Methods

The approach taken here to map consumption of livestock commodities essentially involves taking the FAO estimates of consumption and mapping these, based on the distribution of people. The analysis is constrained by the level of disaggregation of the available data; which provides average consumption rates of livestock products for each country. In reality we know that consumption rates for livestock commodities tend to be higher in the more affluent urban areas and amongst the wealthier sectors of society in general. Production of livestock commodities can be mapped in a similar way – disaggregating estimated production based on the distributions of the relevant livestock species.

Below, we describe the data and methods used to map changing demand and supply of livestock commodities.

HUMAN POPULATION DISTRIBUTION

There are various estimates of current and future populations. The most widely used come from the UN *World Population Prospects* (*e.g.* UN, 2009) and *World Urbanisation Prospects* (*e.g.* UN, 2008). These data include total population numbers and the proportion of the population living in urban areas now and in the future.

Whilst the UN figures provide national totals there have been various projects to disaggregate population data globally, the most important of which are the Landscan project (ORNL, 2008), the Gridded Population of the World (GPW) (CIESIN and CIAT, 2005) and the Global Rural and Urban Mapping Project (GRUMP) (CIESIN et al., 2004).

Landscan provides the most up-to date, gridded (i.e. presented in geographic information system (GIS) format as a raster layer), worldwide population database and its population values are the result of a model that apportions census counts (at sub-national level) to each cell of a 30 arc-second grid (about 1 km at the equator) according to likelihood coefficients. These coefficients are based on proximity to roads, slope, land cover, night-time lights, and other information. The database is updated annually by incorporating new spatial data and remotely sensed imagery, and the distribution algorithms are revised accordingly. Comparing different versions of the dataset, cell by cell over time, therefore, may result in misleading conclusions, and thus the data should not be used to infer change, for example as a result of migration (ORNL, 2008).

GPW and GRUMP gridded data are derived from a simple proportional allocation gridding algorithm of national and sub-national level population data from as close as possible to the time of the estimate. GPW data are available at a resolution of 2.5 arc-minutes (about 5 km at the equator) for the years 1990, 1995 and 2000.

GRUMP has been developed to allow analysis of urban and rural population figures based on a consistent global dataset. It does not provide future population estimates, but it distinguishes urban and rural population taken from around the year 2000, and also provides a map of urban extents, which was derived largely from the night-time lights (Elvidge *et al.*, 1997). GRUMP is available at the finer spatial resolution of 30 arc-seconds (about 1 km at the equator). Details on the methodology and data sources are provided in Balk *et al.* (2004).

Whilst future projections of national totals and rates of urbanisation of human populations are readily available, there have been few attempts to map future human population distributions. One project implemented by the Center for International Earth Science Information Network (CIESIN) and FAO provides projected populations to 2015 but no further (CIESIN *et al.*, 2005)

LIVESTOCK DISTRIBUTION

FAO has an ongoing programme to collate and disseminate sub-national livestock statistics for the globe: the Global Livestock Impact Mapping System (GLIMS) (Franceschini *et al.*, 2009). Sub-national livestock statistics are collected from a variety of sources and geo-registered to digital administrative area boundaries, standardised to the Global Administrative Unit Layers (GAUL)[2] system where possible. One of the products derived from GLIMS is the Gridded Livestock of the World (GLW)[3] (Robinson *et al.* 2007; FAO 2007a), which provides modelled distribution data in ESRI grid format for cattle, buffalo, sheep, goats, pigs, chickens and other poultry. The map values are animal densities per square kilometre, at a resolution currently of 3 arc-minutes (approximately 5 km at the equator) with work in progress to upgrade this to a 1 km product (30 arc-seconds). These maps are updated regularly using the method summarised below (and described in detail in FAO, 2007a).

Firstly the best available sub-national data on livestock populations, at a range of spatial resolutions depending on availability, are collected and standardised. These are converted to densities, at the same time adjusting to account for the area of land deemed suitable for livestock production, for example where satellite-derived vegetation indices indicate there to be insufficient grazing (for ruminant species); 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.

The resulting suitability-adjusted livestock densities are then used to establish robust statistical relationships between livestock densities and an extensive suite of predictor variables, summarised in Table 1. Details and references to the data sources are provided in Robinson *et al.* (2007) and FAO (2007a).

Since the predictors of animal densities are unlikely to be consistent from region to region, or across different agro-ecological zones, models are developed separately for different regions and for different ecological zones defined empirically by clustering (unsupervised classification) of remotely sensed climatic variables. A series of stepwise multiple regression analyses is performed between the livestock densities and the predictor variables and the best-fitting equations are then applied back to the images of predictor variables to generate a map of modelled density for each species. To avoid spurious predictions, the modelled total numbers for each administrative unit are adjusted to equal those reported for a given administrative unit. Further products are then generated, adjusting the modelled data so that national totals match FAO's official national statistics for the years 2000 and 2005, providing time-standardised datasets.

[2] The Global Administrative Unit Layer (GAUL): http://www.fao.org/geonetwork/srv/en/metadata.show?id=12691&currTab=simple

[3] The Gridded Livestock of the World (GLW): www.fao.org/ag/againfo/resources/en/glw/home.html

Table 1. Generic list of variables used in livestock distribution modelling.

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

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

Following from livestock distribution maps, attempts have been made in some parts of the world to map production of various livestock commodities. Livestock production and off-take rates vary across different agro-ecological zones and livestock production systems, and in a broadly predictable way. Thus models for livestock growth and off-take can be applied to the livestock distribution maps – parameterised differentially for different zones or systems. For example, beef and milk production and use of draught power in sub-Saharan Africa have been estimated by deriving annual output per head of cattle within each of seven major agro-ecological zones (FAO, 2002a and FAO, 2002b). These zones were defined and mapped by combining a number of spatial variables (temperature, elevation, Length of Growing Period (LGP) and crop type) in a decision tree. Livestock production was modelled for each zone using the herd growth model within the Livestock Development Planning System Version 2 (LDPS-2) (FAO, 1997). The herd models were parameterised separately for each zone, based on available published data (for some parameters, data were sparse). More recently meat and milk off-take maps were re-evaluated for Africa using the updated GLW cattle distributions (Robinson *et al.*, 2007) and the Thornton *et al.* (2002) livestock production systems to stratify production modelling (FAO, 2007a).

A number of attempts has been made to map future livestock populations. Herrero *et al.* (2008), for example estimated the distribution of African ruminant livestock in 2030 based on FAOSTAT trends applied to the GLW livestock distributions. A more sophisticated approach takes the outputs from global agricultural sector models and makes the conversion from tonnes of livestock products back to spatial distributions of livestock, again based on GLW (Rosegrant *et al.*, 2009). Both of these approaches involve pro-rata adjustments to current estimates, based on GLW. A logical next level of sophistication would be to apply differential growth rates for different livestock production systems. Such an approach has been taken for cattle in West Africa (Shaw *et al.*, 2006) and, more recently, in East Africa (FAO, *in press*; Wint *et al.* 2011) with the specific purpose of mapping the benefits of disease control – trypanosomosis in this instance – over a 20 year period. In these examples cattle herd models have been differentially parameterised for each of a series of cattle production systems and the populations grown accordingly. An estimate of maximum stocking rate, based on climate and human population is further employed to decide when cattle need to migrate away from an area of growth. Such approaches, whilst almost certainly the way forward with the larger, slower growing species of livestock, are not really applicable to the monogastric species with their much higher turnover rates.

PROJECTED PRODUCTION AND CONSUMPTION OF LIVESTOCK COMMODITIES

The methodology used for producing the FAO projections, summarised below, is described in detail in Alexandratos (1995), who stresses the importance of noting that the resulting projections are not 'trend extrapolations', but rather are based on expectations of the future. The overall approach is to estimate the food balance sheets for a base year, driven primarily by estimates of current production levels, and then to project demand for each commodity using Engel demand functions and exogenous assumptions of population and GDP growth. Provisional production targets are derived for each commodity and country based on rules about future levels of self-sufficiency and trade. Specialists in each country and discipline are engaged and the production targets are revised during several rounds of iterations and adjustments based what are considered to be feasible and realistic levels of land use, production intensity, yields and trade.

For the livestock sector a formal 'flex-price model' is used (FAO, 1993) to provide starting levels for the iterations and to keep track of the implications, for all variables, of the changes in any one variable introduced in successive rounds. Again, the results of the model projections are scrutinised at each iteration by specialists, particularly with respect to realistic levels of production growth and trade.

The livestock commodities included in the FAO projections are listed in Table 2 and the countries and country groupings for which FAO projections are available are given in Annex A.

Base year data preparation

First a base year is selected, and represented using a 3 year average centred on that year. For each commodity and country production, demand and net trade balances are estimated. For the demand-supply analysis the Supply Utilisation Accounts (SUAs) framework is adopted, which is structured as follows:

Food (direct) + Industrial non-food uses + Feed + Seed + Waste (+ Discrepancy)

= Demand (total domestic use)

= Production + (Imports - Exports) + (Opening stocks - Closing stocks)

For the base year the SUAs are driven by production estimates. Net trade, feed, seed, waste and industrial use are estimated for each commodity and the food avail-

Table 2. Livestock commodities included in the FAO projections

Commodity groupings
Beef, veal and buffalo meat
Mutton, lamb and goat meat
Pig meat
Poultry meat
Milk and dairy products (whole milk equivalent)
Eggs

Source: Alexandratos (1995)

able for direct human consumption is the residual. For the most recent estimates that are currently available (FAO, 2006b) the base year SUA was constructed using FAOSTAT data from 1999, 2000 and 2001 on crop and livestock commodities where possible, but adjusted by the authors where other sources of data provided more reliable estimates.

A major component of data preparation is the task of unravelling the SUA element *production* for the base year into its constituent components. The rather complex procedure is described in detail in Alexandratos (1995) but, put simply, crop production requires the areas, cropping intensities and yields to be estimated, and livestock production requires the total stock, off-take rates and carcass weights (or yields per animal in the case of milk and eggs) to be estimated.

Production (crops) = Area planted × Cropping intensity × Yield

Production (meat) = Number of animals × Off-take rate × Carcass weight

Production (milk and eggs) = Number of animals × Yield

Projections of human population and GDP

The most recent estimates of human population and GDP now and in the future are described above but the currently available FAO projections are based on earlier versions of these. Whilst the newer figures are being incorporated into the FAO projections these were not available when this paper was written.

Population figures used in the FAO projections were taken from the medium variant UN *World Population Prospects* 2002 revision (UN, 2003). Those estimates projected the world population to grow from the 2000 level of 6.07 billion to 8.13 billion in 2030 and 8.92 billion in 2050. These do vary from the most recent medium variant revisions, which are less conservative: 8.31 billion in 2030 and 9.15 billion in 2050 (UN, 2009).

Estimates of economic performance were based largely on the World Bank's *Global Economic Prospects, 2006* (World Bank, 2006a), which provide economic growth (per-capita GDP) projections for the period from 2001 to 2015. These projections and extensions to 2030 '... *provided the basis for defining the GDP projections used as exogenous assumptions in the present study. Projections for the period 2030-50 were formulated by the authors of this study, largely on the assumption of continuation of the growth of the period to 2030, but with some important exceptions.*'. These exceptions are listed in FAO (2006b).

Projecting supply and demand for livestock commodities

Whilst it may seem more logical to separate the discussion on projecting demand from that on projecting supply, the two sides of the equation are intimately linked so are discussed together. The FAO projections involve three broad steps: a) drawing up SUAs, by commodity and country, for the years to be projected, in this case 2030 and 2050[4]; b) unravelling the projected production into its component elements; and c) drawing up land use balances.

The SUA projections for livestock commodities (as well as those for cereals and oil-crops) are derived using a flex-price model (FAO, 1993). This provides year-by-year world price equilibrium solutions for the commodities covered, it has demand (for food, feed, other uses) and supply (area, yields, animal numbers, etc.) equations for each country, and each country's solution is influenced by those for every other country through imports and exports, which are equated at the world level by price changes. (For some other commodities, such as sugar, rubber, cotton and jute, single commodity models are used to generate the initial projections.) For all commodities parallel projections are prepared for each SUA element, as described in Alexandratos (1995). In the livestock sector, for meat commodities the *food* element is by far the most important as very little of overall production is assigned to the other elements of the demand side (*industrial non-food uses, feed and waste – seed* is not relevant in this case). For milk products, however, there are significant amounts of total demand assigned to the elements of *feed* and *waste* and, with eggs, some of the demand is assigned to *waste* and a proportion to the *seed* element.

The *food* element (more correctly termed 'food available for direct human consumption') is projected in per-capita terms using the base year data, a set of estimated food demand functions (Engel curves) for up to 52 separate commodities in each country, and assumptions about the growth of per-capita GDP. The results are reviewed by commodity and nutrition specialists and adjusted taking into account any relevant knowledge and information; in particular the historical evolution of per-capita demand and the nutritional patterns in each country. The total projected food demand is then obtained by multiplying the projected per-capita levels with projected population.

MAPPING CHANGING CONSUMPTION OF LIVESTOCK COMMODITIES

The first stage in mapping consumption of livestock commodities involves mapping the human population now and in the future. For the base year (2000) the GRUMP population map was used but was adjusted so that national totals matched those used by the FAO projections, which themselves were based on those reported in UN (2003). For the 2030 and 2050 projections the adjusted GRUMP 2000 maps were used, and the base year population figures were multiplied by 'growth' factors, so that the total number of people in each country matched the FAO projected figures. Urban and rural population totals for 2000, 2030 and 2050 were also estimated, based on the proportions of the population living in urban areas from the UN World Urbanisation Prospects (UN, 2008). Then, for each country, the urban and rural population distributions from GRUMP were adjusted to match the UN/

[4] Data were prepared for 2050 in the same way as for 2030, but we do not include any of the 2050 projections in this paper.

FAO urban and rural totals in 2000, and 'grown' separately to map future urban and rural populations. No attempt at this stage has been made to adjust the urban extents (provided by GRUMP) or to disperse population growth from high density rural areas within countries (international migration and movements from rural to urban areas are already accounted for in the UN projections).

For each time period the food consumption for each commodity was distributed equally among the population of each country resulting in a map of absolute consumption, measured in metric tonnes per pixel. Since the population map is based not on an equal area projection but on a geographic Plate Carée projection the actual land area represented by a pixel decreases north and south of the equator (whereas the size of the pixel remains the same on the map). To make consumption values equivalent across the globe, therefore, these were re-expressed as consumption per square kilometre.

Absolute changes in consumption can then be estimated for each commodity by subtracting the map of consumption estimates for the base year, 2000, from those for 2030 or 2050. Since the changes are applied evenly to the population there is little point in mapping the proportional changes in demand growth for livestock commodities as the population distribution cancels out, resulting in two values within each country – an urban value and a rural value – which is merely the proportional increase in food from 2000 to 2030 from the FAO projections, weighted across rural and urban areas. Whilst maps of relative change in demand would be of little value, these important results can be summarised in tabular form.

MAPPING CHANGING PRODUCTION OF LIVESTOCK COMMODITIES

A similar approach can be taken to mapping production but the process is even more complex and there are greater constraints imposed by the available data. Most importantly is that all livestock are not equal – an increase in demand for milk in Kenya, for example, will not be met by increased production in the arid and semi-arid pastoral areas, but by increased production in the temperate and highland areas that are closer to the main population centres. Accounting for this differential growth is no trivial matter and will require a good understanding of livestock production systems, how these systems are likely to evolve, and how that evolution will be influenced by trade in livestock commodities, resource availability and many other factors.

The ways in which increased demand for livestock products will be met will a) vary for different commodities, b) depend very much on accessibility to growth centres, c) depend on the cost and availability of inputs – the most important of which is usually feed and d) depend on competition from potential imports - for example coastal population centres may more readily be served by importation of cheap frozen meat, or dried milk and egg products, than by increasing production in the vicinity. The ways in which increasing demands are met will vary considerably from centre to centre so simply to increase local production *pro rata*, based on existing livestock distributions, could in some places give rise to quite misleading results.

Table 3 shows the commodities that are included in the FAO projections against the livestock species maps that are available globally from the GLW dataset. For beef production cattle and buffalo have to be combined into a large ruminant layer.

Table 3. Livestock commodities included in the FAO projections and livestock species available from the Gridded Livestock of the World (GLW) databases.

Commodity groupings	Relevant livestock species
Beef, veal and buffalo meat	Cattle, buffalo
Mutton, lamb and goat meat	Sheep, goat
Pig meat	Pigs
Poultry meat	Poultry
Milk and dairy products (whole milk equivalent)	Cattle, buffalo, sheep, goats (camels not available)
Eggs	Poultry

No distinction is made between cattle and buffalo by the FAO projections in terms of animal numbers, off-take rates or carcass weights. The same applies to small ruminants. With milk and dairy products, large ruminants and small ruminants are dealt with separately in the FAO projections. Milk from camels is also included in the FAO projections but the GLW datasets do not currently include this species.

With poultry and ruminants a further problem is faced in that there are two primary outputs; meat and eggs, and meat and milk, respectively. In reality it tends to be different animals in different production systems that are specialised to produce one or the other, though these distinctions are much less evident in small-holder systems. Our available livestock datasets, however, make no such distinction so the production of these commodities has to be distributed evenly across all animals.

In order to map production of different livestock commodities now and in the future the production estimates provided in the FAO projections have been spatially disaggregated using the GLW estimates, merging the species that contribute to the same commodity (see Table 3). As with the estimates of consumption these were then re-assigned from estimates per pixel to estimates per square kilometre (by dividing absolute production in each pixel by its area).

The absolute change in production from 2000 to 2030, or form 2000 to 2050 can again be estimated by simple subtraction, but given the assumptions made in mapping production without accounting for the evolution of livestock production systems, maps of changing production should be treated with extreme caution.

As with consumption, the changes are applied evenly to the livestock distribution so there is no point in mapping the proportional increase as the population of livestock cancels out, resulting in a single figure for each country. In the case of production, there is no urban/rural distinction so we have only one value for each country.

A further possibility here would be to produce maps of livestock numbers in the future using the FAO projections. Stock numbers are also provided in the FAO projections but would need to be split out for species groups: cattle and buffalo, sheep and goats, poultry. Currently it is unlikely that the GLW data are sufficiently detailed to assist much with this, though work is underway to incorporate more detail that would enable such analysis. Potential applications for projected livestock distributions are many and include environmental impact assessment and disease risk mapping. To be of real value, however, such projections would need to be explicitly linked to livestock production systems.

MAPPING PRODUCTION SURPLUSES/DEFICITS

With a few exceptions, demand and supply of livestock products tend to grow hand in hand and imports of livestock products comprise a significant share of total consumption in very few countries. In most cases, therefore, one is unlikely to find much difference in demand and supply trends of livestock products at a national level. Within countries, however, the areas of high production, particularly for the more land-based ruminant species, can be very different from the highly populated consumption areas.

Having spatially disaggregated consumption and production, maps of production surpluses (or deficits) can be produced by simple subtraction. Thus, areas where production exceeds consumption can be identified, and vice versa. Such maps have in the past been created and used to infer movements of livestock or products thereof. Two examples of such, summarised in FAO (2007a), are estimated movements of sheep meat in the Near East (FAO, 2004a) and areas of inferred cattle movements in sub-Saharan Africa, assumed to pose a high risk of Foot and Mouth Disease (FMD) transmission (FAO, 2005).

STANDARDISING CONSUMPTION OF ANIMAL-SOURCE FOODS

Comparing consumption of milk and beef, for example, in terms of weight in kilogrammes, makes no sense; milk is made up almost entirely of water, as compared to beef. To make comparisons among commodities, therefore, they must first be standardised. The SUA approach is primarily designed to look at food insecurity in the world and, as such, contains valuable information that can be used to standardise commodities: the amounts of a) protein, b) fat and c) energy that they provide, per unit of weight. The conversion factors provided obviously vary for each commodity, but, for a given commodity, also differ from country to country and from year to year, based on assumptions about the production environments in which they are produced.

We have applied these conversion factors to the consumption estimates and used them to make regional comparisons of the relative sources of animal-derived protein, and to make composite maps of consumption of animal-source food, in terms of protein.