
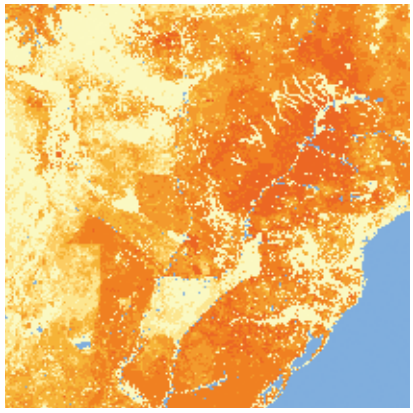

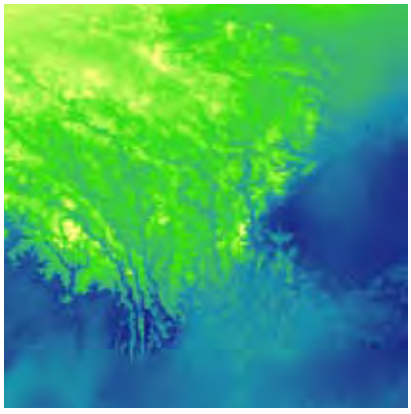
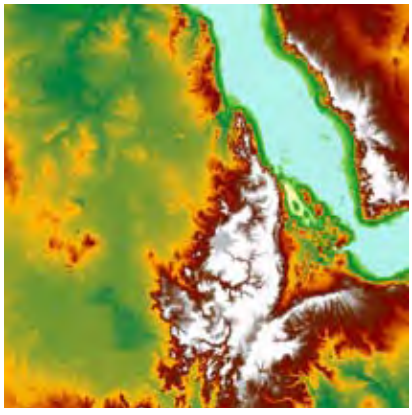


Gridded livestock of the world

2007

Pro-Poor Livestock Policy Initiative
A Living from Livestock

FAO
FIAT PANIS

Photographs on cover:
Goat: L. Hogerwerf
Chicken: I. Hoffmann
Cow: D.K. Sadana

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 2007

Gridded livestock of the world 2007

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Recommended citation
FAO. 2007. *Gridded livestock of the world 2007*, by G.R.W. Wint and T.P. Robinson. Rome, pp 131.

ISBN 978-92-5-105791-9

Contents

Abbreviations and acronyms

AVHRR	Advanced very high resolution radiometer
BTB	Bovine tuberculosis
CIESIN	Centre for International Earth Science Information Network
DEM	Digital elevation model
EROS	Earth Resources Observation Systems
FADS	Farm Animal Demographics Simulator
FAO	Food and agriculture organization of the United Nations
FMD	Foot-and-mouth disease
GAUL	Global administrative unit layers
GIS	Geographic information system
GLC	Global land cover
GLiPHA	Global Livestock Production and Health Atlas
GLIS	Global Livestock Information System
GLW	Gridded livestock of the world
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
IUCN	International Union for the Conservation of Nature
LDPS-2	Livestock Development Planning System, Version 2
LGA	Livestock only - arid/semi-arid tropics and subtropics
LGH	Livestock only - humid/subhumid tropics and subtropics
LGP	Length of growing period
LGT	Livestock only - temperate and tropical highlands
MIA	Mixed irrigated - arid/semi-arid tropics and subtropics
MIH	Mixed irrigated - humid/subhumid tropics and subtropics
MIT	Mixed irrigated - temperate and tropical highlands
MODIS	Moderate resolution imaging spectroradiometer
MRA	Mixed rainfed - arid/semi-arid tropics and subtropics
MRH	Mixed rainfed - humid/subhumid tropics and subtropics
MRT	Mixed rainfed - temperate and tropical highlands
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanographic and Atmospheric Administration
OIE	World Organisation for Animal Health

PATTEC	Pan African Tsetse and Trypanosomiasis Eradication Campaign
SALB	Second administrative level boundaries
TALA	Trypanosomiasis and Land-use in Africa
TLU	Tropical livestock unit
USGS	United States Geological Survey

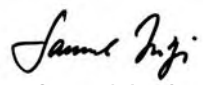
Foreword

The livestock sector is changing rapidly in response to globalization and the ever-growing demand for animal food products in developing countries, some of which are emerging as powerful new players on the global scene. The expanding trade in livestock and livestock products is constantly under threat from disease outbreaks, thereby calling for better management of transboundary diseases. There are social and environmental consequences of the growth and transformation of this sector: small-scale producers are marginalized and environmental degradation occurs, from both industrial and extensive forms of livestock production; intensification of livestock systems and growing market demands also create a threat to the diversity of animal genetic resources.

Given this dynamic setting, there is a clear need for well-informed livestock sector planning, policy development and analysis, but these are frequently hampered by the paucity of reliable and accessible information on the distribution, abundance and uses of livestock. The FAO Animal Production and Health Division has a global mandate to foster informed decision-making on the challenges facing the livestock sector, particularly those of developing and emerging economies. As a contribution to redressing this shortfall, and in collaboration with the Environmental Research Group Oxford (ERGO), FAO has developed the "Gridded livestock of the world" database: the first standardized global, subnational resolution maps of the major agricultural livestock species. These livestock data are now freely available for download via the FAO Web pages.

The spatial nature of these livestock data allows a wide array of applications. Livestock distribution data provide the units to which parameters may be applied for estimating production; they make it possible to evaluate the impact, both of and on livestock, by applying a variety of rates; and they provide the denominator in prevalence and incidence estimates for epidemiological applications, and identify host distributions for disease transmission models.

Gridded livestock of the world describes how these data have been collected and modelled to produce a digital, geo-referenced global dataset. It also provides varied and extensive examples of some of the applications to which the data have been put. This publication is intended as a point of reference to the data and as a vehicle to stimulate further applications and feedback from those most concerned with the development of the livestock sector – be they policy-makers, researchers, producers or facilitators.



Samuel Jutzi
Director
FAO Animal Production and Health Division

Acknowledgements

A project such as this is obviously the work of more than two people. First and foremost, the authors wish to thank the multitude of people across the world who collected livestock statistics and made them available. None of this would have been possible without such a network of data providers. Joachim Otte has fully supported the project over the last four years, and we are especially grateful to him and David Bourn for their detailed editorial contributions to the manuscript. Gianluca Franceschini manages the GLW database and has formatted the maps included in this publication and extracted the livestock statistics presented in the tables and the annex. Where figures and tables have been derived from other publications the source is clearly indicated; where no source is given the original source is this publication.

A number of people has been involved in this project over the years. At the core of the team, Pius Chilonda, Gianluca Franceschini, Claudia Pitiglio, Federica Chiozza and Valentina Ercoli were involved in the day-to-day data collection and processing; Prof David Rogers and Simon Hay of Oxford University were responsible for the processing and provision of satellite data used to disaggregate the livestock data; Carl Morteo and Adhemar Fontes worked closely with us in developing and implementing the Oracle database; and Pierre Gerber and Tom Wassenaar contributed to the livestock suitability mapping. The artwork in this publication was directed by Claudia Ciarlantini, with contributions from Nicoletta Forlano and James Morgan. Monica Umena was responsible for desktop publishing and Brenda Thomas Bergerre edited the publication.

Not surprisingly, a project such as this has a long history. We are grateful to Jan Slingenbergh and Henning Steinfeld for their initial support and development of livestock geography projects within the Food and Agriculture Organization of the United Nations (FAO).

Many of those mentioned above also contributed to developing the applications presented at the end of this volume. The inputs provided by Russ Kruska, Philip Thornton, Alex Shaw, Marius Gilbert, Guy Hendrickx, Keith Sumption, Freddy Nachtergaele and Ergin Ataman, as well as many other colleagues at FAO and at the TALA Research group at Oxford University who supported this work with advice and ideas, are also gratefully acknowledged.

Summary

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 Animal Production and Health Division of FAO has developed a global livestock information system (GLIS) in which geo-referenced data on livestock numbers and production are collated and standardized, and made available to the general public through the FAO website. Where gaps exist in the available data, or the level of spatial detail is insufficient, livestock numbers are predicted from empirical relationships between livestock densities and environmental, demographic and climatic variables in similar agro-ecological zones.

The spatial nature of these livestock data facilitates analyses that include: estimating livestock production; mapping disease risk and estimating the impact of disease on livestock production; estimating environmental risks associated with livestock due, for example, to land degradation or nutrient loading; and exploring the complex interrelationships between people, livestock and the environment in which they cohabit. It is through quantitative analyses such as these that the impact of technical interventions can be estimated and assessed. Also, by incorporating these data into appropriate models and decision-making tools, it is possible to evaluate the impact of livestock-sector development policies, so that informed recommendations for policy adjustments can be made.

The components of the information system thus created include: a global network of providers of data on livestock and subnational boundaries; an Oracle database in which these data are stored, managed and processed; and a system for predicting livestock distributions based on environmental and other data, resulting in the Gridded Livestock of the World (GLW) initiative: modelled distributions of the major livestock species (cattle, buffalo, sheep, goats, pigs and poultry) have now been produced, at a spatial resolution of three minutes of arc (approximately 5 km). These data are freely available through the GLW website[1], through an interactive web application known as the Global Livestock Production and Health Atlas (GLiPHA)[2], and through the FAO GeoNetwork data repository[3].

As well as detailing various components of the GLIS, this publication explains how livestock distributions were determined, and presents a series of regional and global maps showing where the major ruminant and monogastric species are concentrated.

Spatial livestock data can be used in a multitude of ways. Various examples are given of how these and other datasets can be combined and utilized in a number of applications, including estimates of livestock biomass, carrying capacity, population projections, production and off-take, production-consumption balances, environmental impact and disease risk in the rapidly expanding field of livestock geography.

[1] http://www.fao.org/ag/againfo/resources/en/glw/default.html
[2] http://www.fao.org/ag/aga/glipha/index.jsp
[3] http://www.fao.org/geonetwork/srv/en/main.home

1 Introduction

Livestock make an important contribution to the livelihoods of farming communities and the agricultural economies of most countries. They provide food, fuel and transport, contribute to food security, enhance crop production, generate cash incomes for rural and urban populations, constitute the source of a variety of value-added goods with multiplier effects, and generate a demand for services. Livestock rearing can also diversify production and sources of income, provide year-round employment, spread risk and act as a capital reserve for many agricultural households (FAO, 1996).

On the downside, excessive concentrations of livestock and poorly managed production can have a variety of detrimental impacts on the environment, including: overgrazing, land degradation, nutrient accumulations, water pollution, and greenhouse gas emissions (Bourn et al., 2005). Livestock may have a direct impact on human populations, as they constitute a source of zoonotic diseases.

WHY MAP LIVESTOCK?

Given the economic importance of livestock production, it is essential to have some means of reviewing the relative abundance, and distribution, of livestock resources for the purposes of quantitative analysis, strategic planning and decision support. Maps are a clear and concise way of visualizing large geographical datasets, which would otherwise be difficult to comprehend. They are also an efficient way of storing distribution data and making them easily available for further analysis. Better understanding of the geography of livestock has a variety of potential applications, including:

- determining overall levels of livestock production, and associated feed resource and land requirements;
- quantification and distribution of environmental impacts of livestock production;
- assessing risk from disease, drought, conflict, etc.;
- identifying areas of potential conflict between livestock and crop producers;
- comparing alternative land-use options: arable, mixed, pastoral, ranching, conservation, forestry and tourism, for example;
- assessing the likely impact of technical or policy interventions;
- improving the targeting of livestock-related development initiatives; and
- identifying and quantifying strategic domains (so-called segments) for provision of livestock services, development and disbursement of veterinary pharmaceuticals, etc.

In the wake of the foot-and-mouth disease (FMD) epidemic in the United Kingdom and associated outbreaks in continental Europe in 2001, and the recent emergence of Highly Pathogenic Avian Influenza (HPAI, or bird 'flu) in Southeast Asia, attention has focused on livestock distribution mapping, estimating the numbers of animals at risk of infection, and modelling disease dynamics. A prerequisite for disease-risk mapping is a sound knowledge of the distribution of susceptible species and disease vectors.

LIVESTOCK DIVERSITY

Livestock comprise a broad range of species and breeds of domesticated birds and mammals. Bovines (cattle, buffaloes and yaks) are generally the most highly regarded livestock species because of their size and the quantity, diversity and value of products deriving from them. Bovines are also used for traction and represent major cultural and financial assets in many cultures.

Small ruminants (sheep and goats) may be less highly regarded because of their smaller size and lower value. They are, nevertheless, more numer-

ous and widespread; they breed faster and are more affordable, and are possibly of greater general importance to the poor than are bovines.

Monogastric species (poultry and pigs) are less directly dependent on local land resources for their feed than most other livestock species, and are the mainstay of industrial production systems.

Although resources have not been available to include them within these datasets, the less widespread (camels and yaks) and less numerous (horses, donkeys, mules and asses) species should not be overlooked, because they play a significant role in local rural economies.

The composition of regional and subregional livestock species is likely to change over time in response to the ongoing 'livestock revolution' (Delgado *et al.*, 1999) – the gradual move away from more extensive, land-based, ruminant husbandry to more intensive, short-cycle, monogastric modes of production that are less dependent on local land resources. In some rapidly-growing economies of Asia and South America, these transitions are happening surprisingly quickly.

WHICH FEATURES TO MAP?

In addition to basic population statistics on the numbers of animals within specific administrative areas, a variety of other livestock-related data may be mapped, including:

- numbers and densities;
- species ratios;
- production levels (e.g. of meat, milk, eggs, hides);
- age and sex composition (herd structure parameters);
- constraints to production and causes of mortality;
- livestock diseases;
- productivity parameters and intensification levels;
- levels of trade and prices;
- management and husbandry practices, and ownership; and
- breed distribution and genetic diversity.

The mapping units used, however, must be carefully chosen so as to avoid confusion. For instance, displaying numbers per administrative unit gives a radically different impression to numbers per square kilometre or numbers per person. Expressing animal populations in terms of their weight (biomass) rather than numbers gives a very different perspective again, but allows several species to be combined into a single measurement, such as the tropical livestock unit (TLU), thereby providing some indication of the total quantity of livestock in a specific area.

In general, the availability of these types of information is heavily scale-dependent, and varies widely across the world. Numbers, biomass, production and trade figures are available globally, but usually only at the country level. Herd composition, productivity and socio-economic data tend only to be available for small areas of developing countries, often corresponding to in-depth project area surveys, but may be archived at census-unit level for more developed nations.

Livestock population levels vary in both time and space. Numbers tend to increase with the size of human populations and in concert with cropping levels (Bourn and Wint, 1994), although drought, disease and conflict may severely deplete local livestock populations in the short term. Seasonal movements of stock are also a characteristic feature of drylands and mountainous areas. Livestock productivity and levels of production and consumption also vary, and climate change may be already influencing overall patterns of crop and livestock production. With such inherent variability, it is important to recognize that the maps here presented are composite snapshots derived from the most comprehensive information currently available. These maps may therefore be used as a baseline for future estimations of population change or of the impact of development or other interventions.

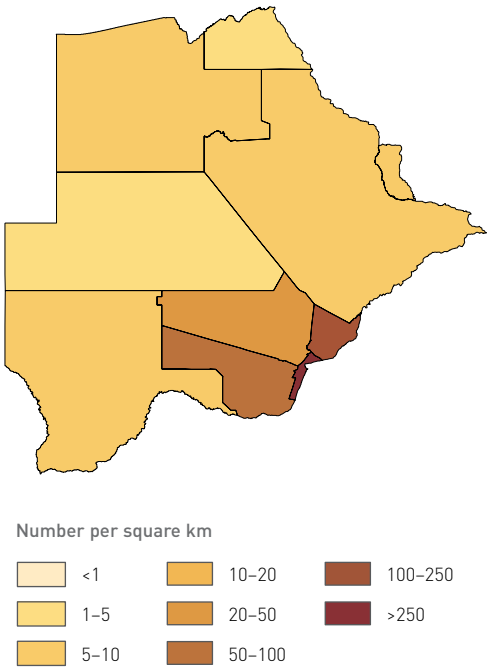
2 Disaggregating population data

Livestock data are available in a range of different formats and numerical units: they may be provided as population numbers or densities per square kilometre and are usually presented as summaries, either for the sample unit (e.g. grid estimates for air surveys) or by administrative region (e.g. census units). These different approaches may give rise to rather different-looking maps, as shown in Figures 2.1 and 2.2.

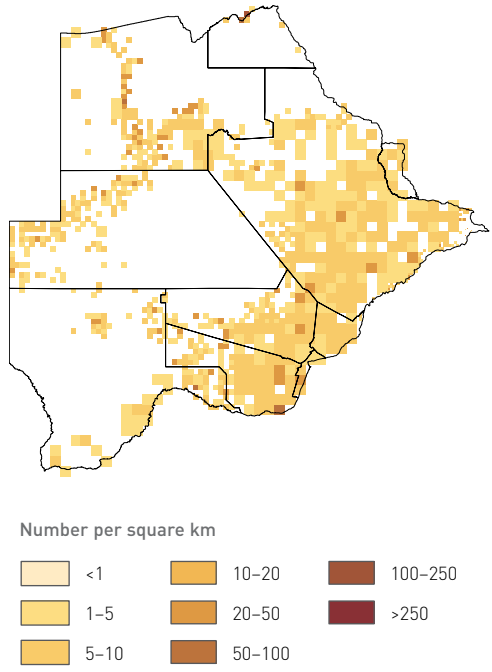
Each approach has a number of advantages and disadvantages: a grid map provides a reasonable representation of a distribution, and can be amalgamated into any number of larger mapping units for comparison with other datasets. There is, however, the temptation to assign an inappropriate degree of reliability to the figures for an individual grid cell, even if the counts are accurate and precise (which is by no means certain), because populations are rarely static. Administrative (or other) unit maps, on the other hand, are rather inflexible, and manipulation into different mapping units may be difficult. Further, administrative units are forever changing – merging, splitting and shifting boundaries – thereby seriously complicating comparisons between one census and another.

In addition, available data are rarely complete or at a sufficiently high resolution to satisfy the demand from analysts, researchers, policy-mak-

2.1 CATTLE DISTRIBUTION IN BOTSWANA, BY ADMINISTRATIVE AREA



2.2 CATTLE DISTRIBUTION IN BOTSWANA, BY UNIFORM GRID, DERIVED FROM AERIAL SURVEY



Source: Adapted from Wint and Gilbert, 2000.

ers, etc., for increasingly detailed animal distribution maps. As a result, some form of extrapolation or interpolation is usually needed to provide maps with a complete coverage and standardized format at a useful resolution.

DATA PREDICTION AND EXTRAPOLATION

A number of techniques can be used to enhance available agricultural data.

Interpolation, typified by various Krigging techniques (such as those in the Golden Software's Surfer package[4], in the ESRI ArcGIS Spatial Analyst[5] and in Insightful's S-Plus for the ESRI ArcView Geographic Information System (GIS)[6], may be an appropriate tool for 'improving' point data. However, if meaningful outputs are to be obtained, considerable care is needed when defining various operational parameters (such as search radius and symmetry, degree of smoothing and method selected). Logistic regression or discriminant analysis methods may also be used to 'fill in gaps', but are largely restricted to the use of binary presence/absence or ranked training data that are not usually suitable for estimating population.

Various weighting techniques have also been used to assign national population figures within countries. The least contentious is to 'remove' animals from areas where they can be assumed not to exist (e.g. glaciers, deserts, vertical slopes, tropical rainforest, water bodies and protected areas) and add them to the remaining 'habitable' areas. This 'suitability mapping' approach is discussed in more detail in Section 4.

More ambitious (and thus less assured) methods have utilized the link between domestic livestock and human densities in partitioning national figures for populations (Wint, 1996a), production (Wint, 1996b) and commodities within agro-ecological zones, in accordance with human population levels. This technique can produce serious anomalies, which may be resolved to some extent by refining the ecological zonations used (White, 1998).

Extrapolation, or distribution modelling, based on established statistical relationship(s) between livestock numbers and a variable, or variables, for which data are available for all the areas of interest, is another possible means for filling data gaps – providing the extrapolation is not taken beyond the value limits of the training data. These, or closely allied, techniques have been used to predict a wide range both of animal distributions, including birds (McPherson *et al.,* 2006) and mammals (Skidmore, 2002) and of arthropod vectors of disease (Rogers *et al.*, 1996; Hay *et al.*, 1996; 2000; 2002; 2006).

FAO has devoted considerable effort to developing this suite of techniques for application at the continental level (e.g. Wint and Rogers, 1998; Wint *et al.*, 1999), which have been extended and enhanced to generate the livestock distribution maps presented in this document. This is the first time such maps have been produced globally and for widespread dissemination in the public domain: it is necessary, therefore, to describe the methods used in some detail. These methods are set out in the following pages and comprise three major stages: the collection of available census and survey data (Section 3); their organization into a standardized data information system (Section 4); and, finally, processing the available data to produce high-resolution distribution maps using statistical modelling methods (Section 5).

[4] http://www.goldensoftware.com/products/surfer/surfer.shtml
[5] http://www.esri.com/software/arcgis/extensions/spatialanalyst/index.html
[6] http://www.insightful.com/products/arcview

3 Subnational livestock statistics

The first stage in the mapping process is to collect available subnational livestock statistics, usually for each country. These may be collected and presented in a number of different ways, which can affect the subsequent processing required.

AGRICULTURAL CENSUS METHODS

Livestock data collection methods and frequencies differ according to both their type and economic importance. More detailed and precise information is required for some species than for others, especially where animals' movements need to be traced for compliance with trade regulations or for disease surveillance.

Livestock statistics are usually collected as part of more general censuses of agriculture undertaken periodically by national governments. Agricultural censuses are organized in various ways in different countries, depending upon the resources available, the importance of agriculture, and institutional traditions. Many countries have insufficient resources to mount a series of detailed surveys for different parts of the agricultural sector and thus restrict their efforts to obtaining data from a single agricultural census, every five to ten years. Such censuses may involve complete or sample coverage, with the agricultural holding as the standard unit of enumeration. It should be noted, however, that many agricultural censuses do not include animals located in communal grazing areas or fallow land under shifting cultivation (FAO, 1995a), both of which may be important categories in many (particularly developing) countries.

The first World Census of Agriculture took place in 1930 under the auspices of the former International Institute for Agriculture in Rome. A follow-up census planned for 1940 was prevented by World War II, after which FAO took on responsibility for promoting and coordinating a regular world census of agriculture that has taken place every ten years since 1950, most recently in 2000 (FAO, 1995b). While FAO has actively promoted the standardization of agricultural census procedures and livestock data collection[7], considerable variation remains in the detail and reliability of national statistics. Livestock statistics are not restricted to numbers: censuses often also assess herd structure, production parameters, and information on marketing and trade.

The collection of livestock statistics is a national government responsibility that is usually associated with obtaining more general agricultural statistics, and should be standardized as far as possible in terms of species, breed and product categories, and units of measurement. The importance attached to the collection of agricultural statistics and thus the resources allocated to this activity, however, vary from country to country.

Livestock censuses are usually conducted by ground-based surveys and questionnaires, often of sample households, and frequently in conjunction with censuses of arable agriculture or, occasionally, agro-economic surveys. Census techniques vary from country to country, depending on circumstances. In countries such as the United Kingdom and the United States, for instance, agricultural census information is obtained directly from farmers, who are required by law to provide information requested in periodic, postal questionnaires. This is effective as long as the great majority of farmers receive and understand the questionnaires, and are willing to provide the information requested. However, this methodology relies on comprehensive registration of owners, if not the animals themselves. And in many less developed countries, where formal registration of farms and farmers is often limited to the commercial sector, this method of postal census

[7] http://www.fao.org/es/ess/rmlive.asp

is clearly inappropriate as it would not only exclude the majority of small-scale, rural farmers but would also require the existence of a functional postal system and universal literacy.

UNDER-REPRESENTATION

The basic unit of enumeration for most, if not all, agricultural censuses is the 'agricultural holding'. Areas of communal grazing, fallow land and shifting cultivation are usually excluded. Unless, in census design, special provision is made to offset this inherent bias in favour of permanent, fixed landholdings, most agricultural statistics will inevitably under-represent the livestock holdings of nomadic and transhumant pastoralists with 'no fixed abode'. This under-representation of pastoral livestock is a considerable problem in under-populated, higher rainfall areas such as the sub-humid zone of West Africa, but is likely to be particularly significant in arid and semi-arid regions of Africa, Asia and South America, large areas of which are, at the best of times, relatively remote and inaccessible; Norton-Griffiths, 1978, for example, makes reference to systematic under-estimation of nomadic livestock.

It is also important to recognize that many developing countries do not have adequate means of collecting, analysing and reporting agricultural (or, indeed, human) population statistics. Available information about cropped areas and livestock resources is, therefore, often incomplete and of uncertain reliability. On its FAOSTAT web site[8], FAO acknowledges that *"... many developing countries still do not have an adequate system of statistics pertaining to the agricultural sector. Some of the available agricultural data are incomplete [and] even when data are available, their reliability may be questionable."* It is for this reason that alternative means of assessing land cover and livestock resources need to be used for remote and inaccessible regions of many developing countries, especially in Africa.

Low-level aerial surveys, originally developed to count wildlife (Norton-Griffiths, 1978), have been widely used to assess livestock populations in many countries across Africa (Clarke, 1986; Government of Kenya, 1996). These have been further developed to incorporate ground survey methods in order that a range of livestock species can be assessed: from larger ruminant and monogastric species to domestic pigeons and beehives. Such direct counting methods may produce markedly different results to those provided by census methods that rely on stakeholder responses. The 1990 National Livestock Census of Nigeria, which pioneered air-ground census techniques, indicated that there were substantially more livestock than estimated by the Federal Office of Statistics: twice as many cattle; one and a half times as many sheep and goats; and four times as many pigs (Bourn *et al.*, 1994).

DATA SUPPRESSION

A frequent problem for the agricultural statistician is that many countries, particularly those in the industrialized world that conduct holding-level censuses, are constrained by data protection and confidentiality legislation to suppress data that could allow an individual holding to be identified. As a result, many data records for the less numerous species, or for those that are restricted to few large holdings within a mapping unit (e.g. industrialized pig or poultry production units), may be withheld from census statistics released in the public domain. Ironically this means that public domain agricultural statistics from the United Kingdom and the United States, for example, may contain more gaps than data from developing countries.

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

4 FAO global livestock information system

Any global archive of subnational livestock data is required to satisfy a number of criteria. Data must be checked and validated to minimize errors and omissions and, where necessary, be converted into standard parameters and units so that information from various sources can be compared. To maintain its usefulness the archive must be regularly and easily updated; sources and procedures must, therefore, be properly documented, catalogued and automated.

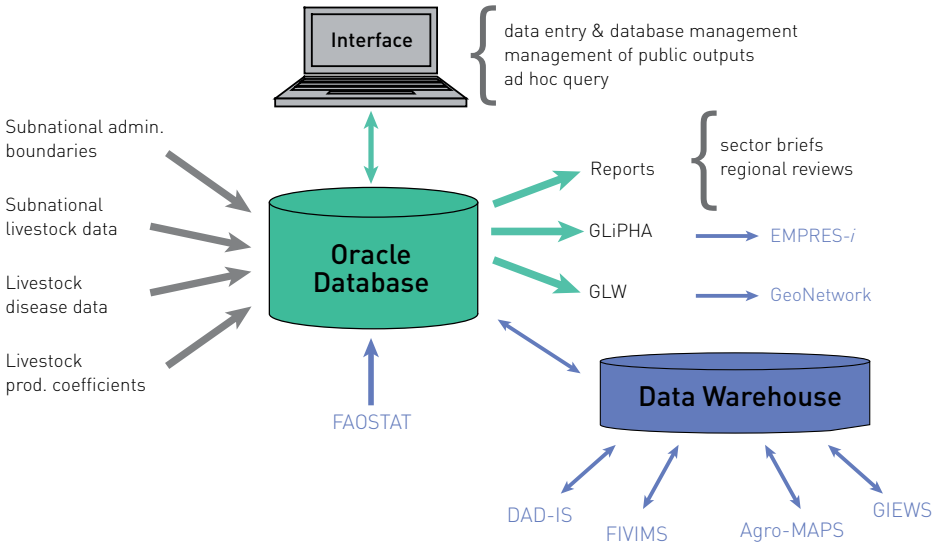
The structure of the FAO livestock information data archive and its processing protocols are described below. Subsequent subsections describe the procedures used to apply supplementary information to enhance the raw data and treat missing data, and explain the exclusion, or masking out, of areas known to be incapable of supporting livestock.

DATA ARCHIVE STRUCTURE AND PROCESSING

For many years, FAO has collated and distributed national-level data on livestock and related commodities through the well-known FAOSTAT database. More recently, however, efforts have been made to systematize the collection, management, processing and distribution of subnational livestock data. This was originally carried out at the administration level 1 (usually the province) through the GLiPHA project, and more recently at the highest available spatial resolution in support of the GLW initiative. Figure 4.1 provides a schematic summary of the information system.

Underpinning the information system is a growing network of providers of subnational livestock data. The sources of data are very diverse and include statistical yearbooks, development project

4.1 SCHEMA OF THE FAO GLOBAL LIVESTOCK INFORMATION SYSTEM



documents, contacts within national departments and an increasing number of sources of livestock data that are available over the Internet. Indeed, even over the four-year development of these distribution data, the rise in official web pages has been remarkable. A database of national partners responsible for livestock statistics, together with website hyperlinks, is maintained for the purpose of providing feedback and value-added data products. Hand-in-hand with the livestock data is geo-referenced information on subnational boundaries. This is sometimes provided with the livestock data but, more usually, different departments are responsible for producing and maintaining these geographic data. This means that the livestock statistics need to be matched with the available administrative data, based on administrative unit names or codes. There are various initiatives to standardize national and subnational boundary data and codes, which are used wherever feasible. The United Nations Geographic Information Working Group of the United Nations Cartographic Service maintains a well-documented dataset of international boundaries and areas under dispute[9], which is used for national boundaries. Two global initiatives exist for standardized subnational boundaries: the World Health Organization's Second Administrative Level Boundaries (SALB) project[10] and the FAO Global Administrative Unit Layers (GAUL) project[11]. These two systems are related but differ in important ways. The SALB datasets, the first initiative to standardize subnational boundaries globally, are only provided to the second administrative level (the national boundary being level zero), and are standardized to the year 2000 and endorsed by the national cartographic units. This slows down the process significantly and tends to restrict coverage. The GAUL system was designed to 'fast track' these procedures and therefore boundaries are not formally endorsed; thus it is not in the public domain but currently restricted to United Nations use. GAUL uses the most recently available boundary data and makes use of whatever resolution is available. To allow rapid updating of boundaries, it has also adopted a more versatile coding system. The FAO livestock information system originally adopted the SALB coding system and used SALB data where available, upgrading it with more recent and more detailed data as needed and available. As new national livestock statistics become available and are entered into the system, however, the GAUL standards will be adopted. Livestock disease data are restricted to the national-level World Organisation for Animal Health (OIE) Handistatus II[12] and supplemented by national reports that provide some subnational resolution information. The OIE is now finalizing the World Animal Health Information System, which will replace Handistatus, and is collating subnational livestock disease data. This new resource will be used once it becomes operational. Livestock performance indicator values from published and grey literature are currently maintained in separate databases.

Once acquired, the raw livestock and boundary data are digitized and managed via a web-based interface to an Oracle database. A number of data verification procedures are embedded, including a direct link to the FAOSTAT database[13] from which country totals are compared against FAO 'official' statistics.

There are various outputs from the primary database. These include ad hoc queries and standardized tables of statistics and maps that are published in FAO's national livestock sector briefs, which provide livestock sector profiles for specific countries and regional livestock sector reviews. A major component of the global livestock information system is GLiPHA[14], an interactive web application that draws livestock and socio-

[9] http://boundaries.ungiwg.org
[10] http://www.who.int/whosis/database/gis/salb/salb_home.htm
[11] http://www.fao.org/geonetwork/srv/en/metadata.show?id=12691
[12] http://www.oie.int/hs2
[13] http://faostat.fao.org/
[14] http://www.fao.org/ag/aga/glipha/index.jsp

economic data from the Oracle database, usually at the first administrative level (province). Data are compiled into national and regional 'projects' and can be viewed and downloaded as tables, graphs and maps, with raster backdrops of layers such as elevation and vector overlays of roads, population centres and other relevant features. GLiPHA also feeds directly into the EMPRES-*i* database[15], where detailed disease outbreak data can be overlain on the standard livestock and other GLiPHA layers.

A further output from the database is to the FAO 'data warehouse', a recent concept within the organization designed to bring together many of the disparate databases and information systems available in-house. The underlying principle is that a standardized spatial coding system is adopted, by which links are established to data and data products that are likely to be of particular relevance to other departments within FAO. These data items are assigned thematic codes and regularly updated by drawing on the most recent statistics from the participating information systems. The data warehouse concept is at an early stage of development and is being piloted by the GLIS project and the Global Information and Early Warning System[16], with interest from other information systems such as the Food Insecurity and Vulnerability Information and Mapping System[17], DAD-IS[18] (an information system on animal genetic resources) and Agro-MAPS[19] (an information system on crop-based agriculture).

The main topic of this publication, however, and indeed the reason for developing the GLIS, is the new GLW. For this output, the most recent livestock statistics in the Oracle database are extracted at the highest available spatial resolution to feed into the GLW analysis chain. The following sections provide a detailed description of the processing involved in producing the GLW datasets.

[15] http://www.fao.org/ag/aga/agah/empres/tadinfo/e_tadh.htm
[16] http://www.fao.org/es/giews/english/index.htm
[17] http://www.fivims.net
[18] http://www.fao.org/dad-is
[19] http://www.fao.org/landandwater/agll/agromaps/interactive/page.jspx

SUPPLEMENTARY AND MISSING DATA

Census and survey records are often incomplete, with gaps that need to be filled to provide complete maps. Various methods have been devised to generate credible estimates of missing data.

There are, for instance, many areas where the number of animals present is known, or can be safely assumed, to be zero – either from country-level statistical records, such as FAOSTAT, or because of a cultural prohibition such as the ban on pigs in most Islamic countries. Known zeros can also derive from land suitability masking, in which areas unsuitable for specific types of livestock are defined according to various climatic, demographic and topographic criteria: for example, cattle do not usually live in deserts or the middle of rainforests. The definition of suitable land is discussed below.

In some instances, particularly for less common species, only country-level population figures are available – often from FAOSTAT – because census summary data, or yearbooks, do not include subnational figures. These can be treated by assigning animal numbers to administrative areas according to the land area of the units, or by weighting the assignment of numbers by some other relevant parameter, such as human population, for which administrative-level data are known. Use of human population distribution to apportion livestock populations is often most appropriate for poultry and pigs, which, in developing countries, are closely associated with human populations. In such manipulations, administrative-level data, rather than pixel values, are used to assign polygon densities. Human population must then be excluded from the suite of predictors used in any subsequent distribution modelling (Section 5).

Complete, subnational population datasets for all livestock species are not available for all countries. Some have administrative-level data available for only part of the country because of incomplete enumeration or data suppression to ensure confidentiality.

These incomplete datasets can be often rectified by using data available for a higher administrative

level. For example, if data for administrative level 2 are available for part of a country and data for level 1 are known, subtraction of known level-2 totals from level-1 totals will give the number of animals in the region for which level-2 data are not available. A single density can then be calculated for the level-2 administrative areas, or numbers can be assigned in relation to an associated parameter, as previously mentioned.

It should be emphasized, however, that the adjustments described in the preceding paragraphs should not be applied to very large polygons unless the area of land deemed suitable for a given species in that polygon is comparatively small.

MASKING LAND SUITABLE FOR LIVESTOCK

Deserts, lakes and high mountains are unsuitable for either arable or livestock production. Cultivation and animal husbandry are also not usually allowed in national parks or game reserves. Such factors must obviously be taken into account in producing livestock distribution maps, in which densities indicate the number of animals per square kilometre of land suitable for livestock production rather than simply the total land area.

Input criteria

Areas known to be unsuitable for livestock must be defined and delineated using standard criteria that can be applied globally, so that animal densities in those areas can be set to zero.

Land suitability criteria for two broad categories – (i) rainfed crop cultivation and ruminant livestock production (cattle, buffaloes, sheep and goats); and (ii) monogastric livestock production (pigs and chickens) – have been defined in terms of a number of globally available spatial variables, as described and explained below.

Protected areas

Depending on their classification and the level of enforcement, protected areas generally exclude livestock. The International Union for the Conservation of Nature (IUCN) protected area categories I-IV were considered unsuitable for livestock. Categories V and above, which include, for example, forest reserves that are frequently used by livestock, particularly in the developing world, were not excluded. The IUCN database is becoming increasingly comprehensive[20] but has been supplemented by the Managed Areas Database for North America[21] and national data for South Africa, Botswana and Kenya.

Infrastructure and demography

Cities were also defined as unsuitable, using demographic layers derived from the LandScan coverages[22] rather than the Gridded Population of the World[23], which had not been finalized by the time the GLW coverages were first generated. Both population density and night-time lights were included, albeit with very high thresholds, because it became apparent that each had been used to define urban areas, but in different ways in different locations. These high thresholds delineated areas that corresponded well, though not precisely, with the developed and partly developed LandScan land-cover categories[24], which were also incorporated.

Closed canopy forest

A variety of digital layers of forest cover are available in the public domain, the most recent being the University of Maryland's 500 m resolution percentage tree cover[25], derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery, and the Global Land Cover (GLC) 2000[26] forest layers under development at the European Commission's Joint Research Centre at Ispra, Italy. When compared with the earlier 1 km resolution layers derived from Advanced Very High Resolution Radiometer (AVHRR) imagery[27], it was evident that closed forest, as defined in the GLC

[20] http://www.iucn.org/themes/wcpa
[21] http://www.geog.ucsb.edu/~gavin/mad/mad.html
[22] http://www.ornl.gov/sci/gist/projects/LandScan
[23] http://sedac.ciesin.columbia.edu/gpw
[24] http://www.ornl.gov/sci/gist/projects/LandScan
[25] http://www.glcf.umiacs.umd.edu/data/treecover
[26] http://www-gvm.jrc.it/glc2000/
[27] http://www.glcf.umiacs.umd.edu/data/treecover

TABLE 4.1 DATASETS AND THRESHOLDS USED TO DETERMINE LAND UNSUITABLE FOR LIVESTOCK

Criteria[1]	Map Layer	
	Rainfed agriculture and ruminant livestock production[2]	Monogastric livestock production[3]
Protected areas (1/0)	1	1
Population density (Landscan) (km^{-2})	> 1 500	> 1 500
Lights (Landscan) (%)	> 90	> 90
Slope (Landscan) (%)	> 40	-
Elevation (m)	> 4 750	> 4 750
Pasture suitability (IIASA) (% area)	0	-
NDVI max	< 0.07	-
Tree cover - South America (Maryland GLCF) (%)	> 75	-
Tree cover - rest of world (MODIS) (%)	> 95	-
Land cover (Landscan) – water (1/0)	1	1
Land cover (Landscan) – developed (1/0)	1	1
Land cover (Landscan) – partly developed (1/0)	1	1
Land cover (Landscan) – wetlands (1/0)	1	1
Land cover (Landscan) – wooded wetlands (1/0)	1	1
Land cover (Landscan) – tundra (1/0)	1	1
Land cover (Landscan) – snow and ice (1/0)	1	1

[1] The datasets used are described and referenced in the text (Section 4.3).
[2] Cattle, buffalo, sheep and goats.
[3] Pigs, chickens and other poultry.

2000 coverage, extended over a much larger area than other coverages, particularly in Southeast Asia. It was also apparent that MODIS estimates were more homogenous and considerably higher than corresponding AVHRR values, at least for the Amazon Basin. As a very conservative definition of forest cover was required, MODIS coverage was used in preference to GLC 2000 in all regions except South America, for which the Maryland AVHRR values were used.

Climate

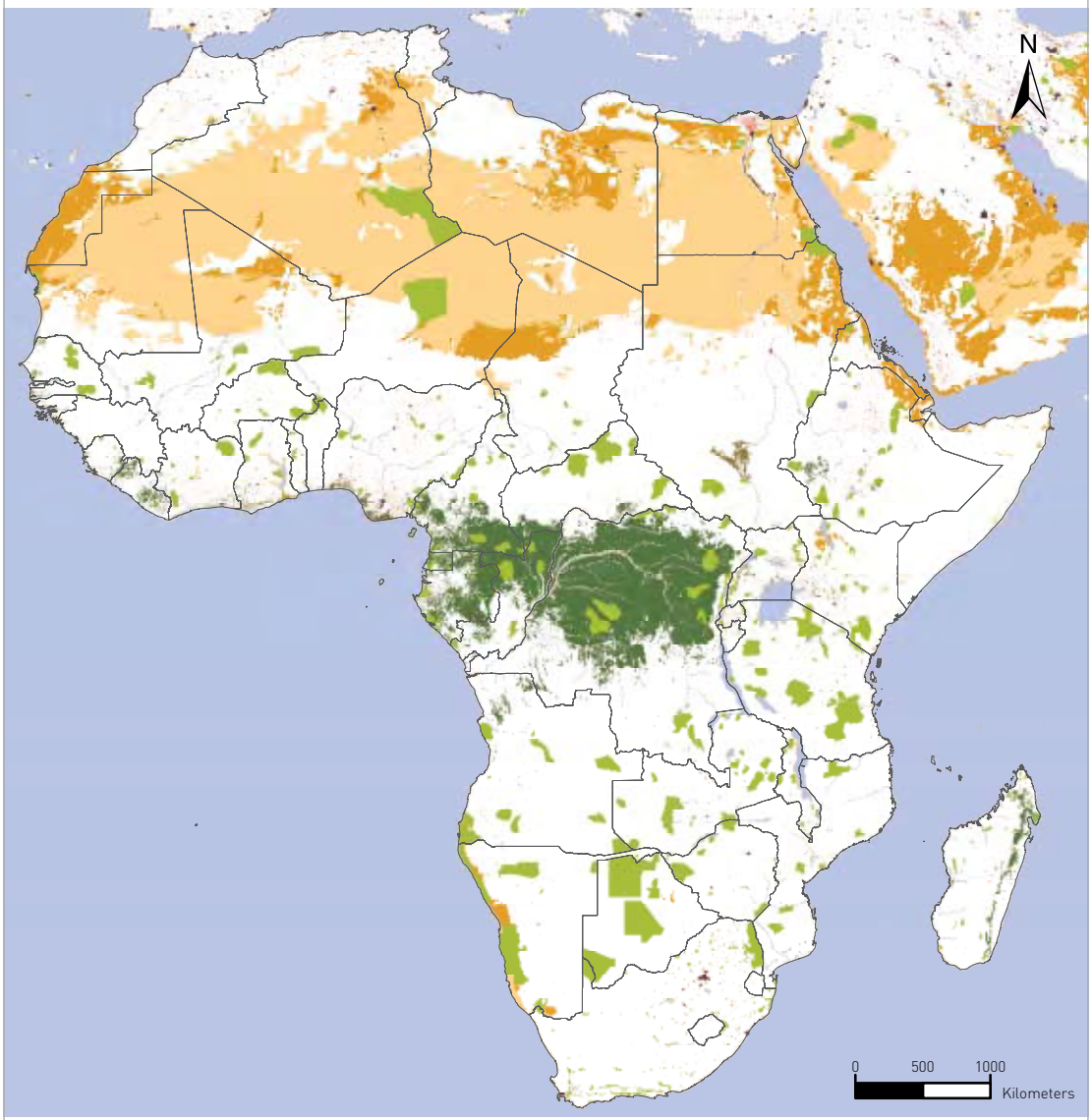
It was initially assumed that land suitable for livestock could be identified from estimated air temperatures derived from the AVHRR satellite imagery of the National Oceanic and Atmospheric Administration (NOAA) (United States). However, regions with very high minimum or mean temperatures – for example, much of the Sahel – are known to support livestock for at least part of the year. Maximum temperatures were also seen as ineffective discriminators, as they excluded large parts of China and Patagonia, for example, which are known to support significant numbers of ruminants. Temperature was thus excluded from the suitability criteria used.

Topography

Threshold values for elevation (derived from the global GTOPO30 1 km resolution Digital Elevation Model [DEM], produced by the United States Geological Survey [USGS], Earth Resources Observation Systems [EROS] data centre[28]) and slope (derived from layers in the LandScan archive[29]), were set

[28] http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html
[29] http://www.ornl.gov/sci/gist/projects/LandScan

4.2 ESTIMATED LAND UNSUITABLE FOR RUMINANT LIVESTOCK PRODUCTION IN AFRICA



Unsuitable criteria for ruminants

- International boundary
- Water
- Land cover: developed, wetlands, snow and ice
- Protected areas
- Night-time lights >90%
- Elevation >4750 m
- Tree cover >95%
- Pasture suitability 0
- NDVI maximum >0.07
- Human population density >1 500 square km
- Slope >40 degree

to exclude the highest peaks in the Himalayas and Andes, and pixels with extremely high slope values.

Vegetation

Satellite-derived vegetation greenness, the Normalized Difference Vegetation Index (NDVI) (Green and Hay, 2002; Hay, 2000; Hay *et al.*, 2006), working maps of pasture suitability provided by the International Institute for Applied Systems Analysis (IIASA) and estimated land cover categories, derived from the LandScan land cover dataset[30], were all considered as potential determinants of land suitability. Apart from the urban categories (see above), only the most inhospitable land cover categories were excluded – water, wetland, cold tundra and snow, or ice – as even the lowest vegetation category (barren) included places in the Near East and the Sahel known to support ruminants. For the same reason, only pixels defined as unsuitable for rainfed pasture (with a score of zero) were deemed unsuitable for livestock.

Maximum NDVI was considered a better indicator of vegetation cover than mean values, on the assumption that land with a very low maximum cover would rarely, if ever, be suitable for livestock, whereas areas with a low mean value could be seasonally well-vegetated and therefore support livestock at some times of the year. Thresholds for maximum NDVI, land cover and pasture suitability were based on the arid Near East, where detailed analyses had been conducted previously (Wint, 2003).

Thresholds and results

It was assumed that subsequent regression procedures incorporated in distribution modelling (Section 5) would help to locate marginally unsuitable areas, as well as those where the boundary values varied from region to region. Each threshold, therefore, was conservatively defined to ensure that this process of thresholding excluded only the most unsuitable land. Each parameter was examined in regions with which the analysts were familiar and thresholds subsequently selected, as set out in Table 4.1.

The estimated extent of land unsuitable for rainfed crop and ruminant livestock production in Africa is given in Figure 4.2 as an example, showing the contribution made by the different criteria to the overall suitability mask.

[30] http://www.ornl.gov/sci/gist/projects/LandScan