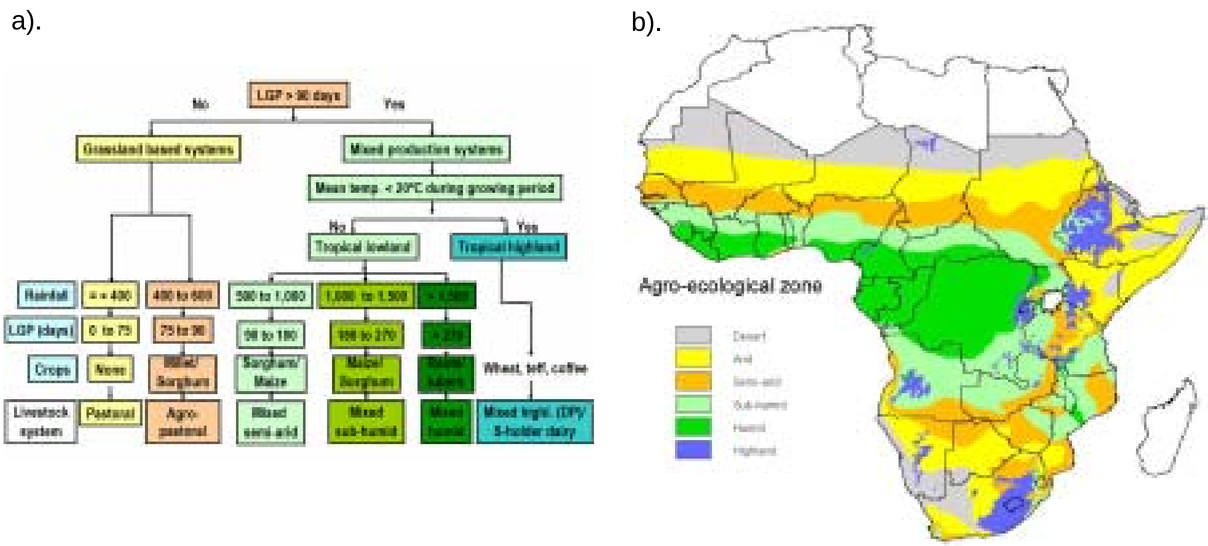
The development of livestock density maps has been described elsewhere (Robinson *et al.*, 2007; FAO, 2007) and estimated cattle and sheep densities in sub-Saharan Africa (SSA) are presented as an example in Figures 15.1 (a) and (b).

Figure 15.1: *Modelled distributions of a) cattle and b) sheep in Africa (from Robinson et al., 2007).*



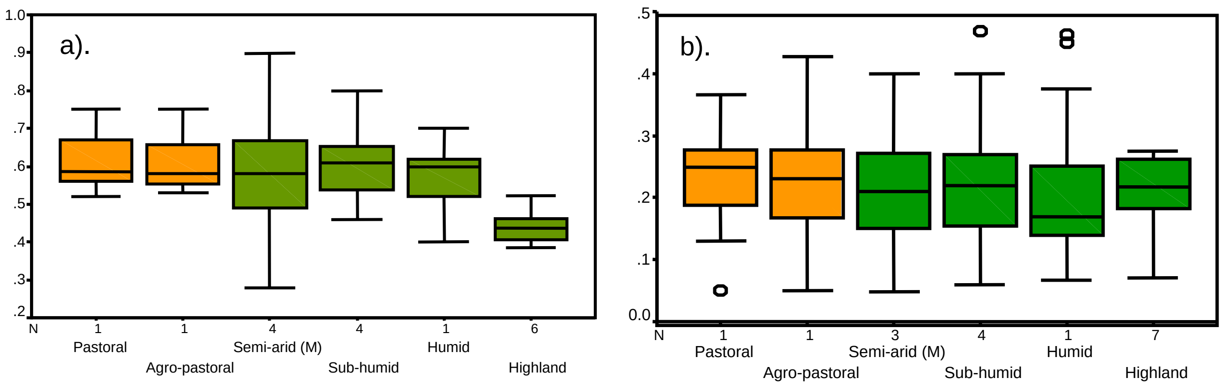
Livestock productions systems can be defined at various levels of detail and a relatively simple classification tree for cattle production systems in SSA determined primarily by agro-ecological zones (Otte and Chilonda, 2002) and the extension of these agro-ecological zones in SSA are shown in Figure 15.2(a) and Figure 15.2(b).

Figure 15.2: *(a) Production systems classification tree, and (b) Spatial extension of agro-ecological zones for sub-Saharan Africa.*



'Average output' (and feed requirement) per animal of a given species can be estimated with a number of readily available livestock production models. FAO uses the Livestock Development Planning System version 2 (LDPS2) (Lalonde and Sukigara, 1997) for this purpose and is systematically compiling scientific and grey literature on livestock performance indicators. Figures 15.3 (a) and (b) graphically displays the distribution of calving rates and calf mortality risks compiled for the above defined cattle production systems in SSA. Default performance indicator datasets have been produced for a number of productions systems.

Figure 15.3: *Distribution of (a) calving rates and (b) calf mortality risks reported for different production systems in sub-Saharan Africa.*



To illustrate the potential of the combination of livestock population maps with livestock production models for *ex-ante* assessments of livestock sector interventions the above approach has been applied for the estimation of the potential increase in offtake resulting from the elimination of *B. abortus* from cattle in SSA (Mangen *et al.*, 2002). Expected changes in the performance indicators of cattle in different production systems were derived from a systematic review of the literature on sero-prevalence of infection and published impacts on cattle production.

15.3 Results

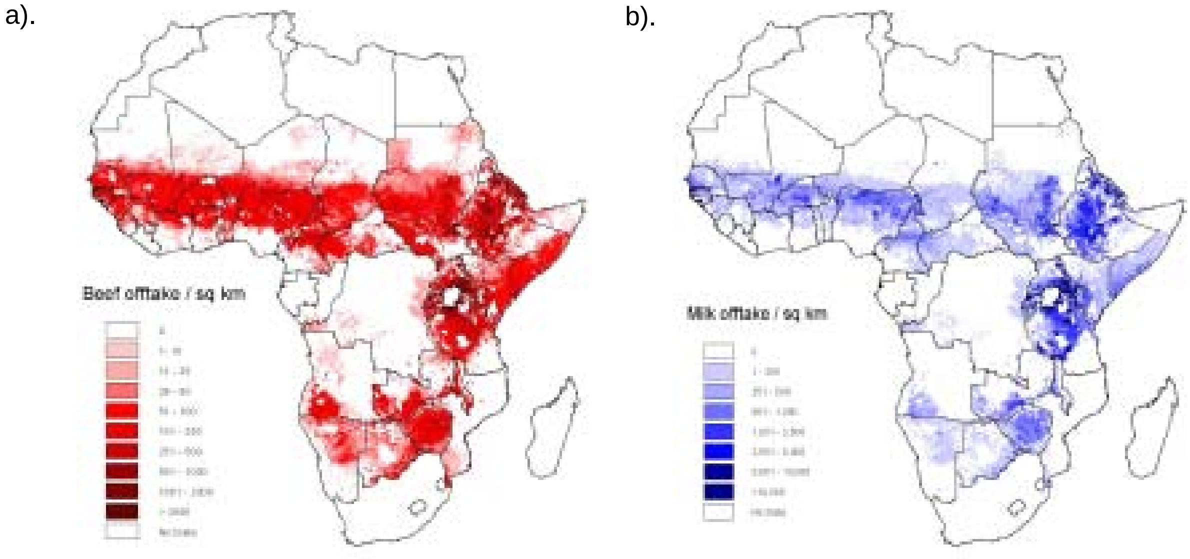
Table 15.1 presents estimates of average annual meat and milk offtake per head of cattle by production system and respective herd growth rates. Surprisingly, in SSA, smallholder dairy systems not only yield the highest milk offtake per head, but also the highest levels of meat offtake.

Table 15.1: Estimated annual herd growth rate and meat and milk offtake per bovine animal in sub-Saharan Africa by production system.

System	**Herd growth rate** (%)	**Meat offtake** (kg/animal)	**Milk offtake** (kg/animal)
(Agro)-pastoral (arid/semi-arid)	0.1	11.8	41.1
Mixed semi-arid	1.5	10.9	40.0
Mixed sub-humid	3.0	12.1	26.6
Mixed humid (Central & West Africa)	3.3	11.9	25.5
Mixed humid (East & South Africa)	3.3	13.2	25.5
Mixed highland	0.2	6.8	24.8
Smallholder dairy	1.7	18.3	599.8

Figure 15.4 shows the estimated meat and milk offtake per square kilometre derived by multiplication of cattle density per square kilometre with estimated annual offtake per head and production system.

Figure 15.4: *Estimated meat (a) and milk (b) offtake (kg/km^2) for sub-Saharan Africa.*



These mapped results can be used to estimate total meat and milk offtake by production system (Table 15.2), and, by relating them to maps of human populations, maps of potential supply for human consumption can be easily constructed.

Table 15.2: *Estimated total meat and milk offtake (1,000 MT) in sub-Saharan Africa by production system.*

System	Meat		Milk	
	1,000 MT	%	1,000 MT	%
(Agro)-pastoral (arid/semi-arid)	398.1	22.7	1,414.7	14.9
Mixed semi-arid	526.2	30.0	1,979.6	20.8
Mixed sub-humid	426.9	24.9	1,017.2	10.7
Mixed humid (Central & West Africa)	50.6	2.9	112.4	1.2
Mixed humid (East & South Africa)	17.8	1.0	45.8	0.5
Mixed highland	206.6	11.8	760.4	8.0
Smallholder dairy	127.6	7.3	9,505.9	43.9
Total	**1,752.1**		**9,459.8**	

The estimated potential for additional offtake per animal resulting from the elimination of *B. abortus* from cattle in different production systems, maintaining herd growth constant, is shown in Table 15.3 and maps of the spatial distribution of these benefits in Ethiopia, Uganda and Kenya are presented as Figures 15.5 (a) and (b).

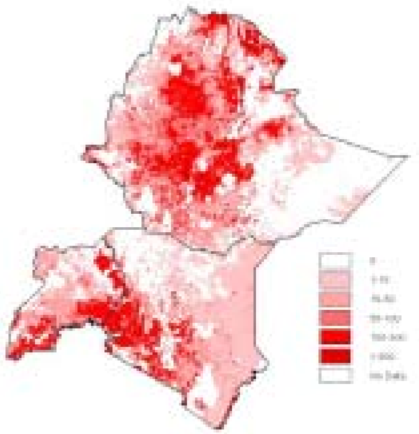
Table 15.3: *Estimated additional meat and milk offtake per bovine (kg/year) by production system after elimination of B. abortus.*

System	Meat	Milk
(Agro)-pastoral (arid/semi-arid)	2.0	2.8
Mixed semi-arid	2.1	2.8
Mixed sub-humid	2.0	1.7
Mixed humid	2.1	1.7
Mixed highland	1.5	2.1
Smallholder dairy	2.3	32.2

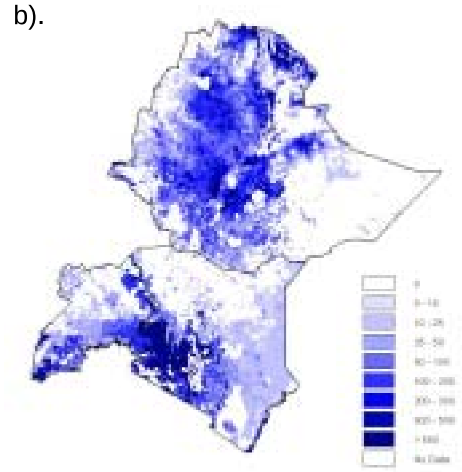
The spatial distribution of these expected benefits in Ethiopia, Uganda and Kenya are presented as Figures 15.5 (a) and (b).

Figure 15.5: *Estimated potential for additional (a) meat and (b) milk offtake resulting from elimination of B. abortus in cattle in Ethiopia, Uganda and Kenya (kg/km²).*

a).



b).



As before, these maps allow summation of the additional meat offtake by production system and, by multiplication with prevailing prices, provide an estimate of the order of magnitude of direct financial returns to the elimination of B. abortus (Table 15.4).

Table 15.4: *Estimated additional meat and milk offtake per bovine (kg / year) by production system after elimination of B. abortus.*

System	Additional meat offtake (million kg)	Additional milk offtake (million kg)	Additional value of meat & milk (million US$)
(Agro)-pastoral (arid/semi-arid)	21.2	29.7	48.3
Mixed semi-arid	11.9	15.8	26.9
Mixed sub-humid	13.8	11.7	29.9
Mixed humid	1.4	1.1	3.1
Mixed highland	39.2	54.9	89.4
Smallholder dairy	11.7	154.2	54.3
Total	**99.1**	**267.4**	**251.9**

Not surprisingly the above rough calculations show that in relation to the number of cattle kept in the different systems, the greatest benefits from the elimination of *B. abortus* would accrue to the smallholder dairy system, confirming that returns to disease control increase with rising intensity of animal production.

15.4 Conclusions

Spatial livestock production modelling can extend insights provided by livestock distribution mapping but results have to be interpreted with caution and numbers must be considered as 'orders of magnitude' rather than as accurate figures. The pitfalls of livestock distribution mapping have been well described (Robinson *et al*., 2007; FAO, 2007). Livestock production modelling adds additional sources of error stemming from unreliable information on animal performance in a given production system and region and from loose definitions of production systems themselves.

Despite countless studies on livestock performance and productivity over the past decades, no concerted effort has been undertaken so far to compile, classify and aggregate this information with the specific aim of making it available for livestock system modelling in support of policy making, livestock sector planning and both *ex-ante* and *ex-post* evaluation. The compilation of literature on livestock performance indicators has highlighted the areas, both regional and in regard to species and parameter classes, for which information is still scarce. This should be considered when planning of future studies. The compilation also highlighted the incomplete description of production location and system in most references, making it difficult to utilise many of the reported values for further analysis. On the other hand, the strict standards applied during data selection resulted in data sets, which can be considered robust and can easily used for relatively large-scale modelling purposes.

A second source of error arises through the definition and mapping of livestock production systems. This again is a process that is evolving, and collaborative efforts between FAO and ILRI are on-going to further develop the recent maps produced by Thornton and Kruska (2005) and defining a way to refining yet standardizing production systems definitions is the main purpose of this meeting.

Despite the above caveats, robust insights in support of livestock sector planning and policy making can be derived from livestock production mapping by rigorous application of sensitivity analysis, comparison of scenarios and peer review.

15.5 Discussion

In the described application, offtake rates were set to keep herd sizes constant in scenarios both with and without brucellosis to avoid the issue of exceeding carrying capacity. Livestock systems and underlying natural resource maps could certainly be used to overcome this simplification. Furthermore, at some stage price effects should be considered, which would however require information on price elasticities of demand and supply. In terms of any indicators of management inputs, it would be possible to use herd size perhaps, at least in the mixed systems, although clearly this would not be appropriate in the pastoral areas.

15.6 References

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16. MAPPING GLOBAL PRODUCTION SYSTEMS IN AN EVOLVING RURAL DEVELOPMENT CONTEXT

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16.1 Introduction

Rural economies in many developing nations are changing. Increasing interconnectedness to national and international markets, the spread of new technology and changing consumer preferences associated with rising incomes and urbanization are driving the industrialization and vertical integration of the food chain and the emergence of international value chains. The phenomenon has been baptized 'New agriculture'. Some of the features of these changes in agriculture are that they reach the poor also through non-food agriculture routes and products, and that they involve many different, and often new, players, particularly the private sector. Moreover, 'New agriculture' is firmly embedded in the global context of trade rules, consumer demands and competition, and change is often rapid and unpredictable.

Notwithstanding such radical changes in some places, food production and subsistence agriculture remain crucial to a large proportion of the rural poor. However, the impact of diseases such as HIV/AIDS, conflict and increasing number of climate-related disasters mean that also in these production systems, people need to tackle an evolving set of production, pests and disease problems often in rapidly declining environmental conditions. Concomitant changes have also occurred in the roles, responsibilities and working practices of rural actors through and increasing decentralization and privatization of public services and the resultant new forms of relationship between public, private sector and civil society, combined with an increasing and strengthening roles and influence of the private sector and civil society in development.

The implications of these contemporary scenarios for rural poverty reduction are similarly significant, as in order to cope, compete and prosper producers need to be able to constantly innovate. To facilitate this, not just knowledge and technology inputs are needed, but also the processes that make knowledge available and make its use possible. Such productive use of knowledge is the distinguishing feature of innovation and enabling this process is at the heart of the changes needed to reduce poverty. Moreover, the capacity to respond and adapt needs to be enhanced in ways that both allow producers to innovate and that safe-guards the livelihoods of poor people linked to the sector.

16.2 Mapping Production Systems and Innovation Capacity

If we accept the prior analysis, one could pose the question: "what missing layers would have to be mapped to present this spatially?", since thus far, mapping has largely been an exponent of the linear, technology-transfer approach to development and poverty reduction.

A spatial presentation of the capacity to innovate would entail the mapping of the temporal and locally specific manner in which the following elements interlock / interact to produce socially relevant outcomes:

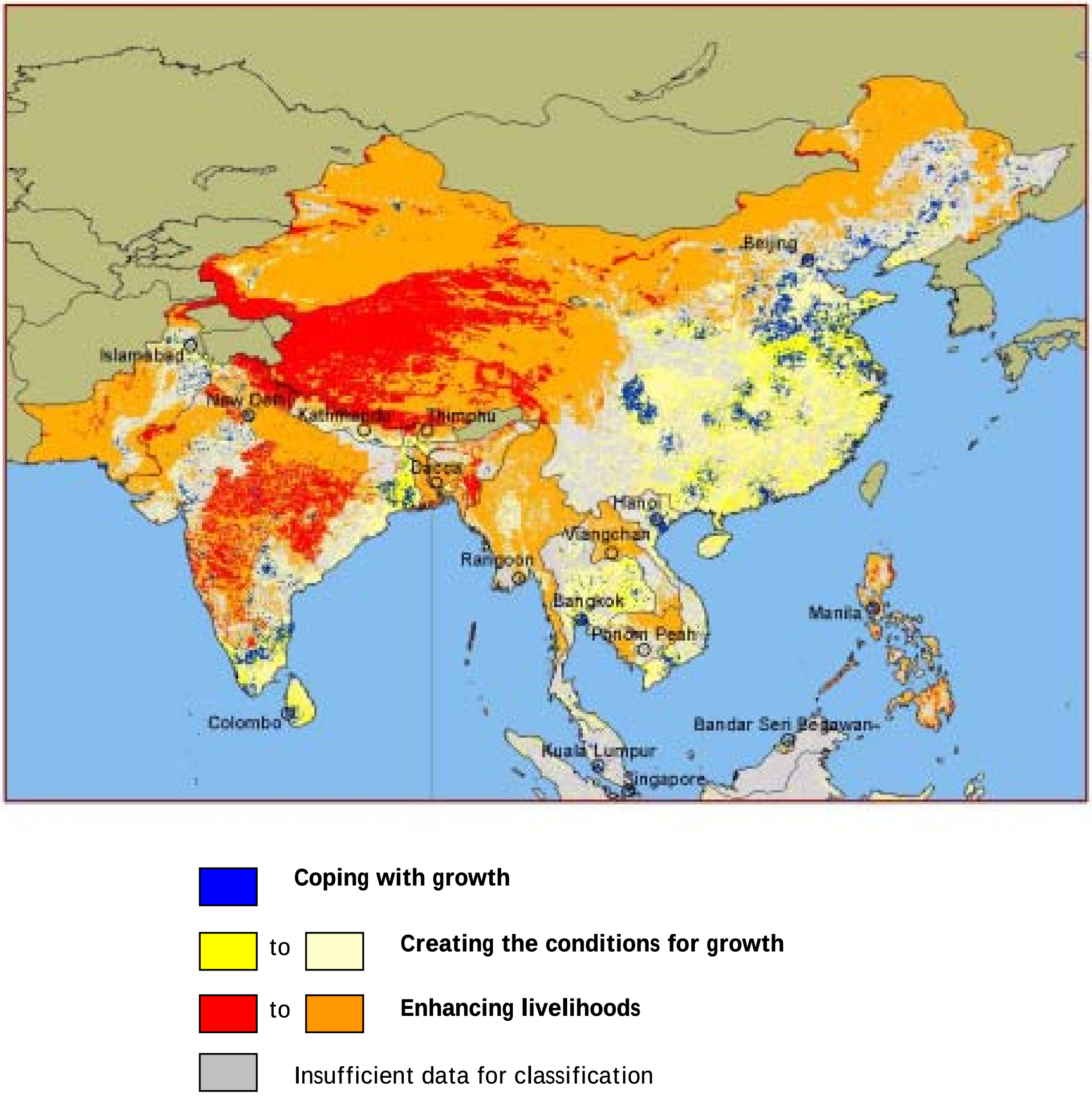
- *Skills*: scientific, entrepreneurial, managerial, others
- *Patterns of interaction*: partnerships, alliances, networks
- *Policies*: clusters of supportive policies and the nature of the policy process

- *Learning*: the ability to continuously learn how to use knowledge more effectively
- *Ways of working*: routines, organizational culture, traditional practices

But beyond the question: “what missing layers would have to be mapped to present this spatially?”, other important issues need addressing; at what scale would we need to map this to be useful?; what would be the costs related to such mapping?; what typologies would one use?; what do mapped intervention domains actually mean in a rapidly changing world?; would it change outcomes or results?

A few years ago, we actually had a go at trying to do some of this stuff by mapping three different intervention domains/development scenarios for southeast Asia, the output of which is shown in Figure 16.1.

Figure 16.1: *Three scenarios: draft distribution map for South and East Asia.*



Whilst interesting from a presentational point of view, and possibly as a first 'filter', the actual operational usefulness of such mapping is limited. Whereas having a first indication of, in this case, innovation capacity, would be useful, for such knowledge to be effective, it must be built on an analysis of local specific conditions, since the used resolution of information does not sufficiently stress the specific kinds of opportunities and threats facing actors, and may generate misguided responses—responses that may be appropriate generally, but not in the specific contexts they are meant to address. The actual data and understanding to intervene effectively is thus required at that level of depth that, when actually available, makes mapping it interesting from an academic or presentational interest, only, once again.

16.3 Building an 'Intelligent' Interface

So, what to do? Do we try and adjust the maps, or do we try and change the environments in which maps are / can be used? My inkling would be to concentrate more on the latter. The question then becomes; what would such an environment look like? It would require a significant shift in attention and underlying thinking away from the linear concept of technology transfer to the development of the capacities that support innovation. This would also mean that scientific endeavors, including GIS, will need to be embedded in a wider network of economic agents and policy actors, contributing to an adaptive capacity that needs to include the ability to learn and respond to change through its interaction with evolving contexts. Obviously such change would need to be supported by new habits and practices that promote the behaviour needed to sustain the above. The use of static data maps of production systems in such an environment, fully cognisant of all the drawbacks, would be of significant use in the course filtering and targeting of intervention options, analyses through the use of 'what if' scenarios and spatial impact monitoring. However, although there appears to be a general acceptance that the agricultural research agenda is now much wider including poverty reduction equity, and environmental sustainability, the way in which most mapping is organised still originates from a time when the task of agricultural research was simply providing productivity enhancing technology for others to diffuse and use. Building innovation capacity, as charity, starts at home. For production system 'mappers' this not only means that they have to accept that their work is accountable to these wider agendas, but also that the relevance of their work and its impact will be determined largely by relationships and actors outside the research domain.

16.4 Discussion

It was noted that there is a disconnect between user groups and what is available. There are plenty of clients for the maps: donors, who often have very specific demands; the research community, who want all the original data coupled with full documentation; and then the people in the middle, who want information on something specific. Often we will need to be mapping rates of change as proxies of systems dynamics, to overcome the problems of 'static maps'.

But what is it that is needed: the mother of all maps, or other types of product, or something more to do with the standardisation of data sets that users can then use in their own ways? Perhaps two things in particular are needed. One is, a set of "standard", global data sets that are freely available, whose borders all match up, etc. The second is some sort of framework that could be used not as a 'map mother' but that would help in (say) livestock distribution modelling revolving around some sort of coherent stratification scheme.

In a sense, perhaps it is more of an information base, rather than a map or a classification system. To make advances, we would need to ascertain what data are needed, and how might they be processed and analysed to meet several different needs. In any case, we need to make sure that there is added value to mapping things.

There may be a lot of work to get to the point where we could map some of these adaptive capacity or innovation capacity issues. But we need to improve the maps as well as change the environment within which they are used. It is probably the case that we need to take more of a demand-led approach: who are the users of global livestock maps, how do/would they use them, and how can we effectively and efficiently meet these needs? There is still a lot of base data on apparently quite simple things (crop distribution, livestock distribution, etc) that we need for baselines, impact assessments and other purposes, that we do not yet have. At the same time, we need to be thinking in terms of the empowerment of local decision makers in situations where spatial analysis can in fact make some sort of difference – we need to facilitate and enhance this.

17. GENERAL DISCUSSIONS

17.1 General Discussion: Missing Pieces

Several "missing pieces" were identified, as being possibly important:

- Crop and livestock diseases; there are some regional data sets (e.g. on trypanosomiasis), but the global situation seems sparse.
- We are missing the entire genetic resources area – gene mapping related to pest and disease pressure, crops and wild relatives.
- Mapping of wildlife and protected areas
- Proximity to water sources -- this can be important in some situations.
- Vulnerability mapping.
- Artisanal fishing. There was only limited knowledge in the group as to who is mapping this and aquaculture. There is some work ongoing at FAO. In this category, we might also include other things related to livelihoods, such as forestry.
- Public transportation networks.

This is a substantial list, and the question was asked, is there a minimum level of data that we need for this work? It was also pointed out that we do need to balance cost and utility of the added data. What is the added value of more global datasets – has this really been demonstrated? However, there is usually a compromise between what is doable and what is financially feasible. Increasingly, we do specific analyses because we are asked to do them, and then these demanded things are balanced against what we would like to do or get done.

17.2 General Discussion: Case Studies

Some general discussion followed concerning the five country case studies, and where these might lead. For Uganda, India, Vietnam and Senegal, there was felt to be scope to continue, in relation to existing activities. The Peru case study was dependent on other activities being funded later on (which has not subsequently occurred).

We discussed two directions in particular. One was to carry out cross-site comparisons for learning purposes; and the second was to take the work one step further to address a specific problem in particular places, such as land degradation in Senegal and trypanosomiasis control in Uganda. In India, the problem could be to do with water allocation and water competition in a situation characterised by rising populations and highly dynamic systems. In Vietnam, as in the other case studies, the work should feed into PPLPI activities, such as an examination of the policy of banning back-yard poultry production (i.e. issues that are short-term and related to livestock and poverty issues).

There was some discussion as to whether water scarcity is a key factor in poverty. This was felt to be somewhat like the livestock issue – there are links here that need to be demonstrated (or demonstrated better). In all this, the larger objective is to come up with and validate an approach that is useful at the national level that is also useful at the global level – the framework should be the same, but the data may be very different. At the same time, the case studies are meant to be linked to on-going pro-poor policy debates.

18. THE WAY FORWARD

18.1 Situation Analysis

The final day of the meeting started with a general brainstorming session using a logical approach to address the following questions:

1. What is the current situation (status recap)?
2. Where do we want to be in five years' time (future vision)?
3. What strategy is required to get from 1 to 2?
4. What specific activities would be involved in achieving this?
5. Who needs to be involved; and who should be responsible?
6. What specific support might be needed; what could be piggy-backed on; and what donor strategy might be appropriate?

This approach helped focus discussions, and the results are summarised below (we did not complete the process, as points 5 and 6 were not addressed in the brainstorming). The table below shows participants' assessment of the current situation, with corresponding estimates of where we want to be in five years' time. The various suggestions on "where we want to be in five years' time" were put into categories relating to products, data and methods, and the "current situation" comments below have been assigned to a category that seems appropriate (although there is of course overlap between some of these). Where no "current situation" comment in the left-hand column relates specifically to one of the "where do we want to be" suggestions in the right-hand column, the cell is left blank. For example, product number 3, "A flexible system that allows non-GIS users to define production systems according to their specific needs", is a good suggestion, but its absence at the current time was not raised specifically as an issue - rather, its absence is assumed.

Table 18.1: *Situation analysis summary.*

Current Situation	Where do we want to be in five years' time?
Products	
1 Lack of coordination of initiatives	**1** Global agricultural production systems maps at 1km resolution that include livestock, crops, forestry and aquaculture, that are useful at the national level, and that allow comparability between systems
2 Large advances in data and resolution but not clear how this is related to improved decision making	**2** Well-documented case studies of the use of agricultural production systems mapping in policy & decision making, together with clear guidelines on the use of products in strategy formulation to tackle priority issues such as poverty and land degradation
	3 A flexible system that allows non-GIS users to define production systems according to their specific needs
4 A variety of approaches based on different data and classification schemes	**4** A standardised, hierarchical classification scheme that has been reasonably widely adopted

Methods	
1.1 No agreement on methodological approaches **1.2** Different approaches using the same datasets **1.3** Little or no input from the agricultural community in land cover classification (many fores classes compared to few agriculture classes)	**1** Well-established methodology for agricultural production systems mapping that can be replicated and updated
2.1 Little use of socioeconomic data in mapping of global datasets **2.2** Socioeconomic data are country-specific and dynamic	**2** Inclusion of agrarian structure (e.g. farm size) and economic orientation in production systems
3.1 Lack of definition and datasets in the mixed farming group **3.2** Current land use/land use mapping classification schemes are incapable of mapping production systems	**3** Disaggregation of the mixed farming category
4 Outputs of existing classification schemes too coarse at the national level	**4** Application of small-area mapping techniques to agricultural production systems mapping
Data	
1.1 Several key/core databases available but they lack standardisation **1.2** Many different systems mapping projects but mostly using the same data **1.3** Inadequacy of existing global data at sub-national level **1.4** Poor dissemination of datasets	**1** Standardised databases that can characterise agricultural production systems at different levels of detail and flexible enough to serve a variety of purposes, that are maintained, documented and updated
2 Poor linkage between production systems and livelihoods	**2** More and better poverty proxies mapped at sub-national level
3 Current gridded crop data: inadequate and expensive to validate	**3** Modelled data increasingly replaced by accurate sub-national statistics
	4 Higher-quality human population projections developed

The next part of the process was to consider a strategy of moving from the current situation to the desired situation (from the left-hand column in the table to the right-hand column, questions 1 and 2 above). Several suggestions were made, summarised below:

- Make systems classification demand-led.
- Influence the remote sensing community to promote more appropriate sensor design.
- Influence on-going land cover-classification activities such as GLOBCOVER.
- Demonstrate the value of appropriate agricultural production systems classifications.

- Inter-institutional collaboration among the appropriate agencies should be fostered and encouraged.

Participants then had several suggestions as to the specific activities that could be embarked on that would contribute to this strategy (question 4 above):

- Re-invigorate the Consortium for Spatial Information (CSI) of the CGIAR.
- Constitute a working group of the key organisations involved, and embark on an iterative process with respect to the production of global datasets, assessment of different classification schemes, and validation activities through case-studies.
- Produce a document that clearly outlines the value of agricultural production systems maps.
- Lobby the broader community for support for these activities, such as the Millennium Development Goals, the Millennium Ecosystem Assessment, the International Assessment of Agricultural Science and Technology for Development, and the international climate change community.
- Implement jointly funded projects.

18.2 Uses and Requirements of Global Production Systems Classifications

A recurrent point during the workshop was that that any global production systems classifications/maps should be demand-led, emphasising the need to understand clearly what might be the applications of such a product. It was realised that, among such a small group it was impossible (and of little use) to produce a long list of all possible uses, but the following broad areas of usage were identified:

- Stratification for modelling (e.g. of livestock and crop distributions and of production off-take and yield estimates).
- Analysis of issues and improving understanding of how systems work (e.g. land degradation / biodiversity; poverty / livelihoods / food security; impacts of plant and animal disease control).
- Targetting of interventions (e.g. for the CGIAR challenge programmes; for donor activities, MDG-related activities; promoting appropriate technological options).
- Scaling out of more detailed analyses.
- Educational purposes.
- Increasing awareness, advocacy etc.

18.3 Preliminary Review of Some of the Relevant Criteria / Determinants (with special reference to those that have global coverage and are relatively reliable)

A very brief discussion was held listing the required datasets, which is summarised in the table below. Clearly, amongst the group present, and with our extended contacts, a very comprehensive list of data and sources could be compiled. The list below therefore represents only a cursory scan of the available datasets, which would be thoroughly revised, and prioritised based on a more clearly defined framework for classifying production systems.

Table 18.2: *Review of key data sets.*

Required DATASET	Resolution spatial and temporal	Source	Quality
Elevation and slope	90 m	SRTM	High
LGP, Highland/Temperate	1km	WorldClim +	High
Crops	10km	FAO / IFPRI	unknown
Hydrology/watershed characteristics	90m - 1km	Hydroshed (WWF)	High
Small waterbodies	30m	SRTM	High
Livestock	5km (1km)	FAO	unknown
Soil fertility	10km	CIESIN	unknown
Irrigated areas	1km - 10km	IWMI and FAO	unknown
Human population 2000 and projections to 2050	1km – 2.5km	CIESIN (GPW, GRUMP etc.); Landscan; ILRI	High
Infrastructure (populated places, accessibility, urban areas)	1km	Various: Andy Nelson, GRUMP	unknown
Land cover	1km	Various: e.g. GLC2000; Africover	variable
Aquaculture areas	Vector	FAO-NASO	Not global, in progress
Forest areas	500m - 1km	Various: e.g. FAO-FRA; Maryland; MODIS VCF	variable
Protected areas	Vector	IUCN (UNEP-WCMC)	High
Primary productivity	500m	MODIS NPP	High
Farm size	unknown	National surveys	unknown
Farm input information	unkbown	National surveys	unknown

18.4 Options to Develop a Common Classification Framework

There were extended discussions on the type of classification framework that might be appropriate, which fell broadly under the following headings:

1. Revised and updated Seré and Steinfeld type approach, but adapted to meet the requirements of a broader range of objectives and the possibility of a wider variety of classification criteria (available globally). [case study: Peru; Uganda]
2. Revised and updated Dixon and Gulliver type approach, with similar adaptations to those mentioned above. [case study: Senegal]
3. And adaptation or development of FAO's LCCS. [case study: Andhra Pradesh]

4. A modelling approach, based on the definition of detailed production systems, applied to detailed household-level data, that could be then be extrapolated and interpolated between observations using models based on more widely available variables. [case study: VietNam]
5. A hierarchical approach with increasing complexity at subsequent levels: level 1 = climate, land cover and population (based on accurately measured datasets); level 2 = land use, incorporating modelled crop and livestock data; level 3 = more detailed land use based on nationally-specific agricultural data. [case study: Uganda]

These approaches are to a large extent being addressed by different case studies and it was agreed that these case studies should be continued, with these in mind, so that comparison of approaches could be made across methods and regions. Initial case studies for the different approaches are indicated above in square brackets.

18.5 Initial Work Plan, Some Roles and Responsibilities, and Possible Sources of Funding

It was agreed that an informal working group should be maintained to forward these activities, and that Tim Robinson and Philip Thornton should continue to coordinate the activities of this working group. Of those present at the meeting the list below expressed an interest in being directly involved in the working group – the others expressed a wish to be involved in a more extended group of interested partners, which would also include members from other relevant and interested institutions such as John Dixon (CIMMYT); John Latham (FAO-SDRN); and Stanley Wood (IFPRI).

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- Epprecht, Michael (FAO Consultant)
- Franceschini, Gianluca (FAO – AGAL)
- George, Hubert (FAO – AGLL)
- Kruska, Russ (CGIAR – ILRI)
- Nelson, Andy (JRC – IES)
- Robinson, Timothy (FAO – AGAL)
- Thornton, Philip (CGIAR – ILRI)
- You, Liangzhi (CGIAR – IFPRI)
- Zomer, Robert (CGIAR – IWMI)

18.6 TOR of Working Group

1. Decide on the key applications/requirements of agricultural production systems maps (links with livelihoods, use for decision making and planning, etc.).
2. Agree on key datasets, and decide how and by which organisations they will be maintained and updated.
3. Develop a prototype hierarchical classification scheme for testing and validation.
4. Produce joint proposals for funding for the development, testing and validating of global agricultural production systems.

5. Develop a strategy of how these activities in the short term are to be covered by existing activities.
6. Coordinate and harmonise the testing and validation of pilot schemes.
7. Establish a wider network of people involved and communicate with them.
8. Produce a document that clearly outlines the value of agricultural production systems maps.
9. Articulate the requirements of agricultural production systems mapping to the agricultural statistical community.
10. Develop and maintain a web site (CSI) to disseminate the working group activities.

18.7 Some Next Steps

TOR 2 – IFPRI to evaluate the entropy method for crop disaggregation for case studies (at 10km resolution), and discuss the possibility of developing a 1km resolution model.

TOR 3 – Collate some ideas for discussion as to what an ideal farming classification scheme might look like (i.e. without any data restrictions in terms of implementing it), and assess how feasible it would be to implement for the case studies (VietNam, Uganda, Senegal, AP and possibly Peru). Towards this end:

1. the working group will produce a list the determinants of a classification scheme
2. assess which of these can be observed/derived/proxied, and how
3. apply existing schemes across a range of case studies

TOR 4 – Sources of funds will be explored (e.g. Bill Gates Foundation) and proposals developed by the working group.

TOR 8 – Preliminary documentation will be assembled, including a review of some examples of how agricultural production system maps can be applied in a priority setting.

All participants have agreed to provide a summary of their presentations. A finalised workshop report, incorporating these summaries and the discussions will be compiled and edited and distributed to participants and a wider audience by Tim Robinson and Philip Thornton.

ANNEX A: PARTICIPANTS

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ANNEX B: AGENDA

Tuesday 4 April		
Overview		*Otte*
9:00-9:30	Overview, background and meeting objectives	Robinson
9:30-10:00	Review of existing global agricultural systems classifications	Thornton
10:00-10:30	Discussion: meeting objectives and outcomes	
10:30-11:00	*Tea/coffee*	
Some ongoing global initiatives		*Thornton*
11:00-11:30	Livestock production system mapping at ILRI	Kruska
11:30-12:00	Livestock distribution mapping	Robinson
12:00-12:30	Crop data I: AgroMAPS	George
12:30-1:00	Global land cover datasets	Nelson
1:00-1:30	Crop data II: Crop modelling	You
1:30-2:30	*Lunch*	
2:30-3:00	Population and poverty	Ahamed
3:00-3:30	Urban areas and accessibility	Nelson
3:30-4:30	Discussion: Ongoing global initiatives	
6:00 onwards	*Workshop cocktails and dinner*	
Wednesday 5 April		
Country case studies		*Steinfeld*
9:00-9:30	Horn of Africa (Uganda)	Robinson
9:30-10:00	West Africa (Senegal)	George, Francescini
10:00-10:30	Andean Region (Peru)	Thornton
10:30-11:00	*Tea/coffee*	
11:00-11:30	South-East Asia (VietNam)	Epprecht
11:30-12:00	South Asia (India-Andhra Pradesh)	Zomer
12:00-1:00	Discussion: Country case studies	
1:00-2:00	*Lunch*	
Requirements of global livestock production system maps		*Robinson*
2:00-2:30	Requirements of global livestock production system maps	Thornton
2:30-3:00	Livestock production modelling	Otte
3:00-3:30	Livestock-environment interactions	Steinfeld
3:30-4:00	Intervention domain mapping	Dijkman
4:00-4:30	*Tea/coffee*	
4:30-5:30	Discussion: Recap and outline for day 3	
Thursday 6 April		
The way forward		*Dijkman*
9:00 onwards	**Expected outcomes:** Requirements revisited (what we need to achieve) Which global datasets to use/develop Developing a common classification framework Work plan, roles and responsibilities, possible sources of funding	tea/coffee: 10:30-11:00 lunch: 1:00-2:00 close: 16:30