3 Mapping global livestock production systems

The classification system of Seré and Steinfeld (FAO, 1996) was outlined in the previous section. To recap, if we disregard the agroclimatic characterization, this scheme classifies livestock systems into four types: 1) landless livestock production systems (LL, which may be monogastric or ruminant); 2) grassland based system (LG, in which crop-based agriculture is minimal); 3) mixed rainfed systems (MR, mostly rainfed cropping combined with livestock); and 4) mixed irrigated systems (MI, in which a significant proportion of cropping uses irrigation and is interspersed with livestock). Seré and Steinfeld (FAO, 1996) used their classification to disaggregate a large number of resource variables (e.g. population, arable land and livestock numbers), production variables (e.g. meat, milk and egg production) and productivity variables (e.g. meat and milk yields per animal). National data from FAOSTAT (or Agrostat as it was then known) were assigned to one or more of ten AEZs using 'prorating factors'. Exactly how the very detailed, farm-level classification was overlaid on these broad AEZs to assign the data to the defined livestock production systems is not clear, however. A more robust method would be to map the systems at relatively high spatial resolution and to overlay them on the variables in question.

METHODOLOGY, DEVELOPMENTS AND CURRENT STATUS

A method was devised to map an approximation to the Seré and Steinfeld classification in the developing world based on land cover, human population density, LGP, temperature and elevation (Thornton *et al.*, 2002; Kruska *et al.*, 2003). This classification has since been used to stratify many analyses (some described in FAO, 2007a). Because climatic and population variables are used as input data, this has enabled the classification to be re-evaluated in response to different scenarios of climate and population change in the future (Thornton *et al.*, 2006). In this section the original mapping of the classification scheme is described, as are the various updates carried out since then, and a brief evaluation of the classification is presented in terms of its uses and limitations. The section concludes with a discussion of one of the key uncertainties associated with mapping this (or indeed any other) classification scheme: identifying crop extent.

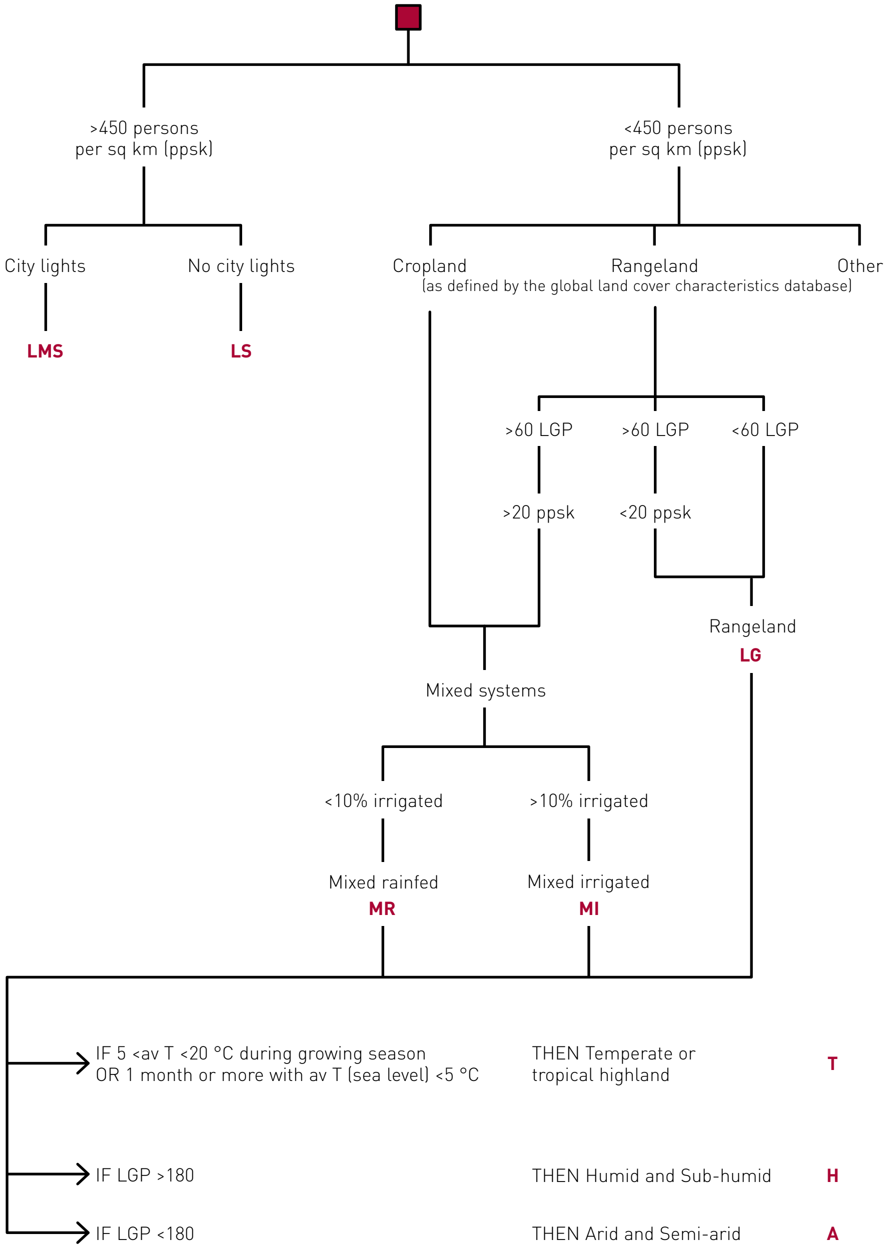
Input data and methods

As discussed previously, mapping of the Seré and Steinfeld (FAO, 1996) classification using all the same criteria that were used in its derivation is not possible because of the unavailability of some key data at the global scale, or indeed for anywhere other than perhaps small areas where detailed studies have taken place. This situation is not likely to change in the foreseeable future. Accordingly, proxies have been identified for which global data exist, and that are at the same time able to represent the spirit of the classification.

Ten systems were mapped for the developing world using the decision tree shown in Figure 3.1. The first distinction was made between landless and land-based livestock production systems. A threshold of 450 people per km^2 was used to identify areas within which landless livestock production occurs, generally highly intensive systems involving ruminants or monogastrics, which can be either large-scale or small-scale operations.

The next branch in the tree required that the mixed systems be differentiated from the grassland-based systems. While cropland extent can be derived from various land cover products, there is wide variation in their estimates (see the end of this section for a discussion of this

3.1 DECISION TREE FOR MAPPING LIVESTOCK PRODUCTION SYSTEMS



Source: adapted from Thornton *et al.* (2002).

problem). Largely as a result of the problems of underestimating cropland extent, the original mapping scheme used LGP and human population to reallocate part of the 'rangelands' (the term generally used by Thornton *et al.* (2002) instead of 'grasslands') to the mixed system category. In particular, the rangelands were divided into 'cultivatable' and 'non-cultivatable', using an LGP threshold of 60 days. (This is quite severe: cropping is extremely marginal in areas with less than 60 growing days, even for drought-resistant crops such as millet and sorghum). Human population density was then used to identify additional cropping areas within the cultivatable rangelands category. All cultivatable rangelands with a population density greater than 20 people per km^2 were added to the cropland category to define the mixed production system category. The remaining area under the rangelands category corresponds to the 'livestock-only' systems as defined by Seré and Steinfeld. The threshold density of 20 people per km^2 was based on comparisons of population data with higher resolution land cover maps for Latin America, West Africa and East Africa, and on expert opinion (Kruska *et al.*, 2003). Human population has been shown to be strongly related to the amount of land cultivated (Bourn and Wint, 1994; Reid *et al.*, 2000), and it was estimated that the threshold of 20 people per km^2 is generally equivalent to 15–25 percent of the land cultivated.

At the next decision point in the tree (Figure 3.1), the mixed systems were classified as either rainfed or irrigated. Seré and Steinfeld (FAO, 1996) defined mixed irrigated systems as those in which more than 10 percent of the value of non-livestock farm production came from irrigated land use. Following this, the original mapping classification used a threshold of 10 percent of area irrigated for each grid cell, above which a pixel was assigned mixed irrigated. The remaining mixed systems pixels were then classified as rainfed.

The mixed rainfed, mixed irrigated and rangeland system categories as defined above were then subdivided based on agro-ecology, strictly according to the Seré and Steinfeld definitions (FAO, 1996). The original datasets used to map the classification are shown in the second column of Table 3.1; Version 1.

Recent updates

The global livestock production systems map has been updated in various ways since it was devised. The basic model has been expanded by making additions to the original LGP breakdown to include hyper-arid regions, defined as areas with zero growing days. This was done because livestock can be found in some of these regions (e.g. Turkana, northern Kenya) during wetter years when the LGP is greater than zero, despite long-term LGP being at or close to zero days per year.

Most of the updating of the systems maps for Version 3 (an intermediate Version 2 is not included in the discussion here) was associated with the use of new datasets. In the GLC 2000 data layer[1] (Mayaux *et al.*, 2004; Bartholomé and Belward, 2005) irrigated areas were included for Africa. Kruska (2006) used this instead of the irrigated areas database of Döll and Siebert (2000); however, this database continued to be used for Asia and South America. For human population, the 1 km Global Rural-Urban Mapping Project (GRUMP) data were used (CIESIN, 2005). Length of growing period data were developed from the WorldClim 1 km data for the year 2000 (Hijmans *et al.*, 2005), together with a new 'highlands' layer for the same year based on the same dataset (methods are outlined in detail in Thornton *et al.*, 2006). Cropland and rangeland were defined from the GLC 2000 and areas classified as rock or sand were included as part of rangelands. As before, areas in the GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2, as well as an LGP greater than 60 days (which can occasionally allow cropping), were included in the mixed system categories. Urban areas were defined by the GLC 2000. The landless systems remained problematic and were not included in this version of the classification.

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[1] http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

TABLE 3.1 DATA INPUTS USED FOR THE DIFFERENT VERSIONS OF THE MAPPED GLOBAL LIVESTOCK PRODUCTION SYSTEMS*

Data inputs	Version 1, 2001 (Thornton *et al.*, 2002; Kruska *et al.*, 2003)	Version 3, 2006 (Kruska, 2006)	Version 4, 2007 ILRI/FAO GLW web site	Version 5, 2011 This publication
Land cover	USGS Global Land Cover Characterization (1 km)	GLC 2000 Global Land Cover (1 km) (Mayaux *et al.*, 2004; Bartholomé and Belward, 2005)	GLC 2000 except now using GRUMP urban extents to supplement the GLC 2000 'urban' category + Africover	Same
Length of growing period (LGP)	LGP 2000 (55 km) (Fischer *et al.*, 2002)	LGP 2000 (5 km) (Jones and Thornton, 2005), based on WorldClim (Hijmans *et al.*, 2005)	Same LGP data, but re-modelled to 1 km resolution by ERGO (Wint, 2007)	LGP 2000 (1 km) (Thornton and Jones, 2010), based on WorldClim (Hijmans *et al.*, 2005)
Highland and temperate areas	Highland and temperate regions 2000 (55 km) (Jones and Thornton, 1999)	Highland and temperate regions 2000 (5 km) (Jones and Thornton 2005), based on WorldClim (Hijmans *et al.*, 2005)	Same highland and temperate regions, but re-modelled to 1 km resolution by ERGO (Wint, 2007)	Highland and temperate regions 2000 (1 km) (Thornton and Jones, 2010), based on WorldClim (Hijmans *et al.*, 2005)
Human population	Population density 1990 (5.6 km) (Deichmann, 1996a; 1996b); 2000 for Latin America (Hyman *et al.*, 2000)	GRUMP population density 2000 (1 km) (CIESIN, 2005)	Same	Same
Irrigated areas	Global Irrigation Database (Aquastat) Version 1.0 (5.6 km) (Döll and Siebert, 2000)	Aquastat Version 3.0 (5.6 km) (Eliasson *et al.*, 2003) (Aquastat Version 1.0 continued to be used for Asia and Latin America)	Aquastat Version 4.0.1 (public product at 10 km) (Siebert *et al.*, 2007)	Aquastat Version 4.0.1 (source data at 1 km) (Siebert *et al.*, 2007)

* Nominal spatial resolutions provided refer to those at the equator.

A further-updated fourth version was produced under a collaborative agreement between ILRI and FAO. Version 4 provided global coverage: urban areas were defined by a combination of the GRUMP dataset (CIESIN, 2005) and the GLC 2000 urban class; irrigated areas were based on the FAO Aquastat map Version 4.0.1. (Siebert *et al.*, 2007).

Again, produced jointly between ILRI and FAO, Version 5 of the global livestock production systems map is now available for download from the Gridded Livestock of the World (GLW) web site[2]. These maps for the developing regions of the world are included in Appendices B to F of this book. In this version the GLC 2000 land cover base map has been replaced by the much more detailed and accurate Africover data sets[3] for countries in Eastern Africa where these are available (Burundi, Democratic Republic of Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda)[4]. Urban areas are defined by the GRUMP dataset (CIESIN, 2005). LGP and highland and temperate areas have been remodelled to 1 km spatial resolution (Thornton and Jones, 2010). The source of human population data remains the same (CIESIN, 2005) and for irrigated areas the same resource has been used (Siebert *et al.*, 2007) though the original 1 km data, which are not publicly available, have been incorporated to specify areas with more than 10 percent of irrigated area (these data are described in Siebert *et al.*, 2005).

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[2] http://www.fao.org/AG/AGAInfo/resources/en/glw/home.html

[3] http://www.africover.org

[4] In-house exercises have been made to integrate other regional land cover products that were developed with a methodology similar to Africover data, e.g. with the aggregate land cover of the Himalaya region developed under the Global Land Cover Network, www.glcn.org

The major versions of the classification, and the evolution of the datasets used to map it, are shown in Table 3.1.

Uses and limitations

The mapped global livestock production systems classification, in its various incarnations, has been used quite widely since it was first assembled. It was first applied in a global livestock and poverty mapping study designed to assist in targeting livestock research and development activities (Thornton *et al.*, 2002; 2003). In these studies, estimates of the numbers of poor livestock keepers by production system and region were derived and mapped. This information was then used by Perry *et al.* (2002), to identify priority research opportunities that could improve the livelihoods of the poor through better control of animal diseases in Africa and Asia. Possible changes in livestock systems and their implications have been assessed for West Africa (Kristjanson *et al.*, 2004). Given that the mapping scheme is based on data for which changes (climate, population and land cover) can be estimated with varying degrees of confidence, it has been possible to predict how the production systems may change in the future. In this context the methods have been used in studies to map climate vulnerability and poverty in sub-Saharan Africa in relation to projected climate change (Thornton *et al.*, 2006), to assess the spatial distribution of methane emissions from African domestic ruminants to 2030 (Herrero *et al.*, 2008), to investigate the role of agricultural science and technology on economic growth and poverty alleviation to the middle of the current century (Rosegrant *et al.*, 2009), and to assess the potential impact of changes in crop–livestock systems on agro-ecosystem services and human well-being (Herrero *et al.*, 2009). Some of these applications are described in more detail as case studies in the applications section below.

Even while the global livestock production systems maps have been used extensively, it is acknowledged that there are various uncertainties and weaknesses associated with them (e.g. Rosegrant *et al.*, 2009). By far the most problematic of these are the vagaries concerning land cover data, particularly related to cropland extent. Other major weaknesses include that the mixed systems categories are too general for many practical applications, and indeed the treatment of crops in the system is weak. In addition, the widespread 'other' class clearly reflects a limitation in interpreting unambiguously all land cover classes for their capacity to support livestock; the annexes in FAO (2007a) show that many livestock fall into this class. Only limited independent evaluation of the maps has been undertaken (one example is Cecchi *et al.*, 2010) and more work needs to be carried out to improve them. Even qualitative expert assessment, particularly for parts of Asia, Latin America and the developed world, would be useful.

For many purposes, maps based on the Seré and Steinfeld classification scheme may be either too complicated or not wholly appropriate. For example, both FAO and ILRI have made efforts to make distinctions between the different ways poor people might be able to benefit from agricultural or livestock development. In terms of understanding how livestock systems may evolve in the future in response to market forces and other drivers of change, as well as the opportunities afforded by the natural resource base, some discussions at ILRI have been framed in relation to a different set of systems. An example is in Perry *et al.* (2002), in which animal health researchable issues are assessed in relation to three pathways out of poverty for livestock keepers: securing the assets on which they depend, reducing constraints to productivity enhancement, and improving market opportunities. Another example is Thornton *et al.* (2007), in identifying three types of livestock system associated with very different issues:

- Agropastoral and pastoral systems in which natural resources are constrained and people and their animals adopt adaptation strategies to meet these constraints.

- Smallholder crop–livestock systems in which natural resources can be managed to intensify the productivity of the system.
- Industrial livestock systems, which are highly intensive and tend not to be so tied to the local natural resource base as are the agropastoral and smallholder mixed systems.

Similarly, work done within FAO has been framed in relation to other types of breakdown of potential target beneficiaries. The idea of livestock intervention domains was a central element of the Pro-Poor Livestock Policy Initiative (PPLPI)[5]. The initiative recognized three intervention domains with respect to livestock keepers and the livestock sector, each requiring different types of policy intervention: reducing vulnerability, creating conditions for growth, and coping with growth. Attempts have been made (e.g. Dijkman in FAO, 2006a) to map these domains using factors such as agricultural suitability, market access and economic potential.

Other work ongoing at FAO takes a socio-economic approach to livestock production systems mapping (reviewed below). Rather than using the environmental data that the global livestock production systems classification mapping is based on, this draws on data collected in the context of livelihood analysis (Cecchi *et al.*, 2010). While the Horn of Africa was relatively well represented by these types of survey, global coverage could not be achieved through this approach.

The mapped global livestock production systems classification is a useful starting point and baseline, but there are clear demands for more information or different system cuts (which could be made in many different ways, if more detail were available about the systems being investigated). Issues such as how intensified systems are, whether there is potential for intensification, and what the scale of production of commodities is in particular places, are all examples of valid questions that the classification scheme needs to move towards being able to answer. This is an important justification for increasing the level of detail in the classification system, which is discussed in the sections below.

ACCURACY OF GLOBAL LAND COVER MAPS: IMPLICATIONS FOR MAPPING LIVESTOCK PRODUCTION SYSTEMS

In order to define livestock systems on a global scale, accurate information on the spatial distribution of different land cover types, in particular cropland and grassland, is essential. Global land cover is derived through the classification of satellite images integrated with ground-based data collection. The use of remote sensing technologies for applications such as land cover is desirable for a number of reasons:

- There are low marginal costs involved.
- They provide higher levels of spatial resolution and sampling frequency than alternative approaches.
- They are the only feasible data gathering mechanism in some locations.
- They provide precise, automated repetition of data collection efforts.
- They can be combined with ground-based data to generate value-added products that can be of great value for decision-making in agriculture.

Global land cover maps represent important sources of baseline information to a wide variety of users: the UN Millennium Ecosystem Assessment (MEA, 2005), the Interim Secretariat for the Convention on Biological Diversity (ISCBD, 1994) and the Global Environmental Outlook Project (UNEP, 2002), to name a few. In the area of climate change modelling, global land cover has been used to verify the predictions from global circulation models where a dynamic vegetation component has been added (Foley *et al.*, 1998). Global models of land use also use remotely sensed land cover maps as inputs: for example, to determine how much land is available for the expansion of agriculture, or to evaluate whether 'Reducing Emissions from Deforestation and Forest Degradation in

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[5] http://www.fao.org/ag/againfo/programmes/en/pplpi/home.html

Developing Countries' is a more cost-effective mitigation option than carbon capture and sequestration. Accurate spatial information on cropland is particularly important for crop monitoring and food security, and satellite-derived land cover datasets have been widely used for this purpose. However, a detailed comparison of different land cover datasets reveals there to be considerable disagreement between them (Fritz and See, 2005; Giri *et al.*, 2005; Jung *et al.*, 2006). These inconsistencies are particularly high for cultivated land (cropland and managed pasture) compared with other vegetation types such as tree cover (Wood *et al.*, 2000). Because of the lack of consistent and reliable data on the location, area and intensity of cultivation from other sources, global land cover datasets are central to the mapping of livestock production systems. This section outlines the most current global land cover datasets available and the methods that have been used to compare the different products in the cropland domain.

Global land cover datasets

A number of global, remotely-sensed datasets has emerged over the last 20 years. The first sensor from which land cover datasets were produced was the Advanced Very High Resolution Radiometer (AVHRR), with a spatial resolution of around 1 km at the Equator. Data from the AVHRR sensor led to the production of the International Global Biosphere Project (IGBP) land cover dataset (Loveland and Belward, 1997), the Global Land Cover characterization dataset (USGS, 2008) and the University of Maryland global land cover products based on AVHRR (Hansen *et al.*, 2000) and the Moderate Resolution Imaging Spectroradiometer (MODIS) (Hansen *et al.*, 2005). The more recent sensors – with increased geometric accuracy and higher resolution – include the Satellite Pour l'Observation de la Terre (SPOT) vegetation sensor from which the GLC 2000 land cover product was produced, the MODIS sensor from which the MODIS land cover and several other products, such as the Vegetation Continuous Field (Hansen *et al.*, 2003; 2006), have been produced, and the European Medium Resolution Imaging Spectrometer (MERIS) sensor, which has led to the production of GlobCover 2005 and GlobCover 2009 (Bicheron *et al.*, 2008). However, to date there is no single satisfactory global land cover product available, and uncertainty in the cropland domain remains high. The most recent products are discussed briefly below.

GLC 2000

The GLC 2000 was developed by the Joint Research Centre for the baseline year 2000, which is a reference year for environmental assessment. The product was created using 14 months of pre-processed daily global data at a spatial resolution of 1 km, acquired by the VEGETATION instrument on board the SPOT 4 satellite. A bottom-up approach to product development was undertaken in which more than 30 research teams around the world contributed to 19 regional windows (Bartholomé and Belward, 2005). The regional legends were derived from the LCCS as a common framework to produce 22 global classes (FAO, 1998; 2005).

MODIS

The MODIS land cover product was created by Boston University using the MODIS instrument on the National Aeronautics and Space Administration Terra Platform using data from the year 2005. Several different products have been created from this sensor, including land cover, a radiation budget and ecosystem variables (Morisette *et al.*, 2002). The land cover product (MOD12Q1) was produced at a resolution of 500 metres and uses information from a number of other MODIS products. The MODIS land cover data set uses all 17 classes of the IGBP legend (Loveland and Belward, 1997) and was created using a global classification approach. The MODIS land cover classification algorithm (MLCCA) uses a supervised classification methodology based on a globally distributed set of training sites. One of the key features of the MLCCA algorithm is a technique known as 'boosting', which allows robust assignments of pixel probabilities (Friedl *et al.*, 2010). Version 5 of the MODIS land cover data set (MOD12Q1 V005) is now available, where the classification algorithm has continued to be developed and improved since 2005.

GlobCover 2005 and 2009

GlobCover is a European Space Agency initiative to develop a service to produce a global land cover map for 2005/6, using 300 metre resolution data acquired by the MERIS sensor on board the ENVISAT satellite (Bicheron *et al.*, 2008). This new product is intended to update and to complement the other existing comparable global products – GLC 2000 in particular – and to improve on their spatial resolution. GlobCover 2009 was released in December 2010.

Comparison of global land cover datasets

In order to compare two global land cover datasets, their respective legends and the specific definitions associated with each legend class must first be reconciled. Various approaches have been developed to achieve this. Fritz and See (2005) created a look-up table to indicate any occurrence of overlap in the definition of two classes in two different land cover data sets. This overlap was treated as 100 percent agreement when these two classes occurred for a given pixel. The remaining combinations of legend classes in the look-up table were considered as disagreement. To determine the degree of disagreement ranging from 0 to 1.0, experts were asked to indicate on a scale of 1 to 5 concerning how important it is to be able to distinguish between each pair of land cover classes for a given application. This importance matrix was then translated into a disagreement fuzzy set that was used to map the degree of disagreement spatially. Experts from different application areas were chosen (e.g. forestry, biomass and agriculture) in order to illustrate that the amount of disagreement can vary by application.

The approach taken by Fritz and See (2005) was a conservative one, because it assumed that any overlap in legend definition between two land cover products resulted in 100 percent agreement. In Fritz and See (2008), this analysis was modified to take into account differences in legend definitions. For example, for the GLC 2000 class 1 (tree cover, broadleaved, evergreen), the defining features are > 15 percent tree cover and tree height > 3 metres. For MODIS class 2 (evergreen broadleaf forest), the defining features are > 60 percent tree cover and tree height > 2 metres. An uncertainty value was calculated based on the amount of overlap in the definitions, which was then applied in the calculation of disagreement.

The disagreement between land cover types can be characterized in three ways: 1) measures of overall disagreement; 2) maps of spatial disagreement; and 3) comparison with FAO statistics at the national level.

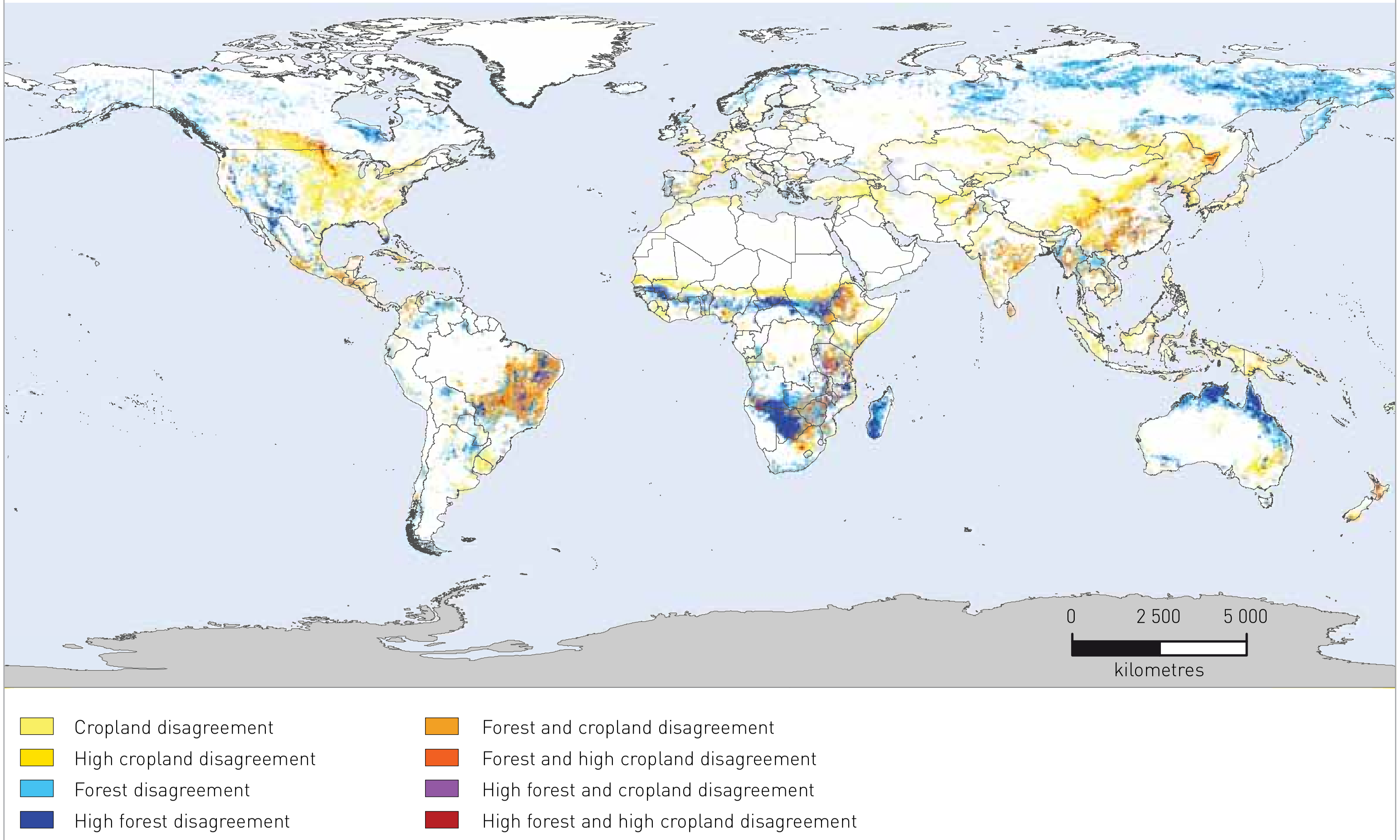
Overall disagreement

The total areas under cropland based on the GLC 2000, GlobCover and MODIS v.5, are 2 057 Mha, 1 642 Mha and 1 711 Mha, respectively. Table 3.2 shows the overall differences in Mha, including as a percentage of the FAO reference figures for 2005 between different pairs of land cover products in the cropland domain. Comparing the two most recent products, GlobCover and MODIS v.5, the disagreement is 506 MHa or 36 percent of the FAO arable land in 2005. These figures clearly illustrate significant differences between the three land cover products. Table 3.2 also shows the considerable disagreement for forest cover among these land cover products. While cropland is important in defining the mixed systems, forest is one of the main contributors to the 'other' class and is also used in suitability masking for livestock mapping; so it, too, has important implications for mapping livestock production systems.

Spatial disagreement

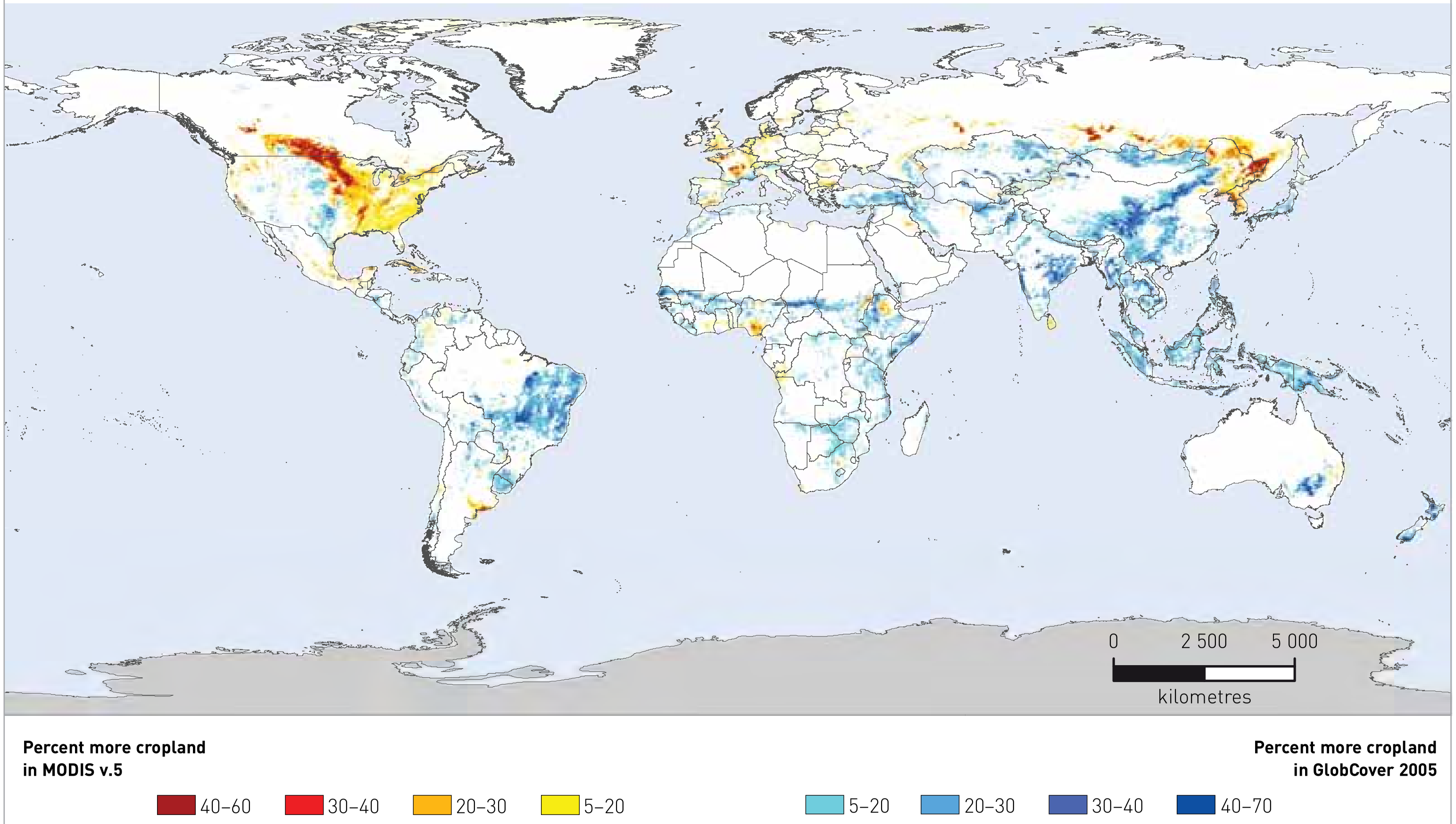
In addition to the global measures of correspondence among the classes, the disagreements can be visualized spatially. Figure 3.2 shows the global distribution of disagreement in the cropland and

3.2 OVERALL DISAGREEMENT AMONG MODIS V.5, GLOBCOVER AND GLC 2000 LAND COVER PRODUCTS IN THE FOREST AND CROPLAND DOMAINS



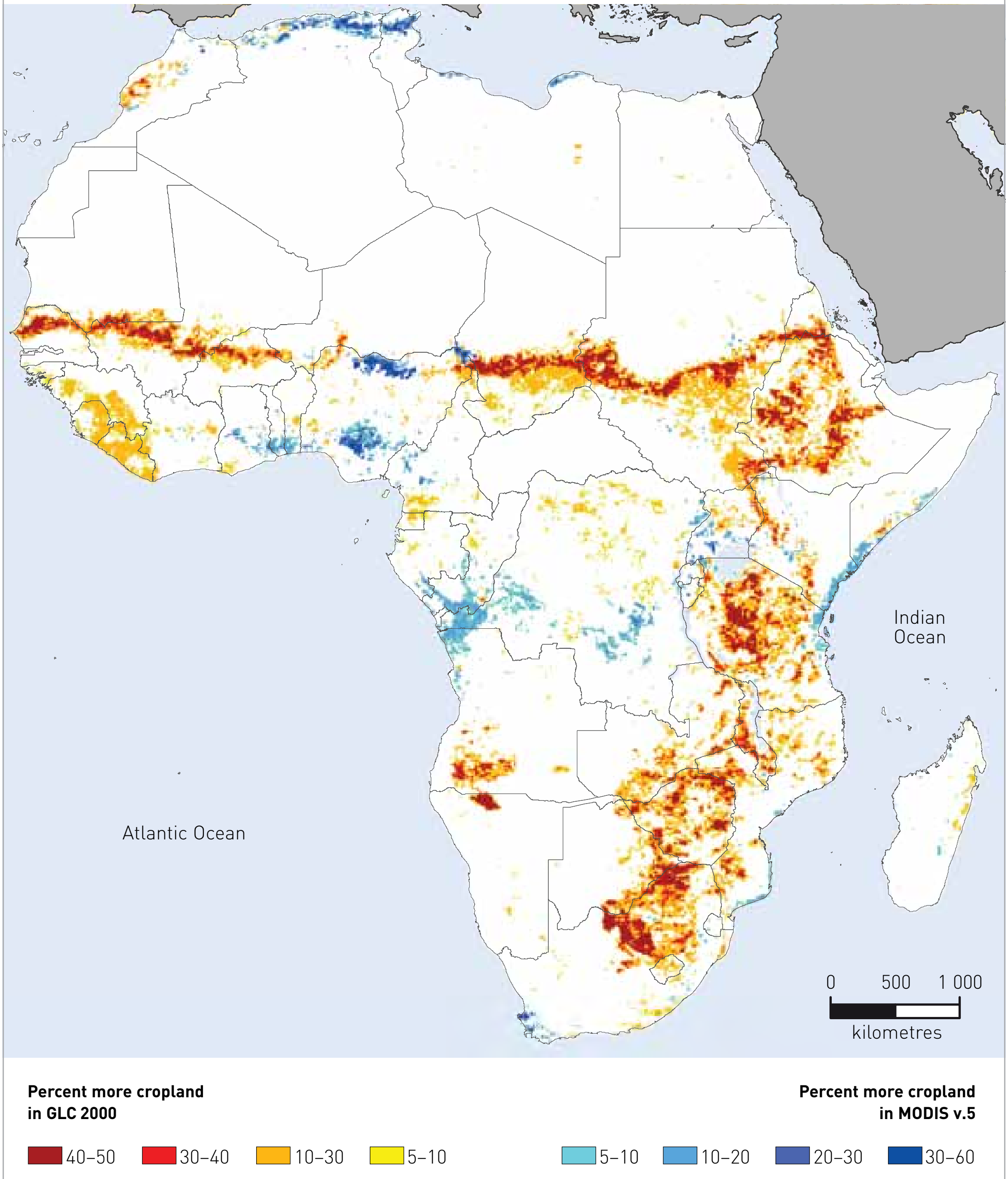
Source: adapted from http://www.geo-wiki.org.

3.3 GLOBAL DISAGREEMENT IN THE CROPLAND DOMAIN BETWEEN MODIS V.5 AND GLOBCOVER



Source: adapted from http://www.geo-wiki.org.

3.4 DISAGREEMENT IN THE CROPLAND DOMAIN BETWEEN GLC 2000 AND MODIS V.5 IN AFRICA



Source: adapted from http://www.geo-wiki.org.

TABLE 3.2 DISAGREEMENT BETWEEN MOST RECENT LAND COVER PRODUCTS IN THE DOMAINS OF FOREST AND CROPLAND

Disagreement between land cover products	Forest (Mha)	% relative to FAO	Cropland (Mha)	% relative to FAO
Overall disagreement GlobCover vs MODIS v.5	**387.2**	**9.5**	**505.9**	**36.3**
Present in GlobCover Absent in MODIS v.5	285.6	7.0	360.0	25.9
Present in MODIS v.5 Absent in GlobCover	101.7	2.5	145.8	10.5
Overall disagreement GLC 2000 vs GlobCover	**314.3**	**7.7**	**395.2**	**28.4**
Present in GLC 2000 Absent in GlobCover	167.8	4.1	162.3	11.7
Present in GlobCover Absent in GLC 2000	146.5	3.6	232.9	16.7
Overall disagreement GLC 2000 vs MODIS v.5	**730.8**	**18.0**	**325.8**	**23.4**
Present in MODIS v.5 Absent in GLC 2000	517.9	12.8	94.8	6.8
Present in GLC 2000 Absent in MODIS v.5	212.9	5.2	231.1	16.6

Source of FAO reference estimates: FAOSTAT data for 2005.

forest domains as well as their combined disagreement. It is clear that there are large differences in many regions of the world.

Extensive disagreement is particularly evident in northern African countries, at the transition between savannah and desert. These areas of disagreement warrant more detailed examination, but are likely to result partly from the complex landscapes in these areas and the prevalence of small-scale farming, which is difficult to map. Another reason for these discrepancies is the difficulty in distinguishing between cropland and natural or semi-natural grassland in those regions, resulting from the similarity of their spectral and temporal profiles. From the livestock production systems perspective, this represents the transition from pastoral through agropastoral to mixed farming systems; accurate mapping of land cover is therefore absolutely critical in order to delineate these systems accurately.

The full set of maps showing the disagreements between each pair of land cover products, and the combined disagreement for cropland and forest, can be found on the Geo-Wiki web site[6]. Geo-Wiki was developed by Fritz *et al.* (2009) as a way of encouraging public participation in the validation of land cover. Geo-Wiki also allows users to explore inconsistencies between remotely sensed data and FAO statistics, as described below.

Disagreement at the national level

The third method for examining disagreement is at the national level. Countrywide area comparisons for the cropland and forest domains are available on the Geo-Wiki web site. An example is shown in Figure 3.5 for cropland in Mali for the GLC 2000, GlobCover and MODIS v.5 land cover products, based on the minimum and maximum thresholds in their respective legend definitions. It is interest-

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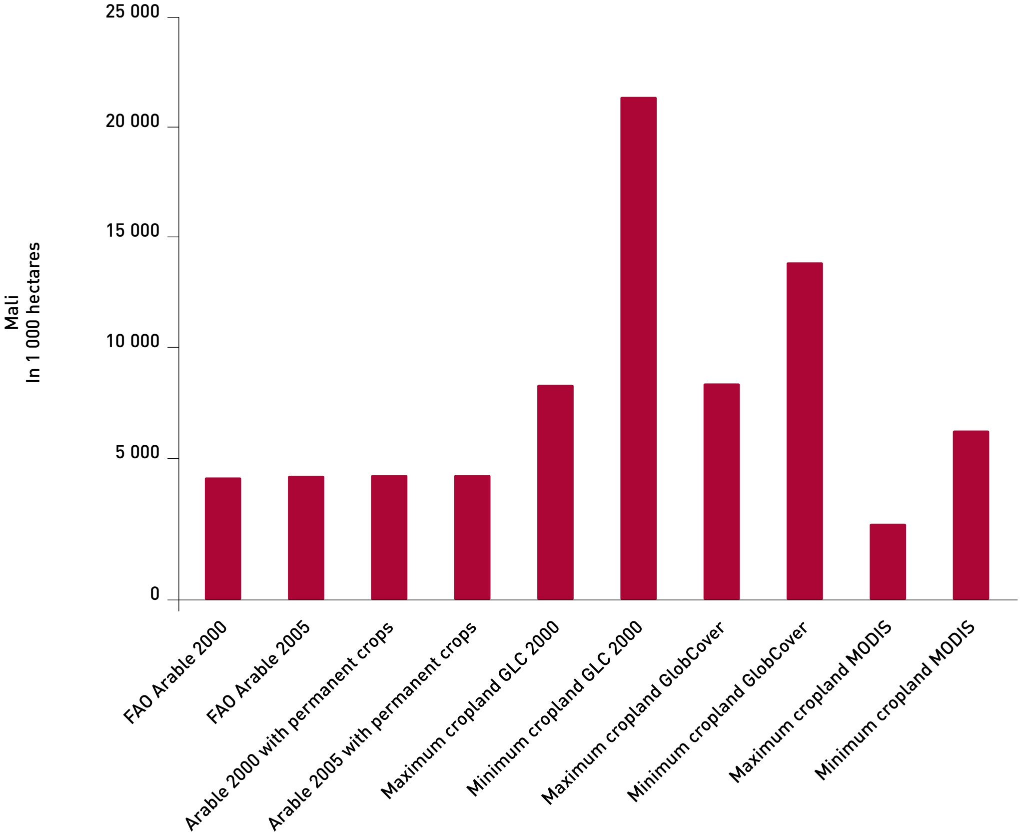
[6] Geo-Wiki: http://www.geo-wiki.org

ing that all land cover products (except the MODIS minimum) record higher cropland extents than those reported by FAO.

Possible future developments and solutions

More research needs to be directed towards finding ways to improve global land cover and to decrease the uncertainty in these datasets. One area for improvement is in the classification algorithms and methodologies used to create these products. The algorithms for creating MODIS products are continually being improved and used to reprocess MODIS data retrospectively. Other initiatives have involved improvements in the resolution of the global land cover products, for example the 300 metre spatial resolution of GlobCover as compared with the 1 km resolution for GLC 2000. However, as shown in Table 3.2, improving spatial resolution alone is clearly not a solution to this problem. This point is absolutely critical, given proposals for the Group on Earth Observations to coordinate the development of a 30 metre global land cover product, announced at the recent geo-ministerial summit in Beijing (US Department of the Interior, 2010). The big issue is to find ways to tackle the lack of sufficient ground data for the calibration and validation of these products. This task is now increasingly discussed by the Committee on Earth

3.5 COMPARISON OF FAO STATISTICS WITH THE GLC 2000, GLOBCOVER AND MODIS V.5 FOR MALI



Source: adapted from http://www.geo-wiki.org.

Observation Satellites, land cover validation and calibration subgroup, which advocates the collection of more 'authorized' hard validation data[7]. On the other hand, the soft validation data collected via crowd-sourcing and web 2.0/3.0 technologies can play a vital role in gathering a vast quantity of validation data quickly and at low cost. Bottom-up initiatives such as Geo-Wiki (Fritz *et al.*, 2009) may provide a short-term solution (Macauley and Sedjo, 2010). This online tool has already resulted in the accumulation of more than 12 000 validation points from around the world, which can be downloaded by any individual or institution for their own calibration/validation purposes. The ultimate goal of Geo-Wiki is the collection of high quality validation data distributed over different ecosystems which can be used in the future for the validation and calibration of products derived from remotely-sensed data, and the production of more accurate, hybrid land cover products. Fritz *et al.* (2011) have shown how five different land cover products can be integrated into a hybrid cropland map for Africa that is more accurate than any of the individual products. More efforts need to be channelled into developing algorithms for creating hybrid products in the future, given the importance of this layer in mapping agricultural production systems.

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[7] See details at: http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=75&Itemid=116