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Locating poor livestock keepers at the global level for research and development targeting

P.K. Thornton[a,*], R.L. Kruska[a], N. Henninger[b], P.M. Kristjanson[a], R.S. Reid[a], T.P. Robinson[a]

[a] *International Livestock Research Institute (ILRI), P.O. Box 30709, GPO 00100 Nairobi, Kenya*
[b] *World Resources Institute (WRI), 10 G Street NE, Washington, DC 20002, USA*

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Abstract

Many research and development agencies are committed to halving the number of people living in extreme poverty by 2015. Knowledge of where the poor are, and what characterises them, is patchy at best. Here we describe a global livestock and poverty mapping study designed to assist in targeting research and development activities concerning livestock. Estimates of the numbers of poor livestock keepers by production system and region are presented. While these estimates suffer from various problems, improvements in global databases are critical to improve the targeting of interventions that can meet the challenges posed by poverty and to chart progress against international development indicators.

Keywords: Livestock; Poverty; Mapping; System; Classification; Global

Introduction

In 1996, a set of International Development Goals was adopted by the Development Assistance Committee of the Organisation for Economic Cooperation and Development (Morton, 2001). One is to halve the proportion of people living in extreme poverty between 1990 and 2015. With this focus on poverty reduction, there is a need for research and development agencies to continually re-assess how best to operate in ways that will benefit poor people. Given the importance of livestock to the diets and incomes of the rural poor (LID, 1999), and the predicted increase in demand for livestock products throughout the developing world over the next few decades (Delgado et al., 1999), understanding how livestock fit into these systems, and how these systems may evolve in the future, are issues of critical importance.

So how can livestock-related research and development activities best be targeted? There are various fundamental questions that first need to be answered, including:

- How do livestock contribute to the livelihoods of poor people?
- Where are significant groups of poor livestock keepers located?
- What other features characterise these groups of poor people?
- How are these populations likely to change in size and location through time?
- How are their physical environments expected to change in the future?

In general, our ability to answer such questions in a satisfactory manner is very patchy, both spatially and temporally. In-depth study of communities in terms of sustainable livelihoods and vulnerability can provide very useful information at the level of the case study (see, for example, Thorne and Tanner, 2001). However, there is an urgent need for poverty assessments at the national, regional and even continental level to assist in targeting research and development activities that can have an impact on large numbers of poor people. Such

*Corresponding author. Tel.: +44-131-667-1960; fax: +254-2-63-14-99.
E-mail address: p.thornton@cgiar.org (P.K. Thornton).

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assessments cannot use case-study methods (although case studies can be used very effectively for validating broader approaches), but have to rely on broader-scale approaches.

The objectives of the work reported here were to estimate the number of poor livestock keepers in the tropics and subtropics, and to produce sets of maps that locate significant populations of them. This was one step in a process of assessing, in broad terms, how poor livestock-keeping populations are likely to change over the next three to five decades—that work is reported elsewhere (Thornton et al., 2002). In this paper, we outline the poverty mapping work, the sources of data used and the assumptions made, and present some of the maps produced. We briefly discuss their limitations and possible future work that could be done to improve them. We conclude with indications as to how this information might be used to help guide livestock research and development activities.

Challenges of mapping the location of the poor at global scale

There seems to be general agreement that human well-being has many dimensions, but poverty can be defined as a pronounced deprivation in well-being. It means lacking food, shelter, and clothing, being sick and having very limited or no access to health services, being illiterate and having few or no educational opportunities, having little security and being very vulnerable to outside events such as natural disasters and economic crises, being excluded from power and political access, and, most of all, not having any hope for the future. No single indicator exists to measure all these dimensions of poverty simultaneously. Efforts to measure human well-being have thus concentrated on collecting data separately for some of these dimensions—for example, with the help of income or consumption measurements to capture material deprivation, and health, nutrition, and education indicators to capture low levels of achievement in health and education.

Producing a map that shows the location of the poor has to rely on these national and international data collection efforts (poverty mapping in general is reviewed by Deichmann, 1999; Henninger, 1998; Ghosh and Rao, 1994). However, current investments in data collection and methodology development for statistical estimation and mapping techniques are not sufficient to produce a global map at a resolution that is significantly higher than the national average. International data collection that captures the income-consumption, demographic-health, and nutrition dimensions of human well-being have probably received a larger share of investment and international coordination than other dimensions (see WHO, 2001, for example). Even in these areas, which have received significant attention by international and national agencies in the past two decades, there are severe limitations that have an impact on our ability to show where the poor are located. These limitations are related to the international comparability of country surveys; for example, income poverty measurements need to overcome differences in survey design and questions asked, such as different recall periods to capture food spending or how to make adjustments for household sizes, different poverty lines, and measurement errors. These limitations are also to do with coverage; for example, 15% of the world's population was included in only one household income or expenditure survey over the past decade, and thus no trend analysis is possible (World Bank, 2001). Most importantly, these limitations relate to the resolution of the data. The typical sample size in these surveys is designed to produce statistics representative at a national level, with a breakdown in a handful of units of analysis, such as estimates for urban and rural areas within 3–5 major regions.

Despite these limitations, however, various efforts are underway to advance the development of poverty maps from both the demand and supply side. This could make a global, high-resolution poverty map a reality within a few years. International and national development agencies have a growing interest in focusing development efforts on the poor. For example, recent fine resolution poverty maps in South Africa are being used to target health and anti-crime interventions towards areas with both deep poverty and high disease/crime outbreaks (StatsSA, 2000). This increasing demand for maps showing the location of the poor could help to shape prioritisation efforts that go beyond country rankings, improve geographic targeting, and illuminate the cause-and-effect relationships between poverty and other dimensions of development, such as environmental and health outcomes. On the supply side, three major developments are driving the process:

- *Increased availability of geo-referenced, especially socio-economic, data*. More spatial data are becoming available because of lower costs of digital mapping software and remote sensing products, and most importantly, because of the convenience of and power for data integration, once a geographic location has been assigned. Over the past 5 years, international efforts have improved the availability of digital census data by administrative units (CIESIN, 2000) and of map layers that are relevant to delineate malaria risks (MARA, 2001), for example.
- *Efforts to distribute survey data with assigned geographic locations.* An example of this was a regional pilot project that assigned latitudes and longitudes to more than 2000 enumeration areas (''clusters'') for 12 different Demographic and Health Surveys collected

in the 1990s that allows the calculation of reliable estimates for new units of analysis such as agro-ecological zones (Croft et al., 1997; UNEP/GRID-Arendal, 1997). Geo-referencing clusters with the help of GPS units is now a standard practice for most Demographic and Health Surveys. Another example is the efforts by various United Nations agencies to compile and distribute past and future nutrition surveys over the Internet. The current online version lists all surveys for a country falling within specific quality criteria, with corresponding sample size and general location information, which easily could be linked to a gazetteer and then presented in map format.

- *Efforts to develop and refine statistical techniques that combine census and survey data to produce maps that go beyond the resolution permitted by the original sample size of the survey*. Activities by the research department in the World Bank and experts within universities have greatly improved modelling techniques for small-area estimation that have led to higher-resolution poverty maps for Ecuador, South Africa, Nicaragua, and Panama, for example (Stats-SA, 2000; Elbers and Lanjouw, 2000).

While work in these areas is increasing the supply of data, methods, and maps, it is still driven mostly by individual research interests, the entrepreneurial spirit of task managers, and ad hoc data compilation and integration efforts. There is a tremendous opportunity to accelerate these activities and move them beyond their research and pilot status to a mainstream effort. It will require increased financial support and a better coordinated strategy between development agencies, international institutions focused on survey, mapping, and analysis, and institutions responsible for national censuses, statistical services, and mapping.

Mapping human population, livestock production systems, and livestock density at the global level

The central element of the analysis described below is a global livestock classification based on that of Seré and Steinfeld (1996), which we have mapped (Kruska et al., 2003). The mapping of the classification is based primarily in terms of climate and human population density, the latter because of the strong association between people and livestock. For these livestock systems, we attached poverty data from various sources to produce a set of poverty maps by production system by country of somewhat greater resolution than the country poverty figures currently available for all countries of the globe. The data inputs to the process are summarised in Fig. 1.

Human population

Human population density layers were developed for Africa, Asia and Latin America for the year 2000. These data were used to assist in defining the livestock systems above. They were compiled from various regional

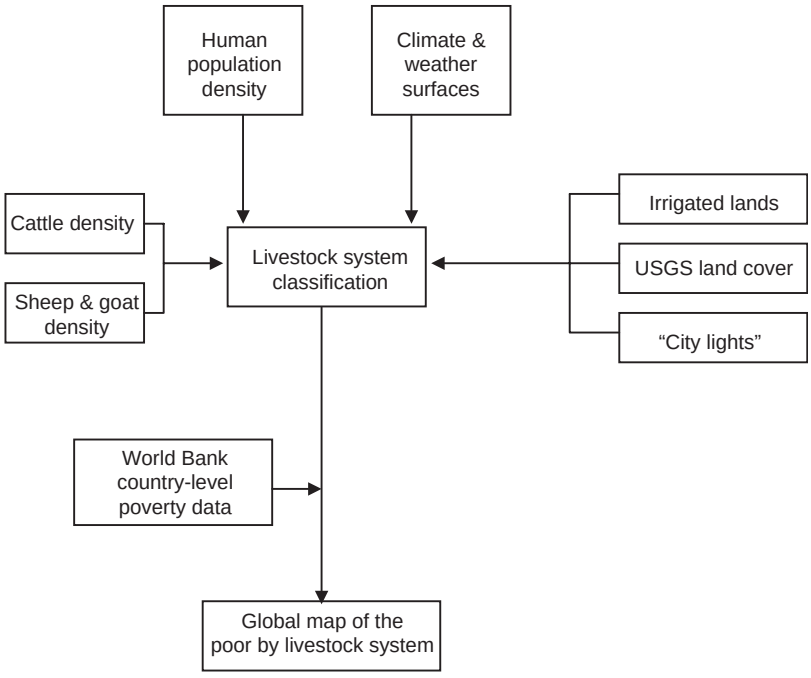

Fig. 1. Data inputs for the analysis. See text for sources. "USGS Land cover" is the United States Geological Survey Land Use/Land Cover System database and legend (Anderson et al., 1976). "City lights" is the Nighttime Lights of the World database (NOAA/NGDC, 1998).

population density data sets: the Africa Population Database, version 3 (Deichmann, 1996a); the Asia Population Database 1996 (Deichmann, 1996b); and the Latin America and Caribbean Population Database 2000 (Hyman et al., 2000).

These data originated from national population censuses carried out at various times during the 1990s. Population estimates were standardised to a common base year (2000) using published province or district-specific inter-census growth rates, typically between 1980 and 1990. The resulting total national population figures were checked against the regularly published population estimates produced by the Population Division of the United Nations. In cases where the estimate was considerably different from the UN estimate, growth rates were adjusted to match the UN-estimated population for each country. In generating the original coverages, Deichmann had redistributed the population counts among grid cells within each administrative unit by "attracting" population towards high-count areas such as urban centres and road infrastructure, and these were what we used in this analysis.

Livestock production systems

Seré and Steinfeld (1996) outline what is still, so far as we know, the only existing global livestock production classification system associated with a detailed data set. Their methods were built on the agro-ecological zone concept used by FAO, and they produced detailed country tables with disaggregated data by area, population, livestock numbers, and livestock outputs for each production system category. This classification provides a starting point for defining global livestock production systems. Seré and Steinfeld (1996) were limited at the time by the lack of availability of relevant global spatial data sets. The situation has improved greatly since then, and this has allowed us to map their classification, with some modifications to their system definitions to make use of new global data sets. The system breakdown presented is conceptually identical, but has slightly modified descriptors for the four production categories: landless systems (typically found in peri-urban settings), livestock/rangeland-based systems (areas with minimal cropping, often corresponding to pastoral systems), mixed rainfed systems (mostly rainfed cropping combined with livestock, i.e. agro-pastoral systems), and mixed irrigated systems (a significant proportion of cropping uses irrigation and is interspersed with livestock). All but the landless systems were further disaggregated by agro-ecological potential as defined by the length of growing period. Three different agro-ecological zones were used: highland/temperate, arid/semi-arid and humid/sub-humid. Details of the steps taken to produce the livestock systems maps are described in Kruska et al. (2003). In summary, the following 10 livestock systems were defined and mapped for the developing regions of the globe:

- Livestock only, rangeland-based, arid/semi-arid systems.
- Livestock only, rangeland-based, humid/sub-humid systems.
- Livestock only, rangeland-based, highland/temperate systems.
- Mixed, irrigated, arid/semi-arid systems.
- Mixed, irrigated, humid/sub-humid systems.
- Mixed, irrigated, highland/temperate systems.
- Mixed, rainfed, arid/semi-arid systems.
- Mixed, rainfed, humid/sub-humid systems.
- Mixed, rainfed, highland/temperate systems.
- Landless (peri-urban) systems.

In mapping the classification, we used human population densities (described briefly above), the United States Geological Survey's Land Use/Land Cover System database and legend (Anderson et al., 1976; Loveland et al., 2000), length-of-growing-period surfaces (Fischer et al., 2000; Jones, 1987; Jones and Thornton, 1999; IWMI, 1999), a global coverage of the irrigated areas (Döll and Siebert, 2000; Siebert and Döll, 2001), and the Nighttime Lights of the World database (NOAA/NGDC, 1998).

Livestock numbers

We assembled global data on tropical livestock units (TLUs, a measure of animal biomass calculated using the species values of Jahnke, 1982) to bring together the distributions of cattle, buffalo, sheep, goats, horses, donkeys, mules and pigs. Data on livestock numbers were assembled from various sources. Cattle densities for Africa are from databases held at the International Livestock Research Institute (ILRI), based on a large number of country-level reports; for Central and South America, from databases at ILRI and the International Centre for Tropical Agriculture (CIAT), Colombia; and for Asia, from Wint et al. (2000) and from FAO country statistics (FAO, 2001). Sheep and goat densities are from Wint et al. (2000) for much of Asia and from FAO country statistics for Central and South America, Africa and parts of Asia (FAO, 2001). Data for buffalo, horses, mules, donkeys and pigs are from FAO (2001) at the country level.

Of the 3882 species of domesticated animals (de Haan et al., 1997), only 12 species dominate global livestock production (Blench, 2000). In Africa, livestock keepers' systems rely on cattle, sheep, goats, donkeys and dromedaries; in central Asia, livestock owners keep horses, cattle, goats, sheep, donkeys, and, in some parts, Bactrian camels. Yaks dominate production in the highlands of Asia. Llama and alpaca are common in

Andean systems of South America. Water buffalo are important in India and Iran. In Africa, most of the cattle are in or near the Sahel, the higher potential areas of East Africa (including the Ethiopian highlands), Zimbabwe and South Africa. Sheep are also concentrated in these areas and also in parts of northern Africa. In Asia, cattle/buffalo are most abundant in far western Asia (Ukraine, Byelorussia, Turkey, Azerbaijan, Armenia), India, Nepal, Bangladesh, Pakistan, China, Indochina and the eastern Asian island countries. Sheep and goats are much more widely spread across central Asia and in many of the same regions as cattle. In Latin America, cattle are concentrated in south-eastern Brazil, Uruguay, Paraguay, and north-eastern Argentina. By contrast, sheep and goats are more common in Peru, Chile, and western Argentina. Cattle are more widespread than sheep and goats in Central America.

The greatest densities of TLUs are found in Brazil, Uruguay, and Argentina; the Ethiopian highlands and around Lake Victoria; India, Pakistan, Nepal and Bangladesh; north-western China around Beijing; Turkey, Ukraine, Byelorussia, Azerbaijan, Georgia, and Armenia. It is as important to recognise where there are relatively few TLUs: much of the Amazon basin, the Sahara, the humid forests of western and central Africa, northern Zambia, Angola, Mozambique, the western part of Botswana and eastern Namibia, the Arabian peninsula, western Pakistan, northern Indochina, and the desert areas of China and Mongolia.

To bring these various strands together, Fig. 2 maps the density of TLUs per person (2000 data, as far as possible) overlaid with the livestock production systems map (the areas in the tropics with no shading indicate that these are classified as non-livestock production system areas).

Locating the poor at the global level

Given existing data constraints, any global poverty maps currently have to be based on national-level poverty rates. Case studies and more detailed country data show a higher incidence of poverty in sparsely populated and remote areas (measured by the headcount, the percentage of poor living below a poverty line) and sometimes in low-potential, marginal agricultural areas. These spatial patterns, however, do not appear in other locations; there is not yet enough quantitative data to generalise across regions or to identify other general patterns.

Even with national-level data, and with poverty measures based on household income and expenditure surveys, there is still significant room for variation in the relative and absolute numbers of poor. A major reason for these differences in the number of poor is the choice of poverty line. The poverty line is the threshold in income or consumption below which a household is classified as poor. Internationally comparable lines, such as the widely cited US $1/day (the most recent line is equal to US $1.08/day using 1993 purchasing power parity (PPP) estimates generated by the International Comparison Program), are useful for producing continental and global totals (World Bank, 2001). Data based on an international poverty line thus show the number of people that cannot purchase a roughly similar basket of necessities (World Bank, 2001). National poverty lines are needed to capture inter-country differences in economic and social status and to assess progress at a national scale. Poverty lines differ between countries and even within countries, to reflect differences in the cost of living between urban and rural areas, for example. Other problems that can be associated with nationally defined poverty levels relate to the fact that they may be defined somewhat subjectively. The following maps and tables based on these national poverty lines, therefore, do not have a common reference point, strictly speaking.

In the study (Thornton et al., 2002) we used four different data sets and poverty lines, two international lines (US$1 and US$2/day) and two national lines—one from the ILRI priority-setting exercise based on data from the technical advisory committee (TAC) of the Consultative Group of International Agricultural Research (CGIAR) (TAC, 1996; Gryseels et al., 1997), and one for the rural population living below the rural poverty line (World Bank, 2001), to compare differences in the number of poor. These are compared for various regions in Table 1, which clearly indicates that an international line of US$1/day underestimates the number of poor in North Africa and Central and South America, which typically have set their national poverty lines closer to the US$2/day figure. US$1/day is closer to the national poverty lines in low-income countries of Sub-Saharan Africa and South Asia. A value of US$2/day is closer to national poverty lines in middle-income countries.

Poverty rates (headcount) are based on the latest household survey, typically (but not always) in the past 5–10 years. No adjustments were made to standardise to a common base year, by applying estimated growth rates of per capita private consumption from national accounts, for example. Survey data did not exist for all countries within each region. For countries where such data were not available, a regional population weighted average was estimated for each of the four regions (Asia, Central and South America, sub-Saharan Africa, and West Asia–North Africa) and then applied to the countries with no data.

Table 3 shows numbers of total poor by region and by production system (the full spreadsheets are available from the authors upon request), using the rural country-based poverty rates. Abbreviations in that

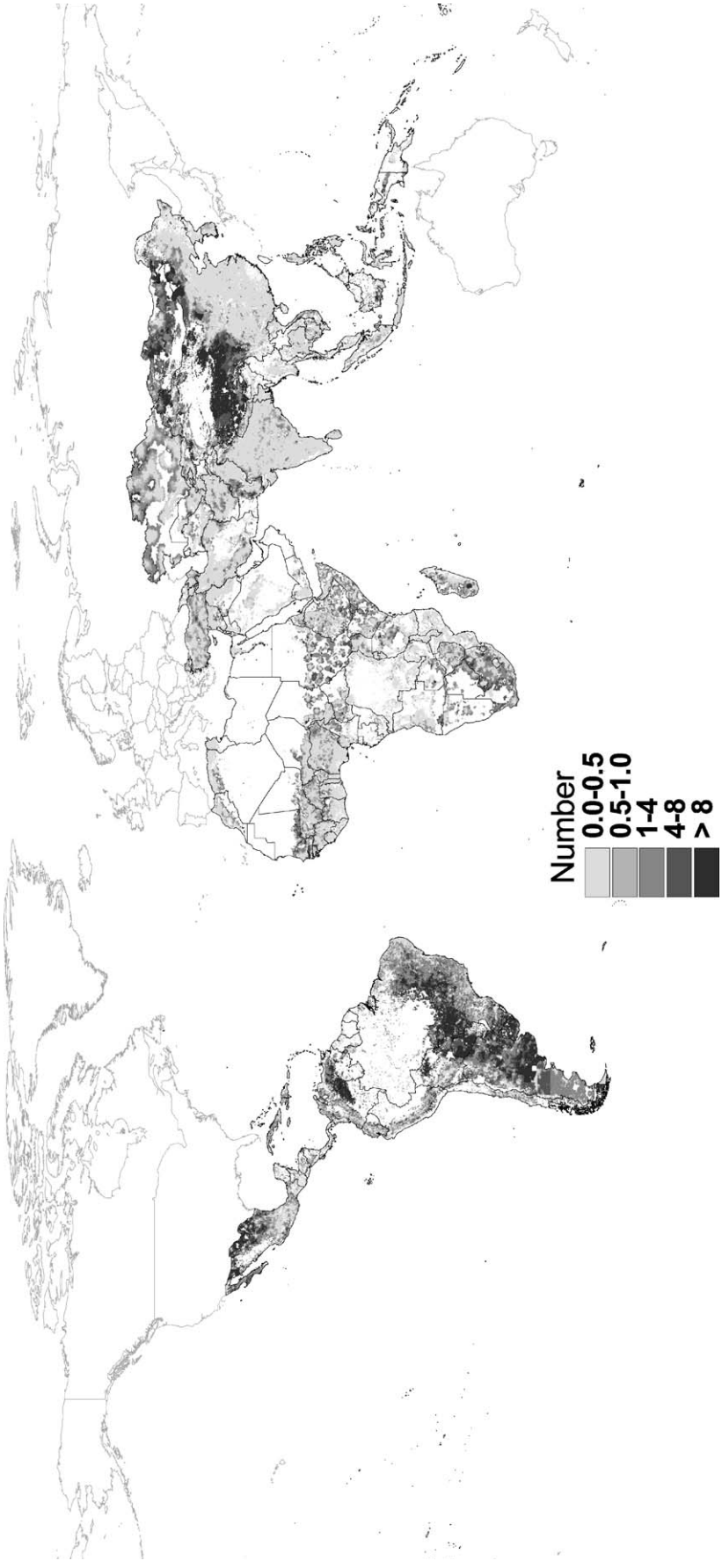

Fig. 2. Tropical livestock units per person (2000 data).

Table 1
Comparison of absolute and relative numbers of poor based on different poverty lines

Region	Millions of people living in poverty, 2000							
	Based on national poverty lines from ILRI priority setting exercise (TAC)[a]		Rural poor (based on national poverty lines)[b]		Less than $1/day (international poverty line)[b]		Less than $2/day (international poverty line)[b]	
Asia	857	56%	733	56%	889	71%	2169	74%
Central and South America	207	14%	194	15%	62	5%	159	5%
Sub-Saharan Africa	350	23%	291	22%	293	23%	495	17%
West Asia and north Africa	104	7%	94	7%	10	1%	105	4%
Total (four regions)	1520	100%	1312	100%	1254	100%	2928	100%

[a] Gryseels et al. (1997).
[b] World Bank (2001).

Table 2
Abbreviations used

EA	East Asia	China, Mongolia, North Korea, South Korea
CSA	Central and South America	Argentina, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guyana, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela
CA	Central Asia	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
SA	South Asia	Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka
SEA	South-east Asia	Brunei, Indonesia, Kampuchea, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Thailand, Vietnam
SSA	Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe
WANA	West Asia–north Africa	Algeria, Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Yemen
Dry range	Livestock only, rangeland based, arid–semiarid system	
Wet range	Livestock only, rangeland based, humid–subhumid system	
Cold range	Livestock only, rangeland based, temperate-tropical highland system	
Dry irrigated	Mixed irrigated arid–semiarid system	
Wet irrigated	Mixed irrigated humid–subhumid system	
Cold irrigated	Mixed irrigated temperate-tropical highland system	
Dry mixed	Mixed rainfed arid–semiarid system	
Wet mixed	Mixed rainfed humid–subhumid system	
Cold mixed	Mixed rainfed temperate-tropical highland system	
Landless	Systems in high population density areas, with and without city lights	
"Other"	Non-livestock systems	

table, and the definition of the various regions, are shown in Table 2.

Locating poor livestock keepers at the global level

The data in Table 3 are based on the assumption that the national poverty rate is equally applicable across all systems or areas within the country. With a breakdown by livestock production system, it is possible to show numbers of poor by livestock production system, but this is only one step towards representing the distribution of poverty among livestock keepers. As noted above, poverty rates will clearly differ within and between production systems. The proportional importance of livestock to household income streams differs

Table 3
Number of poor (millions) by region and livestock production system: nationally defined rural poverty rates (World Bank, 2001)

Region	Dry range	Wet range	Cold range	Dry irrigated	Wet irrigated	Cold irrigated	Dry mixed	Wet mixed	Cold mixed	Land-less	"Other"	Total
EA	0.2	≪0.1	1.4	0.1	4.8	38.9	0.4	4.0	17.9	0.6	7.3	75.5
CSA	6.8	3.7	3.1	6.0	4.4	7.3	15.2	49.8	39.6	19.6	57.7	213.5
CA	0.2	≪0.1	2.5	2.1	≪0.1	5.1	2.3	≪0.1	5.4	0.1	1.8	19.7
SA	8.1	0.1	0.1	196.9	78.4	0.6	108.0	74.0	4.9	2.8	28.3	502.1
SEA	0	0.2	0.1	0.5	64.9	0.6	0.6	61.5	2.0	2.6	28.5	161.5
SSA	19.7	6.1	1.2	2.1	0.1	1.5	77.2	83.9	44.4	2.8	55.2	294.3
WANA	7.2	≪0.1	0.1	22.7	0.5	4.2	21.1	1.4	16.1	0.7	20.2	94.5
Total	42.3	10.1	8.6	230.4	153.0	58.1	224.9	274.9	130.5	29.2	199.1	1361.1

Note: See Table 2 for abbreviations.

from one culture to another and within production systems. For example, mixed crop-livestock farmers have multiple opportunities for income from a variety of sources; thus, income from livestock probably contributes a smaller proportion to their household food basket. By contrast, most pastoralists depend on livestock for a large proportion of their income (although in places this is changing). Thus, any map of poverty among livestock keepers needs to account for the importance of livestock to income at the household level.

At the national (or even regional) level, methods exist to deal with such issues. At the global level, information on the importance of livestock to rural livelihoods is difficult to find. There are several approaches that could be taken to deal with differential poverty rates by production system. One approach would be to use the density of TLUs per person (Fig. 2) as a proxy for the importance of livestock to income at the household level, the assumption being that higher livestock numbers per person indicate that livestock are more important to household incomes, within a particular system. This assumption has some obvious flaws, including the possibility that areas with more livestock per person are areas that have more income opportunities of all kinds. However, an overlay of TLUs per person with the poverty map would give rise to differential poverty rates by system that could give an indication of numbers of poor livestock keepers.

A second approach would be to estimate the proportional importance of livestock to incomes within the 11 different production systems, and to use this to weight the poverty rate by system. Information on this is very scanty, however; the approach using TLUs per person seems more objective, unless databases can be built up with country-level systems poverty rates from a wide variety of countries, to the point where extrapolation could be done with some confidence.

Another approach would use differential poverty rates associated with particular production systems, defined in some way. As an illustration, and to highlight the need for future work on this element of the analysis, Fig. 3 shows (ostensibly) numbers of "poor livestock keepers" by system by country (the numbers are tabulated by region and system in Table 4). These data were derived by assigning differential proportions of poor livestock keepers as a percentage of the total poor by livestock production system. We used estimates of the number of poor livestock keepers globally from Livestock in Development (LID, 1999). These estimates were derived from poverty statistics in UNDP (1997) and other studies on livestock ownership patterns (LID, 1999). Using these data for extensive graziers (which we equated with the three livestock only, rangeland-based systems), poor rainfed mixed farmers (the three mixed rainfed systems), and landless livestock keepers (into which category we lumped all the remaining systems), we derived the proportion of the numbers of poor people in each system who are livestock keepers (76% for the rangeland-based systems, 68% for the mixed rainfed systems, and 26% for the mixed irrigated and all landless systems). These proportions were then applied to the numbers of poor in each system using the nationally defined rural poverty rates. These numbers may be very coarse at the global level, but they illustrate what could be done with more precision at higher resolutions, for example through using household welfare survey results measuring percentages of livestock keepers falling below the poverty line.

Fig. 3 indicates that the density of poor livestock keepers defined in this way is particularly high throughout South Asia (India, Pakistan, and Bangladesh) and in parts of Sub-Saharan Africa (including Nigeria, Ethiopia, Uganda, Burundi, Rwanda, Malawi, and some systems in Kenya, South Africa, and Niger, for example). These high densities appear to occur mostly in the mixed systems—these are the irrigated mixed systems in parts of South Asia, and the rainfed mixed systems in parts of India and in most of Sub-Saharan Africa.

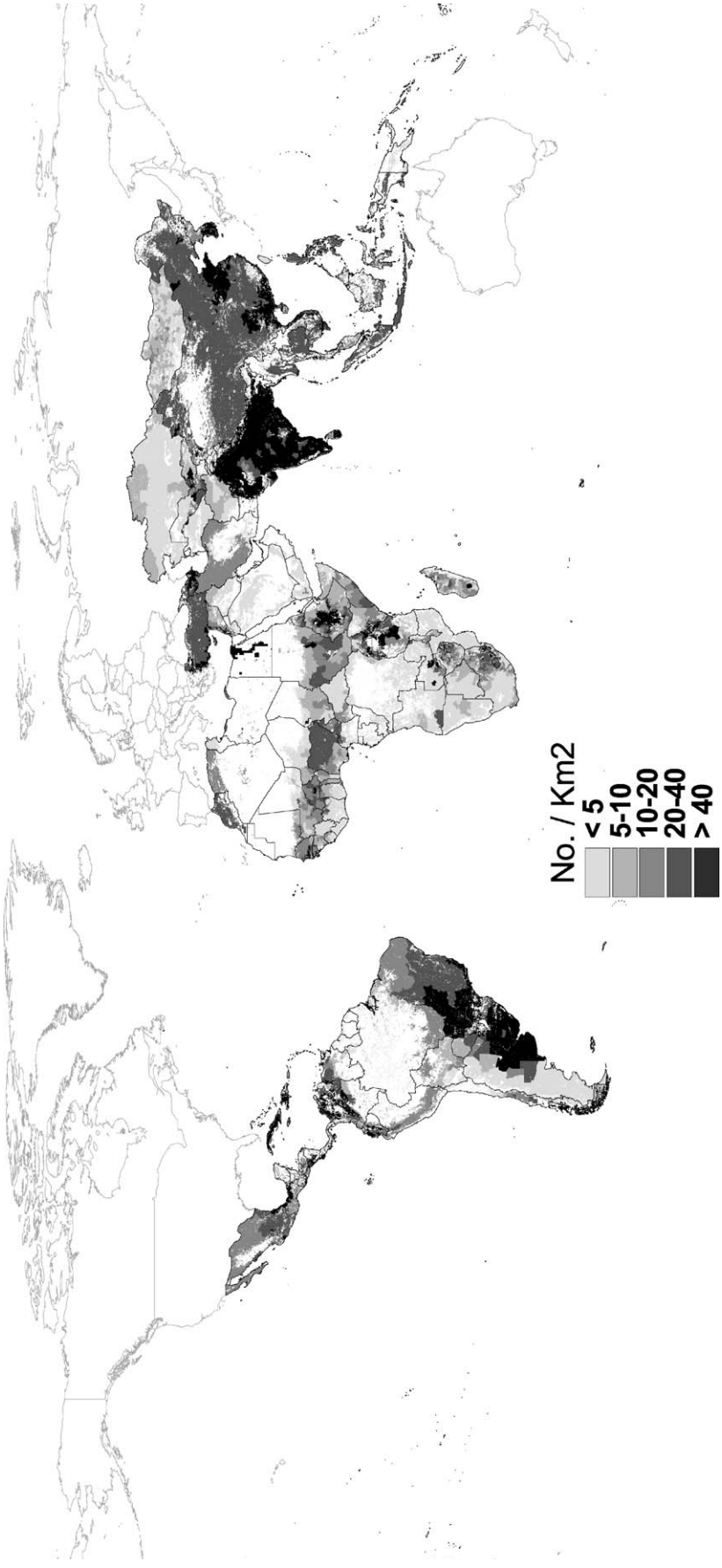

Fig. 3. Density of "poor livestock keepers" by livestock system.

Table 4
Number of "poor livestock keepers" (millions) by region and livestock production system: nationally defined rural poverty rates (World Bank, 2001; LID, 1999)

Region	Dry range	Wet range	Cold range	Dry irrigated	Wet irrigated	Cold irrigated	Dry mixed	Wet mixed	Cold mixed	Land-less	"Other"	Total
EA	0.2	≪0.1	1.1	≪0.1	1.2	10.1	0.3	2.7	12.2	0.2	0	28.0
CSA	5.2	2.8	2.4	1.6	1.1	1.9	10.3	33.9	27.0	5.1	0	91.3
CA	180.4	≪0.1	1.9	0.6	≪0.1	1.3	1.5	≪0.1	3.7	≪0.1	0	9.2
SA	6.1	0.1	0.1	51.2	20.4	0.2	73.4	50.3	3.3	0.7	0	205.9
SEA	0	0.2	0.1	0.1	16.9	0.2	0.4	41.9	1.3	0.7	0	61.7
SSA	15.0	4.6	0.9	0.5	≪0.1	0.4	52.5	57.1	30.2	0.7	0	162.0
WANA	5.5	≪0.1	0.1	5.9	0.1	1.1	14.4	1.0	11.0	0.2	0	39.3
Total	32.1	7.7	6.5	59.9	39.8	15.1	152.9	186.9	88.7	7.6	0	597.3

Note: See Table 2 for abbreviations.

Discussion and conclusions

In terms of the numbers of poor and our estimates of the numbers of poor livestock keepers, the critical regions are South Asia and Sub-Saharan Africa. Some 62% of the estimated 600 million poor livestock keepers (defined using nationally defined rural poverty rates) live in these two regions. This analysis indicates that while the rangeland systems contain relatively few poor (some 60 million), most of these households are dependent on livestock for their livelihoods. Almost half of the poor in rangeland systems are located in Sub-Saharan Africa. The mixed systems contain large numbers of poor (over 1 billion), and the number of poor people who depend to some extent on livestock is considerable—the mixed irrigated systems may contain 113 million poor livestock keepers, and the mixed rainfed system some 420 million poor livestock keepers.

These numbers of poor livestock keepers by system and region should clearly be treated with caution, given some of the assumptions made in the analysis outlined above. In addition, there are several weaknesses in the map of global livestock production systems, identified in Kruska et al. (2003). The classification depends on data of land cover/land use that could be improved. For example, the category classified as "other" contains ecosystems that range from arctic tundra to tropical rain forest to desert. There is also a great deal of variation within all of the production systems categories, particularly with respect to agricultural production potential. There are also likely to be differences in the level of poverty of livestock keepers within the same production system associated with differences in livestock production potential, but there is much that is unknown.

There are several areas where improvements could be made in the future. First, there could be further refinement of production systems categories by accounting for different levels of land-use intensity and different levels of productive potential caused by soil fertility. Second, further studies are needed to quantify rates of poverty between and within different production systems. This would involve substantial improvement in our understanding of the proportion of income that people in different production systems derive from livestock, and thus the importance of livestock to their livelihoods. Third, the time dimension could be incorporated explicitly in these analyses through combining notions of poverty with vulnerability. Some of the poor are bound to be more vulnerable to climatic shocks such as drought or to political shocks such as revolution than others. Global analyses of vulnerability combined with poverty maps could contribute greatly to refining the types of analyses that could be attempted using the data sets described above.

Despite their weaknesses, these poverty maps can still provide information of considerable use. First, this information can be (and is being) used to prioritise and focus livestock research. Different agencies have their own criteria by which to judge the appropriateness of research and development activities within their activity portfolios; these might include a consideration of the absolute numbers of poor, or systems with high rural poverty rates and where environmental issues are important, or systems with large numbers of TLUs and poor livestock keepers, or other similar criteria. Realistic and convincing attempts to prioritise activities will involve trade-offs between the various criteria used. The important thing is to define these various criteria, so that the reasons for priorities can be articulated clearly. An example is the recent priority-setting work at ILRI (Randolph et al., 2001), which involved the development of a framework that could accommodate multiple criteria in evaluating the impacts of the various research themes under consideration, including expected economic impact and the contribution to poverty alleviation. For these, a cost-benefit analysis based on an economic surplus model was used to estimate the economic impact and the numbers of poor likely to

benefit. This work was carried out before the poverty and systems maps was completed, but future priority setting will make use of these to help refine resource allocations to livestock research activities at ILRI. A second example is the study of Perry et al. (2002), which was based on the livestock system and poverty maps described above. This study was carried out to identify priority research opportunities that can improve the livelihoods of the poor through better control of animal diseases in Africa and Asia. A major objective was to promote better donor coordination and complementarity and thereby achieve greater impact on poverty alleviation. Currently, there are plans to put these databases into a format that can be readily accessed by those interested in using them in their own priority-setting activities (e.g. other research institutes, donor agencies, and regional organisations).

A second use of these livestock system and poverty maps is in identifying "hotspots" at the global level that can then be investigated in more detail at higher resolution. These hotspots might be defined in various ways, depending on the purpose: as areas of high population densities of poor livestock keepers, or areas of high densities of poor people coupled with high levels of biodiversity or natural resource degradation, for example. We have started analyses of this type in Kenya, where we are attempting to associate different poverty rates with geographic variables such as market access, natural resource endowment, and climate. The expectation is that this work will ultimately allow us to analyse some of the relationships between land use, natural resource degradation, and poverty. Such information is critical for informing policy decisions from the community up to national levels in many developing countries.

A third use of these livestock and poverty maps could potentially be in contributing baseline data for monitoring progress towards some of the International Development Goals. Disaggregating country-level data by production system could assist in identifying areas where progress is or is not being made, and could possibly provide some insights as to the reasons why.

While analyses based on global data sets are useful, they can go only so far. A key activity in future is to forge the links between household survey data and case studies with the broader picture provided by global analyses. As noted above, methods based on small-area estimation to produce poverty maps at much higher resolution, for instance at the level of census enumeration areas, have been and are being applied in various countries and can greatly increase the analytical options available to policy makers for targeting development assistance of whatever type. Such poverty maps could also be used to spot-check global estimates for accuracy. Poverty maps based on small-area estimation have been or are being constructed for at least 20 countries in the tropics and subtropics (Henninger and Snel, 2002). These, together with household survey data from many of these countries, could go a long way towards assessing the reliability of estimates of numbers of poor livestock keepers and their location globally.

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References

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A land use and land cover classification system for use with remote sensor data. US Geological Survey Professional Paper 964, 28pp.

Blench, R., 2000. "You can't go home again"—extensive pastoral livestock systems: issues and options for the future. ODI/FAO report, London, UK.

CIESIN, 2000. Center of International Earth Science Information Network datasets online at http://sedac.ciesin.org.

Croft, T., Rutstein, S., Brunner, J., Abderrahim, N., 1997. West Africa spatial analysis prototype: development of a geo-referenced regional database. Technical Paper, DHS/Macro International. Available at http://poverty. worldbank.org/library/view/12903.

de Haan, C., Steinfeld, H., Blackburn, H., 1997. Livestock and the Environment: Finding a Balance. WRENmedia, Fressingfield, UK.

Deichmann, U., 1996a. Africa Population Database, 3rd Version. National Center for Geographic Information and Analysis (NCGIA), University of California, Santa Barbara as a cooperative activity between NCGIA, Consultative Group on International Agricultural Research (CGIAR), United Nations Environment Programme/Global Resource Information Database (UNEP/GRID), and World Resources Institute (WRI), http://grid2.cr.usgs.gov/globalpop/africa.

Deichmann, U., 1996b. Asia Population Database 1996. National Center for Geographic Information and Analysis (NCGIA), University of California, Santa Barbara as a cooperative activity between NCGIA, Consultative Group on International Agricultural Research (CGIAR), and United Nations Environment Programme/Global Resource Information Database (UNEP-GRID), Sioux Falls, http://grid2.cr.usgs.gov/globalpop/asia/intro.html.

Deichmann, U., 1999. Geographic Aspects of Inequality and Poverty. Text for World Bank's web site on inequality, Poverty and Socioeconomic Performance, at: http://www.worldbank.org/poverty/inequal/index.html, p. 13.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., Courbois, C., 1999. Livestock to 2020: the next food revolution. Food,

Agriculture and the Environment, Discussion Paper 28, IFPRI/FAO/ILRI, Washington, DC, USA.
Döll, P., Siebert, S., 2000. A digital global map of irrigated areas. ICID Journal 49 (2), 55–66.
Elbers, C., Lanjouw, P., 2000. Intersectoral transfer, growth, and inequality in rural Ecuador. World Development 29 (3), 481–496.
FAO, 2001. Food and Agriculture Organization of the United Nations Statistical Databases. Online at http://apps.fao.org.
Fischer, G., van Velthuizen, A., Nachtergaele, F.O., 2000. Global agro-ecological zones assessment: methodology and results. Interim Report, International Institute for Applied Systems Analysis, Laxenburg, Austria.
Ghosh, M., Rao, I.N.K., 1994. Small area estimation: an appraisal. Statistical Science 9, 55–93.
Gryseels, G., Groenewold, J.P., Kassam, A., 1997. TAC Database for Quantitative Analysis of CGIAR Priorities and Strategies. TAC Secretariat, FAO, Rome.
Henninger, N., 1998. Mapping and geographical analysis of poverty and human welfare—review and assessment. Report prepared for the UNEP/CGIAR initiative on GIS, World Resources Institute, Washington, DC, p. 97.
Henninger, N., Snel, M., 2002. Where are the poor? Experiences with the development and use of poverty maps. World Resources Institute, Washington, DC. Available online from http://population.wri.org.
Hyman, G., Nelson, A., Lema, G., 2000. Latin America and Caribbean Population Database 2000. International Center for Tropical Agriculture (CIAT), Cali, Colombia as a cooperative activity between UNEP/GRID, CIAT, and WRI. http://grid2.cr.usgs.gov/globalpop/lac/intro.html.
International Water Management Institute (IWMI), 1999. World Water and Climate Atlas. http://www.cgiar.org/iwmi/WAtlas/atlas.html.
Jahnke, H.E., 1982. Livestock Production Systems and Livestock Development in Tropical Africa. Kieler Wissenschaftsverlag Vauk, Kiel, Germany.
Jones, P.G., 1987. Current availability and deficiencies in data relevant to agro-ecological studies in the geographic area covered by the IARCS. In: Bunting, A.H. (Ed.), Agricultural Environments: Characterisation, Classification and Mapping. CAB International, Wallingford, UK, pp. 69–83.
Jones, P.G., Thornton, P.K., 1999. Fitting a third-order Markov rainfall model to interpolated climate surfaces. Agricultural and Forest Meteorology 97, 213–231.
Kruska, R.L., Reid, R.S., Thornton, P.K., Henninger, N., Kristjanson, P.M., 2003. Mapping a livestock-orientated agricultural production system classification for the developing regions of the world. Agricultural Systems 77, 39–63.
Livestock in Development (LID), 1999. Livestock in Poverty-Focused Development. LID, Crewkerne, UK, 96pp.
Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, Z., Yang, L., Merchant, J., 2000. Development of global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. International Journal of Remote Sensing 21(6), 1303–1330. Global Land Cover Characteristics Database Version 1.2, available online at http://edcdaac.usgs.gov/glcc/glcc.html.
MARA, 2001. Mapping Malaria Risk in Africa (MARA). Map information available online at http://www.arma.org.za/mapsinfo.html.
Morton, J.F., 2001. International development goals and livestock research: towards meeting the development assistance criteria targets. In: Hainsworth, S.D., Godfrey, S.H., Matthewman, R.W., Richards, J.I. (Eds.), Linkages, Livestock and Livelihoods: Promoting Coordination in Livestock Research for Poor People. NRI International Ltd., Pembroke, Chatham Maritime, Kent, UK, pp. 19–21.
National Oceanographic and Atmospheric Administration/National Geophysical Data Center (NOAA/NGDC), 1998. Stable Lights and Radiance Calibrated Lights of the World CD-ROM. NOAA/NGDC, Boulder, CO. Nighttime Lights of the World database online at http://julius.ngdc.noaa.gov:8080/production/html/BIOMASS/night.html.
Perry, B.D., McDermott, J.J., Randolph, T.F., Sones, K.R., Thornton, P.K., 2002. Investing in Animal Health Research to Alleviate Poverty. International Livestock Research Institute (ILRI), Nairobi, Kenya, 138pp.
Randolph, T.F., Kristjanson, P.M., Omamo, W.S., Odero, A.N., Thornton, P.K., Reid, R.S., Robinson, T., Ryan, J.G., 2001. A framework for priority setting in international livestock research. Research Evaluation 10 (3), 142–160.
Seré, C., Steinfeld, H., 1996. World livestock production systems: current status, issues and trends. FAO Animal Production and Health Paper 127, FAO, Rome.
Siebert, S., Döll, P., 2001. A digital global map of irrigated areas—an update for Latin America and Europe. World Water Series 4, Center for Environmental Systems Research, University of Kassel, Germany, 14pp + Appendix.
StatsSA, 2000. Measuring poverty in South Africa. Statistics South Africa, Republic of South Africa, Pretoria 107pp. http://www.statssa.gov.za/Publications/Publications.html.
TAC, 1996. CGIAR Priorities and Strategies for Resource Allocation During 1998–2000. SDR/TAC: IAR/96/6.1. TAC Secretariat, FAO, Rome.
Thorne, P.J., Tanner, J.C., 2001. The maize crop as food, fodder and fertiliser in intensifying crop-livestock systems in east and southern Africa. Component 2: Analysis of resource use in mixed farming systems. Consultants' Report to the Systems Analysis and Impact Assessment Programme and the SLP, ILRI, Nairobi, 120pp.
Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., Odero, A., Ndegwa, T., 2002. Mapping poverty and livestock in the developing world. International Livestock Research Institute, Nairobi, Kenya, 124pp.
UNDP, 1997. Human Development Report 1997. Oxford University Press, Oxford, UK.
UNEP/GRID–Arendal, 1997. Mapping indicators of poverty in West Africa. Environment Information and Assessment Technical Report, United Nations Environment Programme/Global Resource Information Database, Arendal, Norway.
WHO, 2001. World Health Organization/Department of Nutrition for Health and Development: WHO Global Database on Child Growth and Malnutrition, http://www.who.int/nutgrowthdb/.
Wint, W., Slingenbergh, J., Rogers, D., 2000. Livestock distribution, production and diseases: towards a global livestock atlas. Consultants' Report, Food and Agriculture Organisation of the United Nations Viale delle Termi di Caracalla, 00100, Rome, Italy.
World Bank, 2001. World Development Report 2000/2001: Attacking Poverty. Published for the World Bank by the Oxford University Press, New York.