The Food and Agriculture Organization's Gridded Livestock of the World

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Summary

Livestock sector planning, policy development and analysis are frequently hampered by the paucity of reliable and accessible information on the distribution, abundance and use of livestock. In an attempt to redress this shortfall, the Food and Agriculture Organization's Animal Production and Health Division (FAO-AGA) has, in collaboration with the Environmental Research Group Oxford, developed the 'Gridded Livestock of the World' database which provide the first standardised global, sub-national resolution maps of the major agricultural livestock species. These are now freely available for download on the FAO website. The data are produced in Environmental Systems Research Institute grid format for cattle, buffalo, sheep, goats, pigs, chickens and other poultry. The map values are animal densities per square kilometre, at a resolution of 3 minutes of arc (approximately 5 km at the Equator), and are derived from official census and survey data. Reported statistics are then processed using a combination of suitability masking and spatial disaggregation by statistical modelling of livestock densities based on empirical relationships between livestock densities and environmental variables in similar agro-ecological zones. The spatial nature of these livestock data allows a wide array of applications. Livestock distribution data give an estimation of production; they evaluate 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 the host distributions for transmission models.

Keywords

Disease, Distribution, Food and Agriculture Organization, Geographic information system, Gridded Livestock of the World, Livestock, Modelling, Production.

Il "*Gridded Livestock* of the *World*" dell'Organizzazione delle Nazioni Unite per l'Alimentazione e l'Agricoltura (FAO)

Riassunto

La scarsità d'informazioni accessibili e attendibili sulla distribuzione, abbondanza e uso del bestiame rappresenta frequentemente un ostacolo alla progettazione, all'analisi e alle politiche di sviluppo del settore zootecnico. Nel tentativo di colmare questa lacuna, la Divisione della Produzione e Salute Animale dell'Organizzazione delle Nazioni Unite per l'Alimentazione e l'Agricoltura (FAO-AGA), in collaborazione con il Gruppo di Ricerca Ambientale dell'Universitá di Oxford, ha sviluppato il "Gridded Livestock of the World", *che fornisce la prima mappatura mondiale, a una risoluzione subnazionale, della distribuzione delle principali specie animali di interesse agricolo. Le mappe possono essere scaricate gratuitamente dal sito della FAO. I dati sono prodotti in formato ESRI grid per bovini, bufali, pecore, capre, maiali,*

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polli e pollame. I valori della mappa rappresentano il numero di animali per chilometro quadrato a una risoluzione di 3 minuti d'arco (approssimativamente 5 km alla latitudine dell'equatore) e sono derivati da rilievi e censimenti ufficiali. Le statistiche riportate sono processate applicando una "maschera di idoneitá" e poi con una disaggregazione spaziale, che si basa sulle relazioni empiriche tra le densitá animali e variabili ambientali in simili zone agroecologiche. La natura spaziale di questi dati permette una vasta gamma di applicazioni: stime sulla produzione animale; valutazioni di impatto del e sul bestiame, applicando una serie di tassi di crescita; stime sulla prevalenza e incidenza per applicazioni epidemiologiche e distribuzione dell'ospite nei modelli di trasmissione.

Parole chiave
Bestiame, Distribuzione, Gridded Livestock of the World, Malattie, Modellizzazione, Organizzazione delle Nazioni Unite per l'Alimentazione e l'Agricoltura (FAO), Produzione, Sistema informativo geografico.

Introduction

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

Methods and results

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

Worked example – cattle in Africa

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

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

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of growing period, tsetse fly distributions and human population density (Table I).

The models were developed at several different spatial scales, as follows:

a) the entire continent
b) four continental sub-regions (east, west, south and north)
c) 50 ecological zones
d) each ecological zone within each region.

In addition to no transformation, three sets of transformations of the livestock density data were assessed, namely: logarithmic, exponential and power, to address the possibility that relationships were non-linear. The best relationship for any point was selected according to coefficients of determination (R^2). If the statistical relationship for the analysis at the ecological zone by region level – level d) above, for which the number of observations (*n*) was typically around 250 – had an R^2 value of greater than 40%, then it was used. If less than 40% those equations were discarded and the relationship at the next level up was evaluated, i.e. by ecological zone – level c) above, for which *n* was typically *c.* 250-1 000). If this relationship had an R^2 value of greater than 40% it was used; if not, it was discarded and the regional equations evaluated – level b) above, for which *n* was typically *c.* 2 500-7 000. In the few cases that these still failed to attain R^2 values greater than 40%, the continental equation was used (for which *n* = 19,000 and R^2 values ranged between 38% for chickens and 64% for cattle). The result was that R^2 values typically ranged between 50% and 80%, and all the predictive equations used were statistically highly significant ($P<0.001$).

The selected equations were then applied to the original imagery to generate a map of modelled cattle density at a spatial resolution of three minutes of arc (approximately 5 km at the Equator). To avoid spurious predictions, the modelled total numbers for each

Table I
Generic list of variables used in livestock distribution modelling

Generic type	Variables	Reference
Locational	Longitude, latitude	
Anthropogenic	Distance to roads[a] Distance to city lights[a]	
Demographic	Human population[b]	
Topographic	Elevation[c]	
Land cover	Normalized difference vegetation index	4, 5, 7
Temperature	Land surface temperature Air temperature Middle-infrared	4, 5, 6, 7, 8 3 5
Water and moisture	Vapour pressure deficit Distance to rivers[d] Cold cloud duration[e] Potential evapo-transpiration[f]	4, 5, 7 1
General climatic	Modelled length of growing period[f]	1
Other	Tsetse distributions (for Africa)[g]	

(a) derived from layers in the Landscan archive (www.ornl.gov/sci/gist/projects/LandScan)
(b) taken from the Center for International Earth Science Information Network's (CEISIN) Gridded Population of the World (GPW) version 2 dataset (sedac.ciesin.columbia.edu/gpw)
(c) global GTOPO30 1 km resolution elevation surface, produced by the Global Land Information System (GLIS) of the United States Geological Survey, Earth Resources Observation Systems (USGS, EROS) data centre (edc.usgs.gov/products/elevation/gtopo30/gtopo30.html)
(d) derived from the USGS EROS data centre HYDRO1k data archive (edc.usgs.gov/products/elevation/gtopo30/hydro/index.html)
(e) mean, minimum and maximum dekadal estimates of 'cold cloud duration' were derived from Meteosat remotely sensed data (1961-1990), obtained from FAO's Artemis data archives
(f) PET and LGP were taken from the FAO/IIASA length of growing period data sets (www.fao.org/waicent/faoinfo/agricult/agl/agll/gaez/index.htm)
(g) tsetse distributions used were those developed for the Programme Against African Trypanosomiasis (PAAT) Information system (www.fao.org/ag/againfo/programmes/en/paat/infosys.html)

administrative unit were adjusted to equal those reported for that administrative unit. A further product was generated, adjusting the modelled national totals to match FAO official national statistics for the year 2000, providing a time-standardised dataset.

The modelled cattle distribution in Africa mirrors the observed distribution (Fig. 1) very well and highlights major foci, such as the East and southern African highlands, Tanzania, semi-arid and dry sub-humid West Africa and minor foci, such as the Gezira irrigation scheme in the Sudan, the inland delta of the River Niger in Mali, and south-eastern Zambia.

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

Thus, for cattle, buffalo, sheep, goats, pigs, poultry and chickens, three global products (divided into eight regional tiles) were generated, as follows:

- the reported densities, adjusted for land-suitability
- the modelled densities (adjusted to match the original reported totals, at the administrative level by which they were reported)
- the modelled distributions corrected so that national totals match those provided by FAOSTAT data for the year 2000 (work is currently underway to produce a product standardised to FAOSTAT 2005 national totals).

Data dissemination

The methodology described above relates specifically to the Gridded Livestock of the World (GLW) (www.fao.org/ag/againfo/resources/en/glw/default.html). These data layers are made freely available using FAO's GeoNetwork data repository (www.fao.org/geonetwork) which provides a common portal for spatial data available from the FAO. The underlying database of livestock statistics is

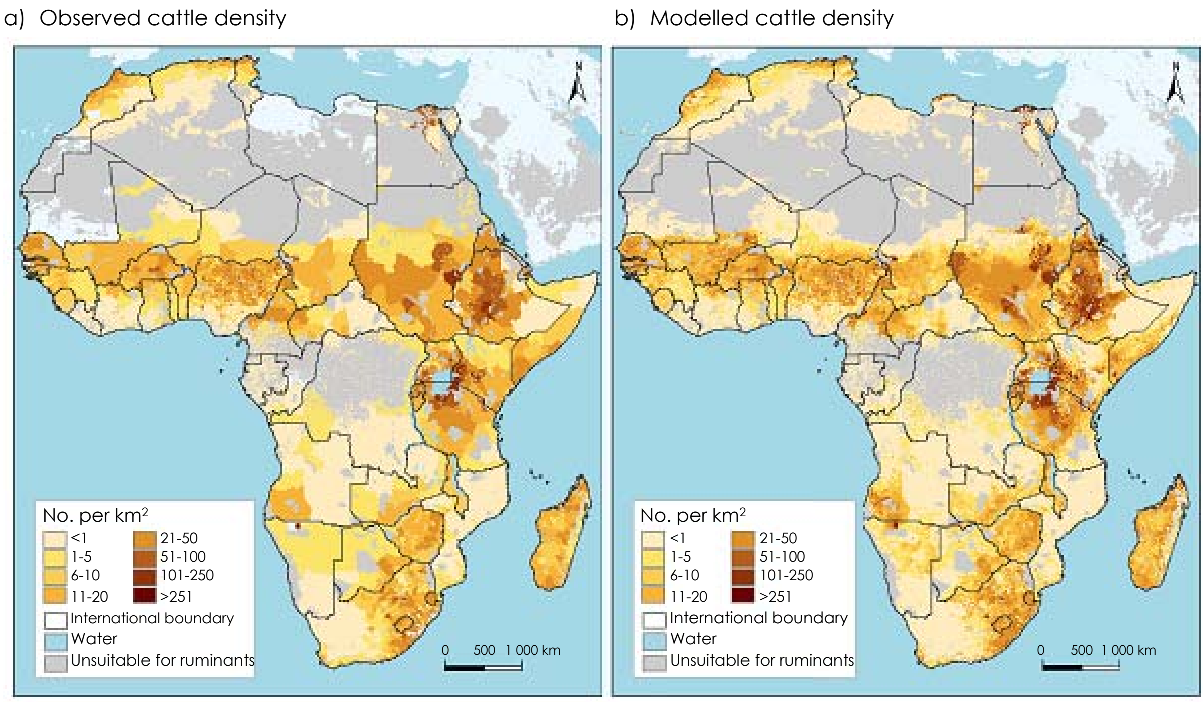

Figure 1
Gridded Livestock of the World products for Africa

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also used to provide statistical input for a number of other information products. One of these is GLiPHA, the Global Livestock Production and Health Atlas (www.fao.org/ag/aga/glipha/index.jsp), a user-friendly, highly interactive electronic atlas, developed using KIDS, the Key Indicator Data System (www.fivims.net). The atlas provides a scaleable overview of spatial and temporal variation of quantitative animal production and health information through the combination of maps, tables and charts. Thematic layers include data on the biophysical environment, socio-economics, livestock population and production, animal health and trade. Data are provided through country projects, usually at the provincial (level 1) administrative level and a global project. The global project contains the following national data: livestock statistics are extracted from FAOSTAT (faostat.fao.org) and disease information is derived primarily from the World Organisation for Animal Health (OIE: Office International des Épizooties) HANDISTATUS II database (www.oie.int/hs2). GLiPHA can be accessed interactively from its website or can be downloaded to a personal computer.

A further route for data dissemination is through the standard reports produced by the FAO AGA. The national Livestock Sector Briefs and the regional Livestock Sector Reviews draw upon the livestock database for their statistical charts and tables. These reports are available from the AGA website (www.fao.org/ag/againfo/resources/en/pubs_sap.html).

Applications

The spatial nature of these livestock data allows a wide array of applications. Livestock distribution data provide the units to which production parameters (for example, calving rates and milk yields) may be applied for estimating livestock production, they can be used to evaluate impacts, both of and on livestock, by applying any number of different rates, they provide the denominator in prevalence and incidence estimates for epidemiological applications and they provide the host distributions for disease transmission models. Many applications to which the data have already been applied are described in some detail in a recent FAO publication (2). The following is a summary.

Estimates of livestock biomass can be produced. Composite measures of livestock, such as 'tropical livestock units' (TLUs), combine population densities with estimates of the sizes of individual animals of each species in different parts of the world (e.g. a North American cow contributes 1.0 TLUs, whilst a North African cow only contributes 0.7 TLUs). A related application is to assess whether livestock populations in given areas exceed defined thresholds, such as the carrying capacity of the land (though the concept of carrying capacity for livestock is somewhat contentious, particularly in pastoral areas). This can be extended, through herd models, to projections of future livestock populations and estimates of production (for example, milk, meat and draft power). Production estimates can then be combined with consumption estimates (derived by multiplying average consumption rates with human population data) to derive production-consumption balances and thus to infer where livestock and livestock products may be moving, an important consideration both in relation to trade and to disease transmission.

By appropriately adjusting the parameters in herd models, the impact of interventions (removing tsetse or controlling brucellosis, for example) can be estimated. By linking these estimates to current price data, they can be presented as cash figures as an input, for example, to benefit-cost estimates for livestock disease interventions. As well as estimating the impact of disease, a prerequisite for disease risk mapping is sound knowledge of the distributions of susceptible species and disease vectors. Following the United Kingdom foot and mouth disease epidemic and associated outbreaks in continental Europe in 2001 and the recent emergence of highly pathogenic avian influenza (HPAI or 'bird flu') in South-East Asia, attention has focused on livestock distribution maps for modelling disease dynamics and estimating the numbers of animals at risk of infection.

Most requests for data currently relate to the distribution of chickens and other poultry species. Using the modelling approach described in this paper, we have been able to meet these demands by providing detailed global maps of poultry distributions. Figure 2 shows the distribution of poultry in east Asia, where the bird flu resurgence has been exacerbated by very high densities of poultry (and particularly of domestic waterfowl).

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

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

It is through quantitative applications, such as those described above, that the impacts of technical interventions can be estimated and assessed. In addition, by incorporating these data into appropriate decision-support methodologies, the impact of livestock-sector development policies can be evaluated so that informed recommendations for policy adjustments can be made. These new global datasets are an invaluable contribution to the

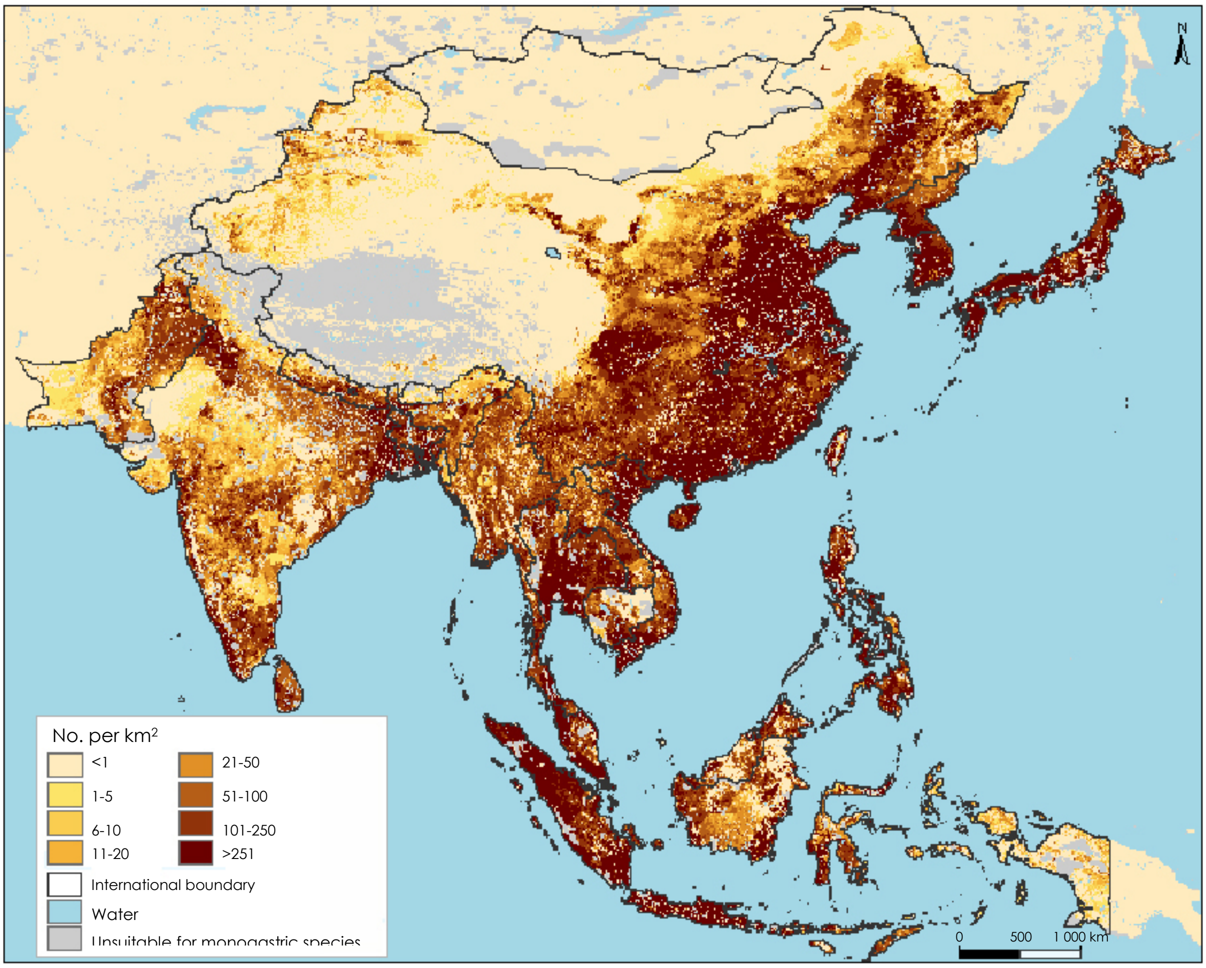

Figure 2
Gridded Livestock of the World products for east Asia: modelled poultry density

rapidly expanding field of livestock geography, enabling us to explore the complex inter-relationships among people, livestock and the environment in which they coexist.

Acknowledgements

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References

1. Fischer G., van Velthuizen H., Shah M. & Nachtergaele F. 2002. Global agro-ecological assessment for agriculture in the 21st Century: methodology and results. Research Report RR-02-02. Laxenburg: International Institute for Applied Systems Analysis and Food and Agriculture Organization of the United Nations, Rome, 119.
2. Food and Agriculture Organization of the United Nations (FAO) 2007. Gridded Livestock of the World (G.R.W. Wint & T. Robinson, eds). FAO, Animal Production and Health Division, Rome, 131 pp.
3. Goetz S.J., Prince S.D. & Small J. 2000. Advances in satellite remote sensing of environmental variables for epidemiological applications. *Adv Parasitol*, **47**, 289-307.
4. Green R.M. & Hay S.I. 2002. The potential of Pathfinder AVHRR data for providing surrogates of climatic variables across Africa and Europe for epidemiological applications. *Remote Sens Environ*, **79**, 165-175.
5. Hay S.I. 2000. An overview of remote sensing and geodesy for epidemiology and public health application. *Adv Parasitol*, **47**, 1-35.
6. Hay S.I. & Lennon J.J. 1999. Deriving meteorological variables across Africa for the study and control of vector-borne disease: a comparison of remote sensing and spatial interpolation of climate. *Trop Med Int Health*, **4**, 58-71.
7. Hay S.I., Tatem A.J., Graham A.J., Goetz S.J. & Rogers D.J. 2006. Global environmental data for mapping infectious disease distribution. *Adv Parasitol*, **62**, 37-77.
8. Price J.C. 1984. Land surface temperature measurement for the split window channels of the NOAA 7 advanced very high resolution radiometer. *J Geophys Res*, **8**, 7231-7237.