Discussion and conclusions

The maps and tabular data described here have many potential applications, but before elaborating on these it is worthwhile to comment on some of the limitations and assumptions in their generation and to mention some ways in which they could be improved upon.

On mapping demand for animal-source foods, growing human populations based only on existing population distributions is probably somewhat simplistic and, furthermore, when growing urban populations no allowance has been made for urban extents to increase. The latter could be investigated empirically by plotting urban extent against urban population for a series of settlements, by region, to see if there is a relationship that could be used to expand the urban extents accordingly. But, even if there were a strong relationship – implementing selective growth of urban extents within the GIS would by no means be simple. A further limitation is the assumption that consumption patterns for all people in a country are the same. Whilst sub-national data on consumption rates of different commodities could be found for some countries, the coverage and degree of standardisation would be poor. In theory, models could be developed that allowed such patterns to be extended to areas where no such data exist, using proxies such as wealth, or proximity to urban areas. Determining the extent to which such generalisations could be made would require a considerable research effort. A reasonable first step, though, would be to estimate differences between urban and rural consumption rates for each commodity.

The limitations and assumptions in mapping production are even greater. Assuming production levels to be the same for all livestock producing a particular commodity in a country is clearly wrong, but dealing with it appropriately was beyond the scope of this paper. We know well that production varies among production systems and agro-ecological zones and, indeed, we regularly use these differences to stratify herd models. This should be accounted for in an intelligent way when mapping livestock production. With the more land-tied, ruminant livestock (cattle, buffalo, sheep and goats) the environmentally-derived production system stratifications (e.g. Thornton *et al.*, 2002) are most relevant. With monogastric species (pigs and poultry) the more important distinction will be in the degree of intensification and industrialization; growing demand in urban centres will be met primarily by intensive, industrial production (Robinson *et al., in press*). Growing the livestock populations based only on existing distributions is even more risky than is the case with human population distributions. Herd models that incorporate feed resource requirements should be used to increase cattle and small ruminant populations – with appropriate dispersal functions coming in to play at high stocking rates. For pigs and poultry, rules should probably be devised for placing the increased production in relation to, and in proportion to the increases in demand, and where access to concentrate feed is good.

Whilst production surplus maps have many potential uses, in addition to the problems relating to each of the components (consumption and production), described above, there are further issues that arise when these two sides of the SUAs are brought together. Consumption refers only to food consumption for a commodity, whereas production refers to all production that goes towards food, industrial non-food use, feed, seed and waste. These differences are relatively small for meat products but significant for milk and eggs. Nor are the effects of the trade balances visible from the maps – in cases where this results in significant importation of a commodity, a proportion of the consumption will be met by imported product, rather than by movements from high production areas within that country. In the reverse situation, where a country is a net exporter – some of the production will be exported rather than moved to areas of high consumption. Whilst the FAO projections do list imports and exports there is no indication of where commodities come from and go to. Since in most cases net trade in livestock commodities is relatively small, no attempt was made here to adjust for trade and the maps should give reasonable indications of movements within countries. A further issue is that the use of human population distributions as a predictor variable to disaggregate the reported livestock statistics (FAO, 2007a), may lead to some circularity when combining maps of consumption and production. The effect of this could not be anticipated, but human population distributions could be excluded from the list of predictor variables used in mapping livestock distribution and abundance, for this purpose.

Many of the above issues could be dealt with, given time and research inputs, but other important issues relate to the SUAs and the projections themselves. It is important to remember that the primary objective of the SUAs is to evaluate how many people in the world are under-nourished. Each year FAO produces its flagship publication: the *State of Food Insecurity in the World* (most recently, FAO, 2010b). Whilst the topical emphasis varies from year to year, the central theme is about how many people in the world are under-nourished. This number is re-evaluated each year using a food balance sheet approach. For a broad group of crop and livestock commodities, national estimates of the food available for human consumption are made using the SUAs, along with the caloric content of each food commodity. These data are used to calculate total availability of calories in the country. Since different age and sex groups have different minimum caloric requirements, data on population structure are used to estimate the total caloric requirements for the entire population. Household survey data, typically used to measure living standards, are used to estimate the country-specific distribution of calories. Then, from the total calories available, total calories needed for a given population, and the distribution of calories, the number of people who fall below the minimum energy requirement is estimated. This represents the number of undernourished people.

With this objective it is quite reasonable to combine bovines; sheep and goats; poultry species; and milk and eggs from different species: eggs from ducks and chickens have relatively similar caloric, protein and fat values per unit of weight, for example. From a production perspective, however, this is far from ideal: ducks and chickens, for example, are produced in quite different production systems, achieving different production efficiencies, often serving quite different purposes and occurring in different areas.

That, for each commodity, the production coefficients - off-take rates, carcass weights and, for milk and eggs, yields – that are applied to the stocks, are averaged across the country presents a significant limitation to the approach. Considerably greater accuracy could be achieved if the stocks in each country were divided among the prevalent production systems, and appropriate production coefficients applied to each. Moreover, when projecting production this would allow a) for the evolution of production systems to be accounted for explicitly, for example a migration from extensive to more intensive systems, and b) for the evaluation of different scenarios of livestock sector growth and evolution. In a collaborative effort between the Economic and Social Development Department (ESS), which is responsible for the SUAs and projections, and the Livestock Production and Health Division (AGA), ways in which this could be done and the benefits of so doing, are being evaluated, initially for the pig sector, globally.

The disaggregation of demand growth, presented here, shows that the majority of the growth will stem from the burgeoning urban areas of the developing world, rather than rural populations, and closely linked to that, will be driven by changing consumption patterns to a far greater extent than by population growth. Demand growth associated with increasing consumption rates and urbanisation will require structural changes to the livestock sector in order that demand is met by increased supply: intensification of production and longer supply chains.

The growth in demand for animal source food offers opportunities for economic growth, poverty reduction and increased food security in rural areas. Livestock producers who can gain access to growing markets may benefit from increased sales and higher prices. Many of these producers number among the livestock-dependent poor, but the extent to which poor, or even small-scale livestock producers can link to the growing markets will vary greatly from place to place, and for different commodities. Even where production is in the hands of larger-scale commercial livestock owners though, there will be employment opportunities generated along the value chain; both up-stream and down-stream of the producer. Growing markets for animal-source foods will stimulate demand for purchased inputs such as young or breeding stock, genetic material, feeds and animal health services, for example. Poorer urban consumers should also benefit from more affordable meat, milk and eggs; enjoying the nutritional benefits associated with increased dietary intake of animal-source foods.

But the outcomes of livestock sector growth are by no means all positive; detrimental social, animal health, public health and environmental impacts of rapid sector growth are well-documented in '*Livestock in the balance*' (FAO, 2010a).

Small-scale, mixed production systems face increasing competition from larger-scale intensive systems. There are social implications for small-holders whose opportunities to supply new markets are constrained, and who can be squeezed out of markets to which they have traditionally been linked. Combining spatial data on demand growth, as described here, with information on livestock production systems and the distributions of poor livestock keepers, (e.g. Thornton *et al.*, 2002; Robinson *et al.*, *in press*) offers the possibility of identifying vulnerable rural populations of livestock keepers. This in turn will help with targetting, impact assessment and the design of policy and institutional measures that that can assist the more commercially-oriented small-holders in accessing growing markets, for example through their ability to meet increasingly stringent health and food-safety standards; to obtain access to capital and credit; and to improve their access to input services. For those small-holders that are unable to compete, policies need to be designed that facilitate their transition from the livestock sector towards other livelihood options.

Significant animal and public health risks have also been associated with the concentration of intensive production systems in close proximity to densely-populated urban areas, and particularly in areas where this may occur among large populations of livestock raised by small-holders, under extensive production systems, with low levels of biosecurity. The fears are firstly of rapid multiplication of pathogens moving from extensive to intensive systems (and vice-versa), which could lead to the emergence or re-emergence of diseases, for example through virulence jumps within high-density, genetically similar, susceptible populations, and secondly the passage of zoonotic pathogens to the human population from these high-density production systems. When thousands of animals are confined in close proximity the probability of pathogen transfer within and between populations is greatly elevated, and in consequence, so is the rate of pathogen evolution. Furthermore, the waste from these livestock can contain large quantities of pathogens, posing further risks of transmission to hosts, often wildlife, outside the production system. It has been shown that highly pathogenic avian influenza (HPAI) viruses can be produced from low pathogenic strains following consecutive passages through chickens of similar genetic makeup; the very conditions found in intensive production units (Ito *et al.,* 2001). Rapid increases in the number of large-scale production units would thus favour the emergence of highly pathogenic strains from a pool of low pathogenic viruses maintained in wild or domestic birds. Panzootic HPAI H5N1 emerged in China in 1996 (Li *et al.,* 2004) following several years of intensification of chicken and duck production. Whilst the specific roles of intensive production systems in the emergence of novel strains of pathogen are not well understood, and there are few if any examples where it has been shown conclusively that the occurrence of intensive systems in the midst of an abundance of extensive production causes elevated risk, CAST (2005) concluded that a consequence of intensive livestock production systems was that they created ideal conditions for rapid selection and amplification of highly pathogenic strains of disease agents. FAO (2007b) provides a comprehensive review of how pathogens can get in and out of such, apparently biosecure systems.

With the extensive use of antimicrobial drugs in intensive production systems, genes for antimicrobial resistance can also be selected for and amplified, posing a risk that such genes migrate into human-infective pathogens (Bonfoh *et al*., 2010). Maps of demand growth are important inputs to predicting where the production of livestock is likely to increase, and where intensive production units may be expected to emerge in close proximity to more extensive production systems.

Maps of production surplus can be produced by combining maps of livestock production with those of animal-source food consumption (Figure 1c, for example). These can be used to infer trade-related movement of livestock or livestock commodities from areas of production surplus to areas where demand exceeds supply. Areas in Africa, for example, where such movements of cattle would be expected, have been associated with risk of FMD transmission (FAO, 2005). Maps of demand growth for animal-source foods, combined with production maps, can therefore make important contributions to mapping the risk of disease emergence, persistence and spread.

Tilman *et al*. (2001) warn of some of the potentially massive, irreversible environmental impacts of agricultural expansion over the coming decades; highlighting the need to anticipate and monitor growth. Whilst intensive systems produce relatively less GHG per unit of output than do extensive systems, they often exceed the nutrient adsorptive capacity of the land on which they occur. It has been estimated that more than 130 000 square kilometres of arable land in China and 30 000 square kilometres in Thailand, have an annual livestock nutrient waste production of phosphate of at least 20 kilograms per hectare per year in excess of the adsorptive capacity of the surrounding ecosystem (World Bank, 2005). Currently, animal waste receives little or no treatment and makes a significant contribution to surface water pollution and terrestrial nitrogen deposition (NRC, 2000). If used to locate the distribution of intensive production units, demand growth maps can contribute to pin-pointing areas of likely environmental pollution. More generally, maps of production growth could be used to identify areas of elevated, livestock related environmental impacts, be they through GHG emissions, land degradation or waste production, so that policies and interventions can be appropriately targetted.

By far the most costly input to intensification of livestock production is feed, which, in highly intensive poultry operations, for example, can account for 60 to 80 percent of the total cost of inputs (FAO, 2004b). As livestock production intensifies, it becomes de-coupled from the land resource; dependent increasingly on traded feed concentrates than on locally available feed resources. In 2004, for example, 34 percent of the global cereal harvest, a total of 690 million tonnes, were fed to livestock (Steinfeld *et al*., 2006). A rapid growth of intensive production of livestock will call for commensurate increases in the production of feed, which will exert considerable pressures on land and water resources in some areas of the world.

There are many factors which influence the demand for animal-source foods now and in the future. Some will come from the supply side; competition for land, carbon constraints and legislation relating to the environment and animal welfare, for example. Others will come from the demand side, such as increasing wealth and urbanisation, human health concerns and socio-cultural trends. How exactly these will interact to determine demand for and production of specific livestock commodities in the coming decades is uncertain (Thornton, 2010). What is certain is that the land use changes required to meet the projected demands in livestock may contribute substantially to undermining the capacity of global ecosystems to sustain food production, maintain fresh water and forest resources, regulate climate and air quality and ameliorate infectious diseases (Foley *et al.*, 2005). It is important therefore, carefully to monitor the situation as it unfolds, and to take timely and appropriate action to ensure that the benefits of livestock sector growth are maximised and that the many possible negative effects are controlled.