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Global change of land use systems

IMAGE: a new land allocation module

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Global change of land use systems

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Abstract
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The Integrated Model to Assess the Global Environment (IMAGE) aims at assessing the state of the environment taking into account the effects of human activities. Although human population often makes use of a land area to satisfy various needs, most of the current global land use datasets and models use a classification based on dominant land use/cover types disregarding the diversity and intensity of human activities. In this working document we investigate if the simulation of land use change and the IMAGE outcomes can be improved by using a classification based on land use systems. An expert based cluster analysis was used to identify and map land use systems. The analysis accounted for population density, accessibility, land use / cover types and livestock and provided a new insight on human interactions with the environment. Then, a conceptual framework was developed and implemented to simulate land use systems changes based on local conditions and demand for agricultural products and accounting for land management changes.

Key words: Land use, land use change, land management change, land use systems, global, IMAGE, cluster analysis, binary logistic regression.

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LUS; Land allocation module

Contents

Summary

The world population is growing, people are migrating, trades in goods and services are evolving and globalizing. Besides, humans use and change their environment to fulfill their various needs in goods and services. Thus, the Integrated Model to Assess the Global Environment (IMAGE) is a tool developed to assess the state of the global environment taking into account the effects of human activities and their environmental impacts. Human population often makes use of a land area not only in a single purpose but to satisfy various needs: housing, food, feed, energy production, etc. Nonetheless, most of the current global land use datasets and spatially explicit land use models (including IMAGE version 2.4) use a classification based on dominant land use/cover types disregarding the complexity and the diversity and intensity of human activities actually going on.

In this working document we investigate if the simulation of global land use change and the outcomes of IMAGE in particular, can be improved by using a different classification scheme which considers a land area as a functional unit aiming at satisfying a single or multiple human needs. The chosen approach is to represent land use globally as Land Use Systems (LUS) defined as distinct landscape patterns of human interactions with the environment and the land in particular. Thus, land use systems were identified and mapped using an expert based cluster analysis. The cluster analysis accounted for population density, accessibility, land use/cover types and livestock providing a new insight on human interactions with the environment. Then, a conceptual framework has been developed and implemented to simulate land use systems changes land management changes based local demographic, economical and environmental conditions as well as on the demand for agricultural products.

1 Introduction

Human populations use, transform and alter the environment in order to satisfy various needs such as housing, transportation, food, livestock feedstuffs and energy. Land cover and land use change (LUCC) is a human activity contributing to many components of global environmental change through the conversion of natural areas into agricultural or urban areas and the modification of land management practices (Ojima, Galvin *et al.*, 1994; Turner, Meyer *et al.*, 1994; Vitousek, Mooney *et al.*, 1997). Thus, land use is a major interface between socio-economical and environmental processes.

Since many years, research initiatives have been undertaken to simulate land use change over time and at different scales, with different time horizons, and intended applications (overviews are given in Baker, 1989; Sklar, 1991; Verburg, Overmars *et al.*, 2004; Matthews, Gilbert et al., 2007; Priess and Schaldach, 2008). In spite of the wide variety of land use change models at the scale of small regions to countries, a limited number of models are available at global scale (MNP 2006, Lotze-Campen, Muller *et al.*, 2008). Global scale land use models are urgently needed to feed all kinds of environmental impact assessment such as climate change models (IPCC, 2007), biodiversity assessments (GLOBIO 3) (Alkemade, van Oorschot *et al.*, 2009) and/or integrated assessment of the state of the environment such as the Millennium Assessment (MEA, 2005) and the Global Environment Outlook (UNEP, 2007). A consequence of the limited number of land use models available at global scale is that most assessments rely on land use simulations as made by the model IMAGE. The IMAGE land allocation module was developed in 1994 based on a series of expert-based decision rules that globally allocate projected land cover types to a grid at 0.5 degrees resolution (Zuidema, Van Den Born *et al.*, 1994). Although critics have been made on the modeling approach (Veldkamp, Zuidema *et al.*, 1996), no alternative for global land use modeling was yet developed. This paper aims at presenting a new approach for global scale land use modeling that takes stock of the developments in land use observation techniques and modeling methods over the last two decades.

Most global LUCC models represent land use on a grid, allocating a single land cover type in each cell (e.g. CLUE (Verburg, Soepboer *et al.*, 2002), GEOMOD (Pontius, Cornell *et al.*, 2001), FORE-SCE (Sohl and Sayler, 2008). However, the spatial resolution of these models is not sufficient to represent land use as homogenously covered areas. Indeed, the simultaneous analysis of most global land cover and land use datasets has a limited spatial resolution of 5 arc-minutes (i.e. ~100 km^2 at the Equator). Consequently, these models use a classification based on the dominant land cover type and disregard the landscape heterogeneity in a considered area. Nonetheless, a grid-cell of 100 km^2 mainly covered by croplands may also contain significant urban areas or forests. Also in this case, the cell will be classified as croplands, even though the environmental and socio-economic conditions as well as the trends of change over time in such an area most likely differ strongly from a homogenous agricultural area. Landscape heterogeneity is an important issue for land use change modeling since different land use types in a considered area are interacting and interdependent. Built-up areas are necessary for housing but decrease land availability for agricultural production and natural areas (Dewan and Yamaguchi, 2009). Cultivated areas are necessary to produce food for humans and livestock (Bouwman, Van Der Hoek *et al.*, 2005; van de Steeg, Verburg *et al.*, 2009), and pastures are required for grazing of bovines and small ruminants. In many cases the different land use components found within a landscape or pixel will be interconnected, thus, changes in land use will not affect a single land use type but multiple land use components at the same time due to strong competition and interactions among land use types. The representation of land use by the dominant land cover at the spatial resolution currently used in global modeling (minimally 0.5 degrees) is therefore insufficient and a representation accounting for the variation within the minimal spatial units would strongly improve land use modeling, even at higher resolutions. Landscape heterogeneity and mixed pixels are a well known issue for the classification of satellite images and un-mixing techniques have been developed within the remote-sensing community with the intent to provide land cover composition at the sub-pixel level (Settle and Drake, 1993; Foody and Cox, 1994; Defries, Hansen *et al.*, 2000).

Apart from changes in land cover, land use intensification is an important aspect of land use dynamics because changes in land management have important impacts on the environment and human well-being (Duvernoy, 2000; Ellis and Ramankutty, 2008). Nonetheless, most global LUCC models focus on the land cover but barely differentiate land use types and do not account for land management related to the intensity of use of land to produce land-based commodities. In practice, land cover and biophysical datasets, retrieved through remote sensing, are spatially-explicit, easily accessible and readily usable. On the other hand, global datasets on land management (e.g. fertilizer use, irrigation, agricultural labor force) or related to the socio-economical context are not spatially-explicit. Socio-economic data are often retrieved through census aggregated at administrative or country level. Thus, the discrepancy between remote-sensing and census datasets makes it difficult to relate the land cover with land use and more particularly land management. A number of methods have been developed to couple remote-sensing and census data in order to provide spatially continuous socio-economic and land management global datasets. These datasets such as areas covered by croplands, irrigated areas or densities of population and livestock, provide better insight on the relation between land cover and land use (Bhaduri, Minner *et al.*, 2001; Siebert, Doll *et al.*, 2005; Monfreda, Ramankutty *et al.*, 2008; Ramankutty, Evan *et al.*, 2008). However, in all cases these datasets refer to specific aspects of the land use system and disregard the interaction between the different elements of land use within farms and landscapes.

Various studies have shown that, at global scale, LUCC dynamics and land use intensity changes are driven by a wide range of drivers operating over multiple spatial scales. The macro-economic demand in land-based commodities induces land cover and land use intensity changes which are constrained locally by the environmental, societal and spatial contexts.

Globally or regionally, the macro-economic demand for various agricultural commodities (e.g. wood products, crops, meat and dairy products) drives the expansion of cultivated and grazing areas, as well as their intensification in order to meet production requirements (van Meijl, van Rheenen *et al.*, 2006). Furthermore, the economic context, such as the Gross Domestic Product (GDP) or Parity Purchase Power (PPP), influences the macro-economic dynamics of agricultural commodities as it has been observed that increasing incomes induce an increase in food consumption per capita and a diversification of the diet composition and (Sanderson, 1988). Locally, the potential use of a land is not only determined by biophysical conditions (e.g. topography, soil, climate, land quality, water availability), but is also influenced by the socio-economic and spatial contexts (i.e. accessibility). Population density is considered an important indicator of the intensity and the type of use made from a land area by human population (Boserup, 1981; Smil, 1991; Netting 1993). Besides, the development and intensification of land-based activities such as cropping, livestock breeding or forestry depend on local economic and spatial contexts i.e. accessibility to market places (Staal, Baltenweck *et al.*, 2002; Verburg, Overmars *et al.*, 2004; van Meijl, van Rheenen *et al.*, 2006), land availability and prices as well as agricultural labor force and available capital for technological investment. In addition, livestock forms and density are an important factor to account for

LUCC modeling as most of croplands expansions are induced to increase feedstuffs production for livestock (Mertens, Sunderlin *et al.*, 2000; Bouwman, Van Der Hoek *et al.*, 2005; van de Steeg, Verburg *et al.*, 2009). Different disciplines and methods are used to address these issues operating at different scales without strongly connecting the analysis across scales (Verburg, Eickhout *et al.*, 2008).

This working document proposes a new conceptual framework to simulate land use dynamics which account for multi-scale drivers, landscape heterogeneity and land use intensification. Based on a systematic approach, comparable to the approach used by Ellis and Ramankutty, 2008 to derive anthropogenic biomes, land use is described as a system of human populations using and structuring the environment. These systems are called Land use systems and their classification will take into account the land cover composition of landscapes, the human population and livestock densities as well as the spatial context (i.e. the accessibility to market places). This new approach is intended to improve spatially-explicit modeling of land use changes by linking its processes to changes in human pressures and interactions with the environment. Moreover, land use systems are expected to better account for the competition and interactions among land use types at the local scale. In addition, this approach will enable to account for land use intensification within cultivated and pastoral areas as part of land use change processes. Finally, the developed land use systems allocation model is expected to better benefit integrative assessment of human impacts on the environment such as IMAGE, by strengthening the link between land use and environmental state indicators such as habitat fragmentation, nitrogen leaching or land carrying capacity.

2 Land use change: conceptual framework

2.1 The IMAGE model and the land allocation module

The IMAGE model aims at assessing the current and future state of the environment accounting for interactions and reciprocal effects between human population and the environment. Issues related to global human-environment interactions are multidisciplinary, thus IMAGE is a model integrating various sub-models specialized on different aspects of these interactions. Figure 1 shows the relevant sub-models for the socio-economic system as well as the Earth system and how they are linked in the framework of IMAGE. Population growth is simulated by the demographic sub-model PHOENIX Hilderink, 2000 which provides population input to the land allocation module. Besides, the Global Trade Analysis Project (GTAP) simulates the macro-economic demand in agricultural goods (Hertel, 1997).

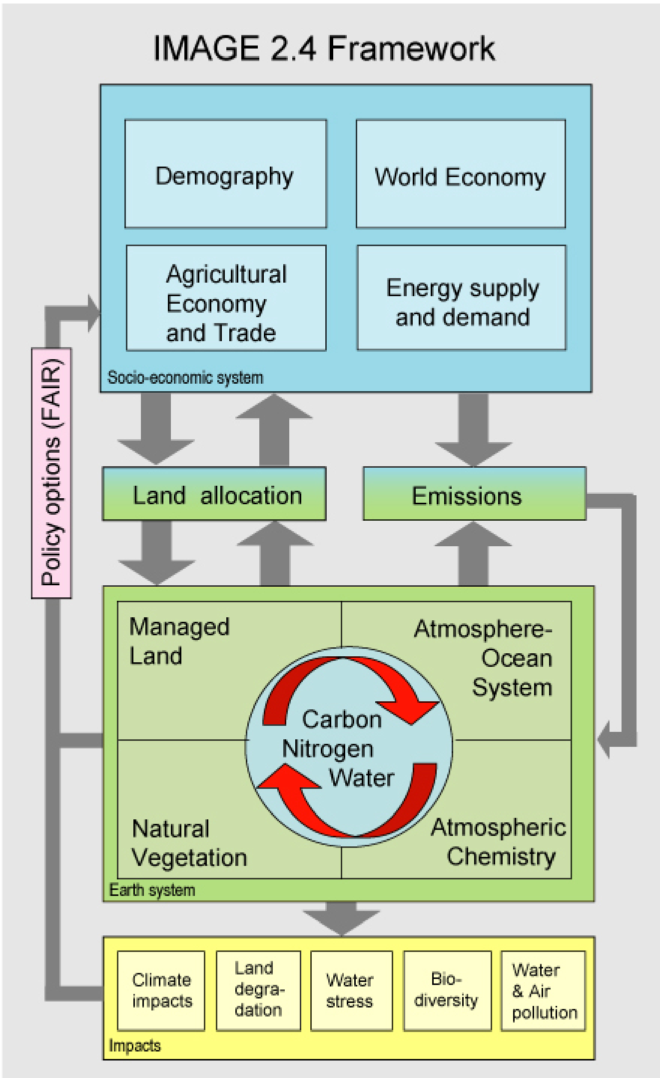

Figure 1 IMAGE 2.4: structure of the sub-models integration (after IMAGE website).

GTAP determines the demand in agricultural goods based on a simulation of global trade, market prices, land supply curves and accounts for policies, climate change and crop yields. Concerning the Earth system, the simple IMAGE climate model and a downscaling method provides climatic inputs to the land allocation module and the rest of IMAGE (Strengers *et al.*, 2006). The outputs of the land allocation module are used as inputs to other IMAGE sub-models. GTAP uses the current areas of each land use types (i.e. bare soils, tree cover, croplands, pastures and urban) to compute regionally the land supply curves for the next time-step. Additionally, the land allocation outputs are used as inputs by the Terrestrial Carbon Model (TCM), the Land use Emissions Model (LUEM) and the Land Degradation Model (LDM) to determine various environmental impacts. It also illustrates how land use (the land allocation model) is at the interface between human activities (socio-economic system) and the environment (Earth system).

2.2 Drivers of land use change

Over the last two decades, various studies have shown that land use changes are driven by a range of drivers operating over multiple spatial scales. Agricultural economy and policies influence the expansion and intensification of agricultural lands but local demographic and environmental context can explain land use patterns deviating from economical incentives (van de Steeg, Verburg *et al.*, 2009). Land use is defined as the total arrangement, activities and inputs that people undertake in a certain land cover type (FAO and UNEP, 1999), hence, considering land use dynamics, two major land use change processes need to be taken into account: land cover changes and land management changes. The latter cannot be captured by remote-sensing survey and its prevailing drivers are socio-economic factors and policies influencing decision-making in land management (Lambin, Rounsevell *et al.*, 2000). In this study, land management change is considered as changes in croplands yields, grazing intensities and land-less livestock densities.

Agricultural economy

Apart from cultural factors, the human demand in land-based commodities (crops, meat and dairy products) is influenced by the economic context which may be represented by the Gross Domestic Product (GDP) or Parity Purchase Power (PPP). Increasing incomes induce an increase in food consumption per capita and a diversification of the diet composition (Sanderson, 1988). For instance, industrialized countries populations, having higher GDP, tend to have diversified diet with higher meat consumption and a variety of vegetables. The population demand in agricultural commodities can be met either by expanding or abandoning croplands and pastoral areas or by adapting crop yields and livestock density. In addition, increasing demand in meat and dairy products has an influence not only on pastoral areas but also on croplands as most of their expansion occurs to meet the demand in livestock feedstuff (Mertens, Sunderlin *et al.*, 2000; Bouwman, Van Der Hoek *et al.*, 2005; van de Steeg, Verburg *et al.*, 2009). Thus, at the global scale, dynamics of agricultural economy induces changes in land cover and management of agricultural lands i.e. croplands and pastures.

Local demography and biophysical conditions

Often land use changes are constrained and specific to the local context (Lambin, Rounsevell *et al.*, 2000). Climate and soil characteristics determines the suitability of a land for agricultural use or specific crops (Wolf, Bindraban *et al.*, 2003). Besides, increase in population density causes urban sprawling, reducing land availability for agricultural production; traditional subsistence agriculture cannot support population denser than 2500 inhabitants/km^2 (Smil, 1991; Dewan and Yamaguchi, 2009). Even though land use patterns and their dynamics cannot be explained solely by population density (Lambin, Turner *et al.*, 2001), it is a proxy for agricultural labor force and is considered a relevant indicator of the intensity and the type of use made from a land area by human population (Boserup, 1981; Smil, 1991). In addition, the economic and spatial contexts (i.e. accessibility) also influence the potential use of a land as well as its related intensity (Lambin, Rounsevell *et al.*, 2000).

Purchasing Power Parity (PPP) or Gross Domestic Product (GDP) per capita is a relevant proxy to determine the capital available to invest in the expansion and intensification of agricultural lands. Besides, Staal, Baltenweck *et al.*, 2002 and Verburg, Overmars *et al.*, 2004 showed that distance to market places can influence choices in agricultural technology and consequently potential development of agricultural activities as well as changes in land use intensity. In this study, market place is defined as a location where land-based commodities can be traded or exported such as major urban agglomerations and large maritime ports.

2.3 Land use systems: rationale

Human populations shape the landscape and use the land to satisfy various needs. Landscapes often cover large areas and cannot easily be represented by their dominant land cover. The spatial units used in this study cover an area of approximately 100 km^2 (i.e. a grid-cell area) that will be composed of a mosaic of land cover and land use types. Different land use components found in heterogeneous landscapes are interdependent. Built-up areas are necessary for housing but decrease land availability for agricultural production and natural areas (Dewan and Yamaguchi, 2009). Cultivated areas are necessary to produce food for humans and livestock (Bouwman, Van Der Hoek *et al.*, 2005; van de Steeg, Verburg *et al.*, 2009), and pastures are required for grazing of bovines and small ruminants. Thus, changes in global agricultural trade and/or demographic, economic and biophysical local conditions affecting a single land use type may indirectly affect multiple landscape components due to strong competition and interactions among land use types. Nonetheless, land use cannot be solely described by the landscape composition nor its dynamics solely based on land cover changes. Land use is defined as the human activities, and inputs, undertaken in a certain land cover type (FAO and UNEP, 1999) and land use description must consider human aspects of the landscape in order to provide insight on human interactions with the environment and more particularly land use intensity.

The chosen approach is to represent land use as Land use Systems (LUS) with spatial units of 10 by 10 km at global scale. Densities of human populations and livestock as well as the travel time to the nearest market place should be accounted for during the identification and classification of LUS (Figure 2).

Thus, LUS can be defined as distinct landscape patterns of human interactions with the environment. In this framework, land use change processes are simulated by trajectories of LUS change.

2.4 Model set-up

Multiple external models are used to generate projections of land use driving factors; climatic and demographic drivers as well as simulated macro-economic demands for land-based commodities. These demands result from changing consumption patterns, trade between world regions, policies and supply cost. These projections are used to induce changes in LUS patterns.

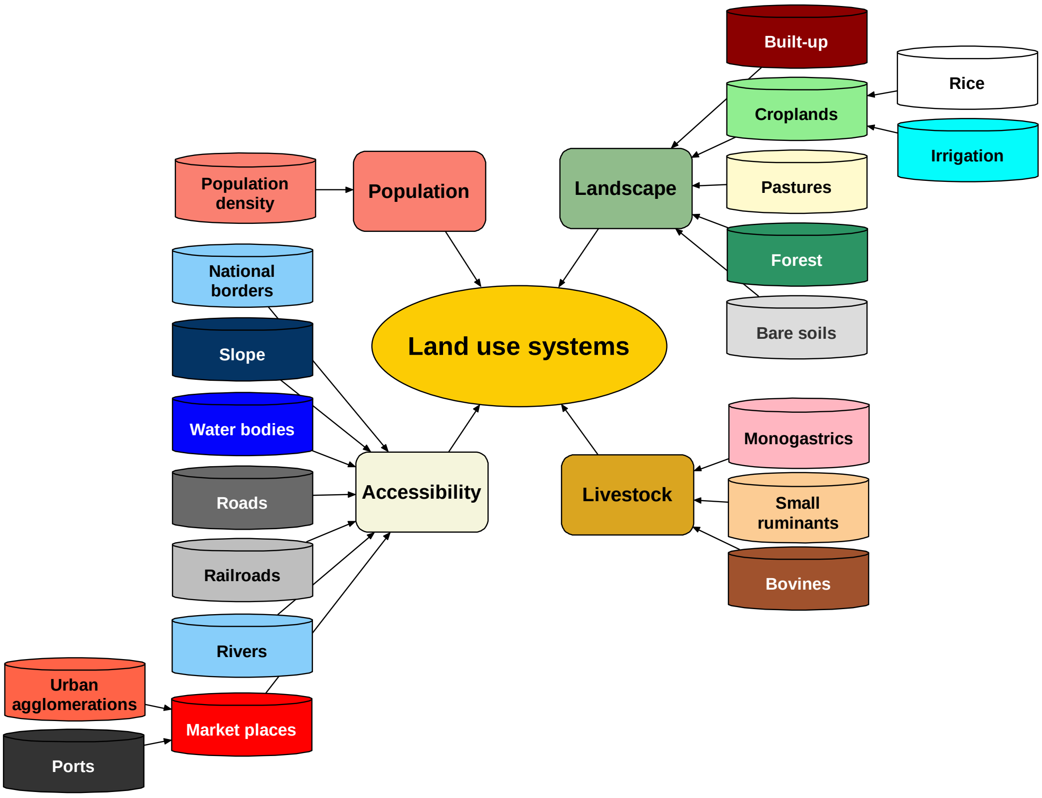

Figure 2 Variables used to identify land use systems.

The Phoenix model (Hilderink, 2000) provides population growth projections and the IMAGE climate module provides future estimates of climatic conditions. In addition, the Global Trade Analysis Project (GTAP) (Hertel, 1997) model is coupled to IMAGE model (van Meijl, van Rheenen *et al.*, 2006) to simulate macro-economic demand in land-based commodities. The coupled models GTAP-IMAGE accounts for policies and agricultural trade among world regions as well as climate change and crop yields. The projected macro-economic demands at the regional level are expressed as the cultivated land areas and yields necessary to reach croplands production requirements. Besides, economic demand in animal product are also accounted for and expressed as the change in livestock densities. Based on these drivers' inputs, the model simulates four important processes of LUS change.

First, adaptive land use changes that result of changes in local conditions are allocated. Such changes are not economically driven but are necessary land use adaptations induced by local population and environmental changes. Adaptive land use changes are related to land use change processes such as urbanization due to population increase or landscape changes caused by environmental changes such as desertification or land degradation. Therefore they are the first to be allocated. During a second step, LUS conversions induced by projected demands in land-based commodities are allocated accordingly. Changes in global economy induce LUS changes related to changes in areas and land management of croplands and pastures and, therefore, imply land use change processes such as deforestation, land abandonment, irrigation or intensification of livestock systems. This model set-up explicitly relates land use change processes to their specific drivers where land use change induced by economical incentives are locally constrained by the biophysical and demographic conditions which effects on land use are allocated in the first step (Figure 3).

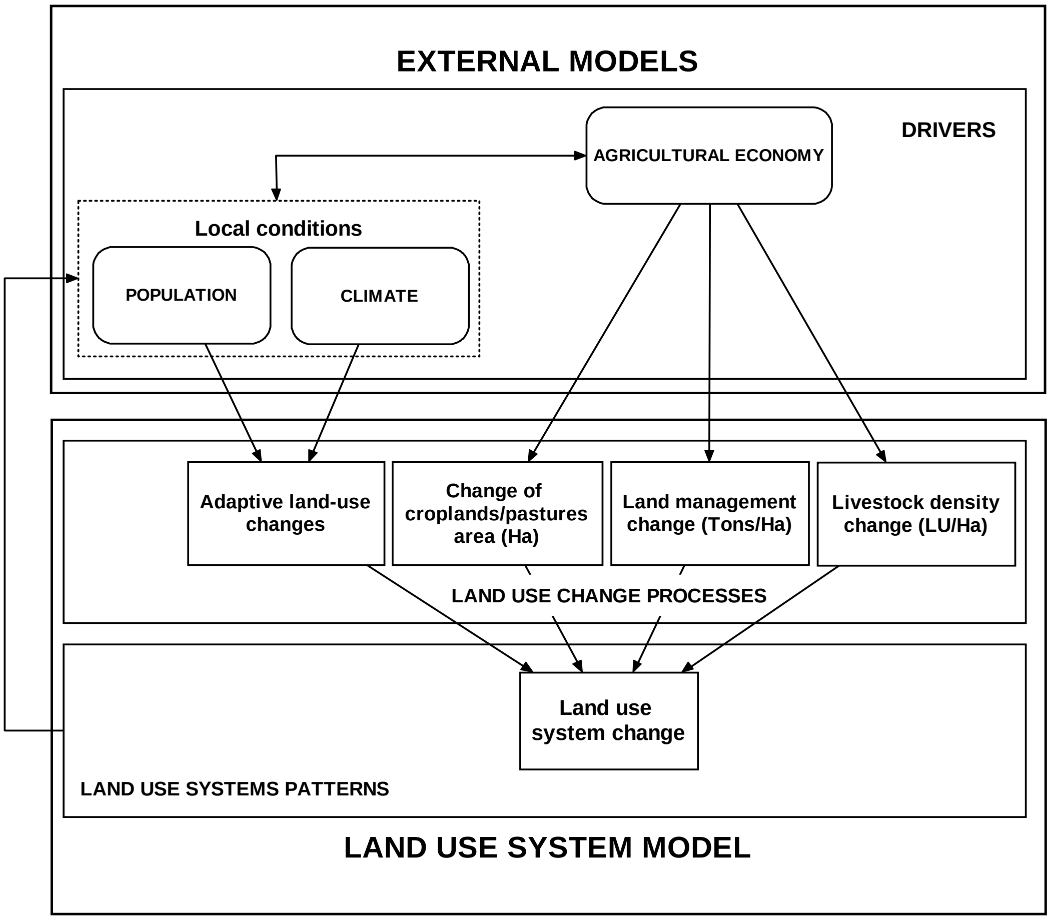

Figure 3 Model setup and representation of the interactions among population, climate, land use and global agricultural economy

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3 Classification and spatial analysis of land use systems

In this chapter the method applied to classify land use systems is described in detail. LUS have been identified globally by cluster analysis accounting for multiple factors listed in Figure 2. Then, the average land use intensity per LUS was derived based on potential croplands productivity. Furthermore, a spatial analysis of land use patterns has been carried out in order to determine the relation between multiple socio-economic and biophysical factors and the occurrence of each LUS as well as presence of large croplands and pastoral areas, highly productive croplands and intensive livestock breeding.

3.1 Input data for the classification and spatial analysis of LUS

As described in Figure 2, LUS were classified accounting for multiple aspects of a grid-cell. Global gridded population density datasets were obtained from LandScan (Dobson, Bright *et al.*, 2000) at 5 arc-minute resolution. The accessibility i.e. the travel time to the nearest market place was computed at 1 km^2 resolution and then resampled to 5 arc-minutes. Major urban agglomerations with at least 750,000 inhabitants and large maritime ports were identified as relevant market places. These destinations were located by the map of capitals and urban agglomerations over 750,000 inhabitants provided by UNEP global dataset and the global maritime port database created by General Dynamics Advanced Information Systems. It was assumed that travel time was facilitated by the transportation networks (roads, railways and navigable rivers). On another hand, national borders, cells with no transportation network, steep slopes, inland water bodies and wetlands (retrieved from the Global Lakes and Wetlands Database (Lehner and Döll, 2004) were considered to increase the travel time. Thus, different speeds were attributed to the cells according to the occurrence of transportation facilities and obstacles (see Annex 4 for detailed allocated speed). The slope was derived from the altitude dataset available from Worldclim datasets providing the average elevation of each grid cell (Hijmans, Cameron et al., 2005). The data on the roads, railroads and river networks were gathered from the ESRI Digital Chart of the World (DCW) released in 1992 (USA/DMA, 1992).

Then, a friction map was computed by attributing the minimum time to go through each cell in h/km. Finally, the accumulative time cost to reach the nearest market place was computed for each grid-cell (see global map in Annex 5). As we aim at identifying LUS based on landscape composition i.e. the combination of land use types; high resolution land use dataset such as GLC2000 were discarded since they are based on categorical variables. Instead, data providing the fraction of grid-cell area covered by croplands and pastures were preferred but available at a coarser resolution of 5 arc-minutes (Ramankutty, Evan et al., 2008). For that reason, 5 arc-minutes is the highest resolution where all the variables of interests could be analyzed consistently although data on population and livestock densities as well as bare, trees cover and built-up areas were available at finer resolution. The Vegetation Continuous Field dataset (derived from MODIS satellite images) provided the grid-cell area covered by bare soils and trees at 30 seconds resolution (Hansen et al., 2001). Built-up areas at 30 seconds resolution were obtained from the Global Impervious Surface Area dataset (Elvidge, Tuttle et al., 2007). Livestock density data were derived from the Gridded Livestock of World (GLW) dataset (FAO, 2007) and converted to livestock unit density according to FAO livestock unit equivalence table for each continent (http://www.fao.org/ES/ess/os/envi_indi/annex2_p.asp). This conversion allows comparing densities among the different type of livestock (bovines, pigs, poultry…). Furthermore, pigs and poultry data as well as Goats and sheep data were merged into two categories; respectively monogastrics livestock and small ruminants. Irrigated croplands and area rice cultivations were also accounted for during the classification of LUS. Data on the area equipped for irrigation were obtained from the Global Map of Irrigation Areas version 4.0.1 (Siebert, Doll *et al.*, 2005). Data on rice croplands areas were retrieved from harvested areas of 175 crops dataset (Monfreda, Ramankutty *et al.*, 2008).

Additional data for wheat, maize and rice areas and yields were also gathered from the same dataset to derive the average land use intensity within each LUS. These datasets were created by combining national censuses data on crop areas and yields with global croplands areas spatial datasets (Monfreda, Ramankutty *et al.*, 2008).

Economic and biophysical data were gathered in order to analyze the spatial distribution of the LUS. A measure of the economical context was obtained at national level and expressed as the Parity Purchase Power (PPP) which accounts for the Official Exchange Rate (OER). The average PPP within each grid-cell was then estimated by downscaling national PPP estimates from the CIA World fact book with the travel time to nearest market place. The IMAGE climate model provided annual average temperatures and precipitations for the year 2000 (Strengers et al., 2006). Besides, the net primary productivity (NPP) was obtained from the IMAGE terrestrial carbon model (MNP, 2006). Multiple soil parameters estimates were derived from the Digital Soil Map of the World (FAO 1995) and obtained from Batjes, NH (2004). Finally, 24 world regions, as defined within IMAGE, were used to discriminate major regional areas.

Prior to analysis, all datasets were projected in Eckert IV so that each grid-cell in the map has the same area. Detailed information on input dataset can be found in Annex 2 and Annex 4 provides detailed information on data preparation and harmonization prior to analysis.

3.2 Land use systems classification: Expert driven cluster analysis

In order to identify LUS globally, an expert driven classification was conducted at ~100 km^2 resolution using the two-step cluster analysis procedure from SPSS 17.0 which is able to handle very large datasets. Cluster analysis is a statistical procedure which classifies objects (i.e. grid-cells) into natural groups (i.e. LUS) based on the overall similarity of multiple factors accounted for. Furthermore, SPSS Two-Step clustering method is designed to identify an optimal number of clusters based on the log-likelihood distance among cases. The first step of the procedure, pre-group all the cases (i.e. grid-cell) into many small sub-clusters using a sequential approach described by Theodoridis and Koutroumbas, 1999. In this step, the cases are scanned one by one and a decision is made as to merge them with previously formed clusters or to create a new one. Here the cluster feature tree created during the first step was set to a maximum of 8 branches per leaf node on 3 levels leading to a maximum of 512 nodes. Then, the algorithm groups the sub-clusters into the optimal number of clusters, first based on the Bayesian Information Criterion (BIC) and then refined based on the greatest log-likelihood distance among clusters.

We used a progressive expert driven procedure, including different set of factors, to identify and classify LUS globally during each stage of the classification. The first stage of the classification aimed at identifying wild systems where no human population, croplands or pastures can be observed. Then, major categories of landscapes were determined (i.e. bare soils areas, forested, grazing, croplands and dense settlements systems). Next, each major category of LUS was classified based on relevant aspects and a hierarchy was established among the factors accounted for. Irrigated and rice croplands areas as well as livestock densities were only used to refine the classification of relevant LUS such as croplands, grazing and dense settlements systems. For instance; cropland systems were further classified considering the area of irrigated croplands, whereas pastoral systems classification was solely refined based on grazing livestock densities. On the other hand, Population density and accessibility were accounted for at each stage of the classification procedure since human activities occurring in considered landscape can be related to these characteristics.

Therefore, a hierarchy was established among the different variables:
Level 1: Population density and accessibility were the most important aspects of land- use systems since they are relevant aspects of land use and important drivers of land use change.
Level 2: Land use/cover types: bare soils, trees cover, pastures, croplands and urban fraction covers had a high influence on the classification since these variables were used in the first stage of the classification and the following ones only if appropriate.
Level 3: The irrigated areas, the land cover of rice croplands and livestock densities were only use to refine the classification of the relevant land use systems i.e. croplands areas, grazing areas and dense settlements.

The classification of LUS was done in 18 stages and is illustrated in Figure 4. Population density and the accessibility were used during all the steps of the classification except for steps 1 and 18.

1. Identification of wild cells having a population density, croplands area and pastures area equal to 0.
2. Classification of anthropogenic cells, based on the grid-cell fraction covered by bare soils, trees, pastures, croplands and urban areas.
3. Classification of bare soils only based on population density and accessibility.
4. Classification of wild areas based only on bare soils and trees land cover.
5. Classification of remote forests based on trees land cover.
6. Classification of populated accessible forests based on croplands and pastures land cover.
7. Classification of mosaic systems based on trees, croplands and pastures land cover.
8. Classification of densely populated croplands based on urban areas and croplands land cover.
9. Classification of croplands based on the areas equipped for irrigation.
10. Classification of irrigated croplands based on the land cover of rice cultivation.
11. Classification of dense settlements based on irrigated areas and the land cover of rice cultivation.
12. Classification of villages surrounded by irrigated croplands based on rice and livestock densities.
13. Classification of rainfed croplands based on: bovines, small ruminants and monogastrics densities.
14. Classification of partly irrigated croplands based on livestock densities.
15. Classification of irrigated croplands based on livestock densities.
16. Classification of rice croplands based on livestock densities.
17. Classification of pastures based on bovines and small ruminants densities. The landless monogastrics livestock was discarded for classification of grazing land use systems.
18. Classification of intensive pastures based on bovines and small ruminants densities.

Figure 4 Classification steps to identify land use systems.

3.3 Description of the land use systems

This classification procedure produced 45 land use systems classes. The number of classes was then reduced to 24 by merging land use systems sharing similar profiles (see table and graphs of the land use systems profiles in Annex 6 providing the centroids within land use system classes for each variable used for the classification). Map 1 provides the global map of land use systems for the year 2000.

The land use systems were named according to the average population density, accessibility, fraction cover of land use/cover types and livestock density in each land use system class.

As mentioned previously the differences among land use systems relies in the combination of all the variables used during the classification steps. Therefore, two grid-cells may be equally irrigated but assigned to different land use systems because significant differences appear in population density and/or accessibility for instance. Similarly, land use systems classes may overlap when considering only one variable.

Wild areas

Nearly 50% of the globe is covered by wild areas i.e. bare soils, natural vegetations or forests where the human influence is very small with a population density below 10 inhabitants per km^2. Not surprisingly, these areas are also the most remote locations. Four types of land use systems where identified in wild areas:

- Remote and accessible bare soils areas: these land use systems are mainly covered by bare soils (respectively ~72 and ~93% of the area); they have very low human population and livestock densities. A distinction is made between extremely remote bare soils system mainly found in the highest latitudes of the globe and accessible bare soils systems which can be found in deserts along the transportation network or surrounding cities.
- Areas covered with sparse trees: are bare soils covered with trees for ~22% of the area and are mainly found in high latitude. Similar to the class bare soils the population and livestock density are close to zero.
- Remote forests: have an average tree cover of 66%. They are located mainly in the tropics (e.g. Amazon rainforest) and high latitudes (e.g. tundra) and are very remote from the nearest market place.
- Populated areas with forests: were separately identified given their high population density (~ 43 inhabitants / km^2) compared to the remote forests (~ 5 inhabitants / km^2).

Grazing systems

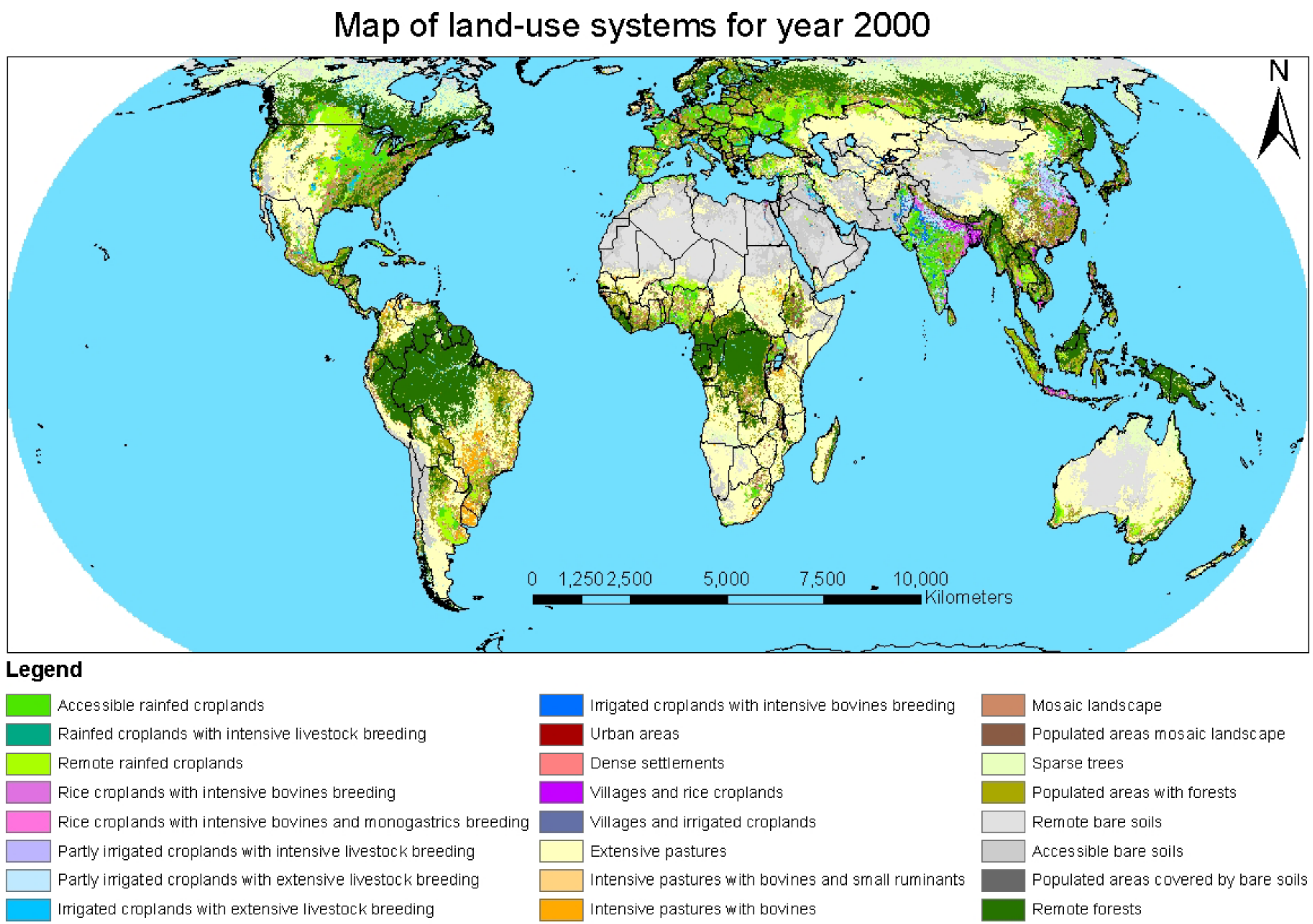
Three different pastoral land use systems have been identified, mainly consisting of grasslands used for grazing. Africa, South America and Australia are dominantly covered by extensive pastoral land use systems. On the other hand, most of the more intensive grazing systems are found in Europe, South America and New-Zealand.

- Extensive pastures: is the most extended land use system on the globe by covering nearly a quarter of the ice-free terrestrial land. These land areas are mainly covered by grasslands used for grazing with low livestock densities (~ 7 LU/km^2).
- Intensive bovines' pastures: are pastoral land use systems with a high density of bovines (~51 LU/km^2) mainly found in Southern Brazil, Uruguay and North-East of Argentina.
- Intensive bovines and small ruminants' pastures: is characterized by a high density of bovines and small ruminants (respectively 56 and 40 LU/km^2 on average) and is mainly found in Ireland, United-kingdom, the Netherlands, Australia and New-Zealand. It should be noted that the area covered by this type of land use systems is very small as compared to the other grazing systems.

Cropland systems

Cropland systems are mainly found in Europe, South-East Asia and North-America. We can note that croplands are on average less remote and have higher population densities than grazing systems (extensive and intensive). Nine different cropland systems have been identified, dominantly covered by croplands (~60 %) and subdivided based on differences in accessibility, irrigation, rice cultivation and livestock.

- Rainfed croplands: Remote rainfed croplands are the less accessible lands mainly used for crops and have the lowest human population and livestock densities. In comparison, accessible rainfed croplands, which are closer to major market places, have higher human and livestock densities.



Map 1 Land use systems map for in year 2000.

A third rainfed cropland system was identified based on its high density in monogastrics livestock. It can be found almost everywhere but is mainly located in Northern Europe in areas with intensive pork production.

- Irrigated croplands: Four different irrigated cropland systems have been identified, based on the area of the cropland which is irrigated, the density of livestock and human population density. Irrigated land use systems are areas where croplands are completely irrigated. They are less densely populated and accessible as compared to land use systems which are partly irrigated (i.e. half of the cropland area is not irrigated). Partly irrigated land use systems are often found at the edge of urban agglomerations. Thus, the difference between fully and partly irrigated land use systems may be explained by the residential function of partly irrigated cropland systems with less area available for crops. Partly irrigated croplands with intensive livestock breeding are mainly found in surroundings of European urban agglomerations and in China. Irrigated land use systems with intensive livestock breeding are mainly found in India, whereas irrigated land use systems with extensive livestock breeding are mainly found in Europe and North America.
- Rice croplands: are land use systems where rice is the dominant crop and are characterized by high population and livestock densities. They are mainly found in South-East Asia. Two different rice cropland systems have been identified based on the occurrence of intensive pork production systems found in China.

Mosaic systems

- Mosaic land use systems: are land areas equally covered by pastures, croplands and forests with low livestock density.
- Populated mosaics: were separately identified given their high population density (~ 185 inhabitants / km^2) compared to the rest of the mosaic systems (~ 30 inhabitants / km^2).

Mosaic land use systems are often found at the transition between land use systems such as forests and croplands.

Dense settlements

Four different land use systems with a population density above ~1000 inhabitants / Km2 were identified.

- Villages and irrigated croplands: are areas covered for approximately 10 % by urban areas and surrounded by irrigated croplands. They are found within regions predominantly covered by irrigated land use systems.
- Villages and rice croplands: are land areas mainly covered by rice croplands (~70%) and built-up areas for ~10%. They are characterized by very high population densities compared to other cropland systems.
- Dense settlements: are characterized by lower population density and croplands extent compared to the village systems. They are found within regions predominantly covered by rainfed croplands or at the edge of urban areas.
- Urban areas: are land use systems predominantly covered by built-up area (~32%) and hold the highest population density (3830 inhabitants / km^2 on average).

Villages and dense settlements have similar livestock densities as compared to land use systems with intensive livestock breeding and especially monogastrics which a landless livestock.

3.4 Land use systems and land use intensity

Due to the lack of globally consistent spatial data on land use intensity such as fertilizer use, the land management associated with each LUS was determined based on estimates of agricultural production efficiency in the year 2000. Hence, the ratio between actual and potential yields for wheat, maize and rice was used as an indicator of land management and computed following:

$$PEic = APic / PPic$$ (**Equation 1**: Agricultural efficiency)

Where i is the i^{th} cell in the raster and c is the crop considered. AP is the actual productivity as given by Monfreda, Ramankutty *et al.*, 2008. PP is the potential productivity (without water limitation) obtained from IMAGE crop model simulations and PE is the production efficiency.

The land management within croplands systems with no or marginal rice cultivation was assessed using the production efficiencies of wheat and maize. In order to estimate the LUS production efficiency based on those two crops, the production efficiency of wheat and maize was weighted according to their current areas within the considered grid-cell. The land management of rice systems was assessed solely based on rice production efficiency. Once production efficiencies were known for each grid-cell, the average production efficiency has been computed for each LUS class following:

$$PE_{(LUS)} = \frac{1}{n_{(LUS)}} \sum_{i=1}^{n_{(LUS)}} PEi$$ (**Equation 2:** Average land use intensity per land use system)

Where PE is the observed production efficiency, LUS is the considered LUS, $n_{(LUS)}$ is the number of cell classified as the considered LUS and i is the i^{th} cell in the raster. The average production efficiency within each LUS is given in Annex 6 .

3.5 Spatial analysis of land use systems patterns

Assuming that LUS are adapted to local socio-economic and biophysical conditions, an empirical analysis has been carried out to determine the relation between observed land use patterns and these local factors listed in Table 1. A binary logistic regression is a statistical method providing the contribution of local socio-economic and biophysical factors to the likelihood of occurrence of each LUS and is expressed according to

$$Log(\frac{Pi}{1-Pi}) = \alpha + \beta_1 X_{1,i} + \beta_2 X_{2,i} + ... + \beta_n X_{n,i}$$ (**Equation 3:** Logit model: general formula}

Where Pi is the probability of occurrence of the considered LUS in the ith grid-cell and $X_{n,i}$ is the value of the considered factor in the ith grid-cell. α is the intercept and β_n are the coefficients of the logit model representing the contribution of each factor to the likelihood of occurrence of the considered LUS.

Furthermore, the suitability of a location to expand croplands and pastoral areas as well as intensifying crops yields or livestock breeding was determined using the same method and the same socio-economic and biophysical determining factors. Here, suitable cells for the expansion and intensification of croplands and livestock breeding were identified based on the croplands and pastoral areas, agricultural production efficiency and livestock densities observed in the year 2000. Table 1 shows examples of logit models for the likelihood of occurrence of various LUS as well as logit models for the suitability of a location to face changes in land cover, land management and livestock densities.

Table 1 Standardized coefficients obtained from various binary logistic regressions.

	Croplands	Rice	Irrigated	Villages	Pastoral	Mosaic	Bare soil	Forest	Location of change		
Variables	lus 1	lus 5	lus 9	lus 11	lus 14	lus 17	lus 21	lus 24	Croplands expansion	Croplands intensification	Bovines intensification
Intercept	-7.818	-7.442	-4.899	1.377	-0.570	-1.166	-3.556	1.075	-4.209	-4.100	-5.703
Population density	-0.277	1.311	0.354	6.611	-1.369	-1.026	-26.356	-10.003	0.172	0.046	0.041
Time travel	-27.723	-6.656	-17.035	-3.818	-2.353	-5.600	2.642	-0.732	-6.755	-4.661	-5.041
PPP	-0.296	-0.788	-0.574	0.732	-0.319		-1.487	-0.135	-0.086	0.178	0.040
Atitude	-0.321	-1.858	-0.392		0.229	-0.316	0.346	-0.135	-0.837	-0.099	-0.441
Slope	-0.186	0.319		0.090	0.045	0.075		0.186	-0.352	0.018	-0.104
Annual temperature	-0.561	0.741	0.844			-0.203	0.587	-0.487	-0.276	0.105	0.048
Annual precipitations	0.114	0.786	-0.844	0.173	-0.268	0.257	-1.089	1.044	0.124		0.226
NPP	-0.258	-0.222		0.163	-0.164	-0.119	-1.302	1.882	-0.305	0.161	0.041
Cation exchange	0.491		0.833		0.269		-0.287	-0.063	0.214	0.031	0.239
Clay content	0.112				0.208	0.156			0.115	0.138	0.604
Soil pH	0.112	-0.308	0.327		0.327	-0.135	0.407		0.232	-0.024	-0.023
Sand content			0.286		0.315	-0.122	0.476		-0.324	-0.344	0.735
Silt content	-0.189				-0.055		0.468		-0.024	-0.077	0.474
Drainage 0	-0.013	2.317	0.150	0.031	0.357	0.071	0.496	-0.043	0.011	-0.155	0.483
Drainage 1	-0.365	1.358	-0.349	-0.156	0.015	0.151	0.099	0.270	-0.289	-0.248	-0.016
Drainage 2	-0.130	7.393	0.118	-0.206	0.258	0.205	-0.105	0.348	0.031	-0.110	0.333
Drainage 3	-0.041	4.803	0.026	-0.265	0.332	0.412	-0.382	0.481	0.008	-0.136	0.482
Drainage 4	-0.125	7.100	-0.082	-0.168	0.409	0.604	-0.579	0.699	0.033	-0.191	0.565
Drainage 5	-0.177	8.953	-0.110	-0.186	0.607	0.706	-0.874	1.102	0.006	-0.443	0.752
Drainage 6	-0.230	6.169	-0.300	-0.238	0.599	0.654	-0.527	0.950	-0.072	-0.271	0.404
Canada	-0.054	0.284	0.570	0.301	-0.769	-0.124	-0.539	0.667	0.364	0.100	-0.064
USA	0.092	2.895	1.078	0.460	-0.257	-0.001	-0.547	0.280	0.415	0.453	0.121
Mexico	0.064	-0.187	0.371	0.178	-0.142	0.144	-0.269	0.040	0.201	0.136	0.040
Rest Central America	0.095	-0.286	0.237	0.084	-0.069	0.067	-0.698	-0.156	0.126	-0.096	0.060
Brazil	-0.068	2.519	0.077	0.190	-0.068	0.194	-0.002	-0.108	0.139	0.301	0.565
Rest South America	-0.186	-1.654	0.175	0.215	-0.148	-0.009	-0.633	0.045	0.056	0.545	0.327
Northern Africa	0.074	2.475	0.484	0.277	-0.509	-0.443	-0.224	-0.433	0.003	-0.202	-0.140
Western Africa	0.289	3.459	-0.293	0.192	-0.284	0.208	-0.327	0.159	0.345	-0.390	-0.243
Eastern Africa	0.220	-1.648	0.099	0.179	-0.083	0.165	-0.319	-0.072	0.114	0.177	0.214
Southern Africa	-0.143	-1.323	-0.421	0.106	0.158	-0.038	-0.237	-0.093	-0.052	-0.115	0.011
Western Europe	0.070	-0.147	0.878	0.211	-0.206	0.009	0.049	0.228	0.265	0.367	0.258
Central Europe	0.232	-0.188	0.306	0.090	-0.243	0.066	-1.156	0.073	0.226	0.217	-0.181
Turkey	0.123	-0.099	0.432	0.104	-0.112	0.132	-1.043	0.007	0.190	0.022	-0.031
Ukraine	0.241	-0.175	0.124	0.064	-0.294	-0.002	-1.025	0.032	0.228	0.103	-0.093
Asia-Stan	-0.312	-0.037	0.860	0.096	0.110	-0.038	-0.488	-0.234	-0.055	0.037	-0.366
Russia	-0.054	-0.091	0.657	0.279	-0.848	0.007	-0.370	0.810	0.341	-0.172	-1.264
Middle East	-0.138	2.425	0.595	0.295	-0.446	-0.275	-0.316	-0.205	0.014	-0.006	-0.331
South Asia	0.595	6.326	2.232	0.078	-0.482	-0.083	-0.596	0.162	0.593	0.395	0.660
Korea	-0.049	0.975	0.347	0.086	-0.103	-0.023	-0.450	0.080	0.030	0.045	-0.083
China	0.008	7.876	1.093	0.262	-0.357	-0.093	-0.474	0.328	0.294	0.721	-0.018
South-East Asia	0.257	5.934	0.633	0.129	-0.415	0.025	-0.030	0.161	0.307	0.142	-0.214
Indonesia	0.259	4.450	0.492	0.087	-0.583	0.083	-0.210	-0.241	0.766	-2.365	-0.054
Japan	-0.085	1.699	0.278	0.090	-0.123	-0.097	-0.609	0.117	-0.049	0.056	-0.239
Goodness-of-fit (ROC)	**0.948**	**0.987**	**0.965**	**0.984**	**0.868**	**0.828**	**0.963**	**0.937**	**0.891**	**0.893**	**0.920**

All coefficients siginificant at 0.01 level, except cells marked

The determining factors have different range of values and their related coefficients were standardized in order to compare the relative contribution of each factor to the likelihood of occurrence of each LUS and land use changes. The interpretation of the standardized logistic regression coefficients is closely parallels the interpretation of standardized coefficient in linear regression: a 1 standard deviation increase in $X_{n,i}$ leads to a $\beta_{n\ (standardized)}$ standard deviation change in $Log(\frac{Pi}{1-Pi})$.

The goodness of fit of a logit model cannot be computed based on least squares error. Therefore, the model accuracy was determined by computing the Receiver Operating Characteristic value (ROC) (Manel, Dias *et al.*, 1999; Pontius Jr and Schneider, 2001;

Lesschen *et al.*, 2005) which evaluates the percentage of properly classified grid-cells by the logit model as compared to observed classes. The results show that LUS patterns (average ROC = 0.940) as well as the location of extensive and intensive croplands and pastures, are significantly explained by the chosen factors (average ROC=0.938).

Annex 9 and Annex 10 provides the summary results of the logit models and their goodness-of-fit for the complete set of logit models.

4 Allocation of land use systems changes

In this chapter, the procedure to allocate future LUS patterns is described. The map of LUS in the year 2000 will be used as the starting map for the model simulation. Based on projections of socio-economic and biophysical inputs (see Annex 3 , Annex 7 and Annex 8), the various logit models are used to determine the location of land use change and the type LUS conversions in order to allocate future land use patterns in the subsequent time-steps of the simulation.

4.1 Land use changes simulation

The transition from one LUS to another represents one or multiple land use change processes occurring simultaneously. Thus, land use changes over time are simulated within each world region through the conversion of LUS. However, LUS were obtained by clustering method; hence the LUS classes have significant variation of their land use components (listed in Figure 2 and Annex 6). For instance, Figure 5 shows various levels of bovine densities within each pastoral LUS.

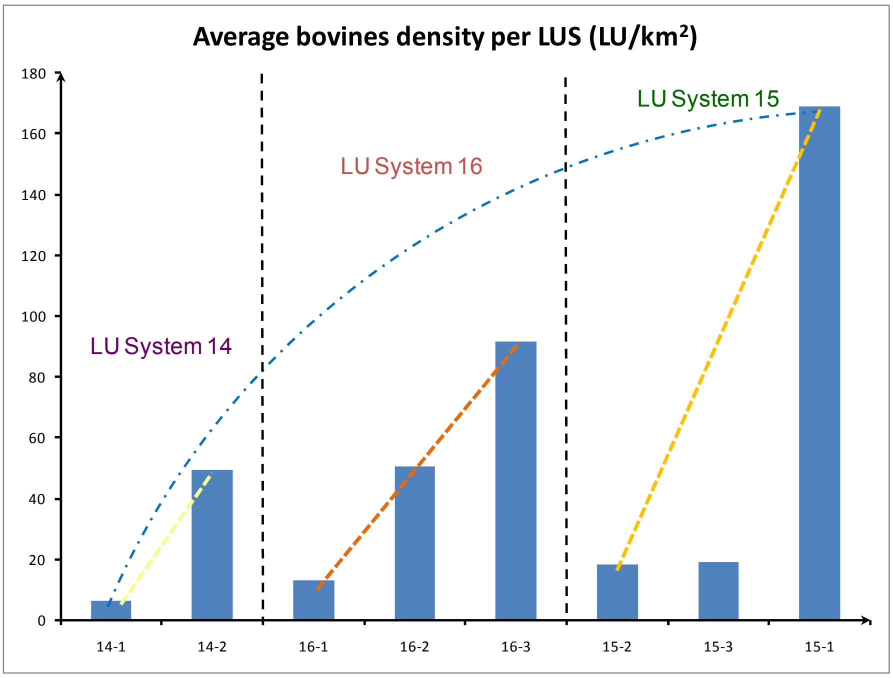


Figure 5 Average bovines' density levels per LUS.

This example shows that bovine density can increase or decrease within a considered pastoral LUS without requiring a conversion towards another class of LUS. Nonetheless, once the bovine density has reached a "maximum" for a considered LUS class at a defined location, only a LUS conversion can occur in order to further increase bovine density (e.g. between LUS 14 and 16).

For each cropland and pastoral systems, levels have been defined using univariate clustering method for the croplands and pastures land cover, the land management of croplands and rice cultivation as well as densities of the three livestock types (see Annex 6). Thus, land use changes induced by macro-economic drivers can be allocated within a LUS class, by changing the levels of various LUS aspects prior to convert the LUS.

4.2 Allocation procedure

During one time-step representing 5 years, the allocation of land use changes is carried out in ten phases as shown in the upper part of Figure 6. Each phase is related to a specific driver of land use change and their corresponding land use change processes are simulated by converting the LUS to another one or by changing a considered aspect of the LUS which are:

- Land cover of croplands, rice cultivation and pastures,
- Land management of croplands and rice cultivations,
- Livestock densities.

Each phase follows a similar procedure to allocate land use changes through the conversions of LUS as shown in details for the allocation of land management changes in the lower frame of Figure 6.

4.2.1 Allocation order of land use change processes

As a LUS conversion can represent multiple land use change processes, an allocation order has been defined as to limit the effect of a considered land use change process on other aspects of the LUS and to fulfill the various macro-economic demands consistently. First, effects of changes in local conditions on LUS are allocated since they are necessary adaptive land use changes to the new demographic and biophysical conditions (phase 1). Then the regional production in agricultural commodities is updated to account for those changes and changes induce by macro-economic demand in multiple agricultural commodities are allocated (phases 2 to 10). In this framework, it is considered that land use changes related to croplands prevail changes in pastoral areas.

Furthermore, it is considered that decisions related to land management and livestock densities are taken once available areas in croplands and pastures are known. Thus, changes in croplands areas are allocated prior to land management changes and changes in pastoral areas prior to changes in grazing livestock density changes. Hence, changes in croplands and rice cultivation land cover are allocated in phases 2 and 3, and then changes in bovines and monogastrics densities are applied in phases 4 and 5. During phase 6 and 7, the land management changes are allocated to fulfill the regional macro-economic demand in rice and other food crops production. Once land use changes related to croplands and croplands systems have been allocated, the demand in rangelands expansion or abandonment is updated. Then, relevant LUS conversions are allocated in phase 8 to fulfill the macro-economic demand in pastoral areas. Finally the densities of grazing livestock are updated and the relevant LUS conversions are allocated to meet bovines and small ruminants densities required to fulfill the macro-economic demand in phases 9 and 10.

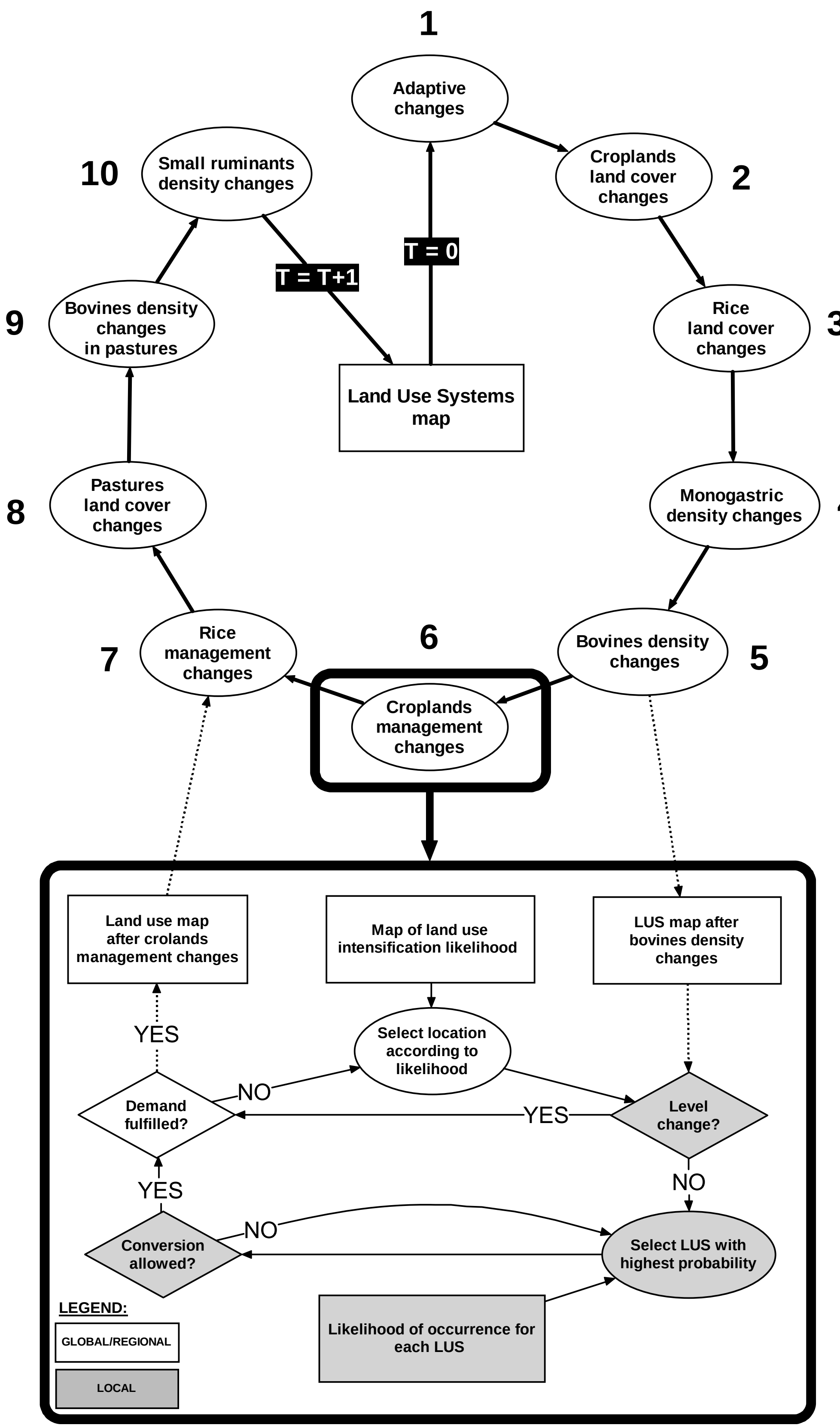


Figure 6 Land use systems allocation procedure for one time-step.

4.2.2 LUS allocation during each phase

As mentioned previously, the allocation of LUS conversions during each phase follows a similar procedure. First, the locations most likely to face land use change induced by the considered driver are identified within a region. Then, changes in LUS components levels are allocated if possible, otherwise relevant LUS conversions are allocated locally according to the likelihood of occurrence of each LUS. Locations facing adaptive land use changes are determined locally and based on significant differences between new and previous demographic and biophysical conditions. A difference of 10% in population density is considered a significant change in demographic conditions. An absolute difference of 2°C in average annual temperature or a change of 0.25 mm in average annual precipitations is considered significant climatic changes.

The locations of land use changes induced by macro-economic drivers are determined by a logit model based on the new socio-economic and biophysical conditions which provides the likelihood to increase agricultural productivity. The lower frame in Figure 6 shows as example the procedure for the allocation of land management changes. The suitability map for intensive croplands used to locate land management changes can be found in Annex 11 . If the macro-economic demand requires an increase in agricultural productivity, the LUS allocation starts with at the location having the highest likelihood to intensify its land use (i.e. increase the agricultural productivity). Otherwise, the allocation starts by the location less likely to face an intensification of croplands. Maps examples representing the likelihood for croplands, rice croplands and pastures land cover increase as well as the likelihood for croplands productivity, rice croplands productivity and livestock density increase are given in Annex 11 .

Once the location most likely to change has been identified, changes in LUS components levels are allocated if possible, otherwise the likelihood of occurrence of each LUS is determined using logit models given the new local conditions (map examples are given in 0). If a LUS conversion is required, a conversion matrix (see next section) is used to constrain the potential LUS conversions so that only relevant conversions to the considered land use change driver are allowed. If the conversion is relevant, the new LUS is allocated. If not, the following most probable LUS is selected and the conversion feasibility is checked. This verification is repeated until a feasible conversion can be allocated. Once the LUS conversion has occurred, the model moves to the next location most likely to change and repeat the same LUS allocation procedure until all land use changes induced by the considered driver are allocated.

4.3 Conversion matrices

During the allocation procedure, each allocation phase makes use of specific conversion matrices in order to associate relevant LUS conversions to the various land use change drivers. Nonetheless, general LUS transition rules based on expert judgment, can be used throughout the allocation procedure. Concerning systems with dense settlements, built-up areas are considered to never be reclaimed for cropping and grazing activities or by natural vegetation. Thus, LUS conversions resulting in a significant loss in built-up areas are discarded and dense settlements systems are always expanding. Forested systems cannot change directly towards systems mainly covered by bare soils and only populated systems with forests can be converted in dense settlements. Systems mainly covered by bare soils except populated bare soils systems cannot change directly towards systems with croplands, mosaic landscape and dense settlements. LUS covered by a mosaic of land covers (i.e. heterogeneous landscapes) cannot change directly into systems with bare soils. Populated systems composed of mosaic landscape can change into dense settlements. Pastoral systems cannot change directly to forest and systems with croplands cannot change directly to wild systems i.e. remote areas with marginal human presence and mainly covered by bare soils, sparse trees or forests. Finally, once changes affecting an aspect of the LUS, such as croplands area, have been allocated, the following conversions must induce only limited change for this considered aspect of the LUS. In other words, once croplands changes in area have been allocated, any LUS conversion resulting in a change in cropland area are discarded during the next phases of the allocation procedure.

Based on these general rules, allowed LUS conversions are further refined in each allocation phase to reflect appropriately the intended land use change processes. Adaptive land use change processes are related to land use processes such as urbanization, land abandonment or desertification induced by local changes in population density and biophysical conditions (phase 1 in Figure 6). Therefore, only LUS conversions relevant to changes in population density or relevant to landscape changes induce by climate change are allowed to allocate adaptive land use changes as shown in Table 2. Detailed conversion matrices for local adaptive changes are accessible in Annex 13.

Table 2 Conversion matrix for the allocation of adaptive land use changes.

From \ To	Dense settlement	Crop system	Pastoral system	Mosaic system	Wild system
Dense settlement	V	X	X	X	X
Crop system	V	V	X	X	V
Pastoral system	X	X	V	X	V
Mosaic system	V	X	X	V	X
Wild system	X	X	X	X	V

Where V represents feasible LUS conversions and X discarded conversions.

Effects of macro-economic drivers on land use are related to land use change processes such as deforestation, conversion of pastures into croplands, land use and livestock systems intensification (phases 2 to 10 in Figure 6). During the allocation of land use changes induced by the macro-economic demand in croplands and/or pastoral areas (phases 2 and 8 in Figure 6), LUS conversions must provide a sufficient change in croplands and pastoral land cover. Therefore, only conversions across major categories of LUS are allowed as shown in Table 3.

Dense settlements systems are discarded for this allocation phase assuming that they are mainly influenced by changes in population density and results from local adaptive changes. Besides, relevant LUS conversions depend on the expansion demand induced by agricultural economy. If the macro-economic demand requires an expansion of croplands or pastures; only LUS conversions providing an increase in croplands are allowed. Reciprocally, if a decrease of croplands/pastures area is required, only LUS conversions providing a decrease in croplands/pastures are allowed. Once the croplands area required by the macro-economic demand has been allocated, conversions from croplands systems are discarded during the allocation of pastures land cover change. Detailed conversion matrices for agricultural expansion are accessible in 0.

Table 3 Conversion matrix for the allocation of croplands and pastures land cover change.

From \ To	Dense settlement	Crop system	Pastoral system	Mosaic system	Wild system
Dense settlement	X	X	X	X	X
Crop system	X	X	V	V	V
Pastoral system	X	V	X	V	V
Mosaic system	X	V	V	X	V
Wild system	X	V	V	V	X

Where V represents feasible LUS conversions and X discarded conversions.

For the allocation of land management changes (phases 6 and 7 in Figure 6), only LUS conversions providing a significant change in agricultural production efficiency are allowed and only croplands systems are considered for this allocation phase (see 0). Land use change processes related to land management change are, for instance, irrigation of previously rainfed croplands and should imply limited changes in land cover. Therefore, only conversions among croplands LUS are considered during this allocation phase (Table 4). Allowed conversions are depending on the macro-economic demand in land-based commodities. If the macro-economic demand requires an increase in croplands productivity, only LUS conversions related to croplands intensification are allowed and reciprocally, if the demand is negative, only LUS conversion resulting in a decrease of croplands productivity are allowed.

Table 4 Conversion matrix for the allocation of land management changes.

From \ To		Rangelands		Croplands	
		Extensive	Intensive	Extensive	Intensive
Rangelands	Extensive	X	X	X	X
	Intensive	X	X	X	X
Croplands	Extensive	X	X	V	V
	Intensive	X	X	V	V

Where V represents feasible LUS conversions and X discarded conversions. Here, the terms extensive and intensive are related to croplands productivity.

As for the allocation of land management changes, changes in livestock densities should imply limited changes in land cover. Therefore, only LUS conversions within major category of LUS are considered for the allocation of livestock density changes (phase 4, 5, 9 and 10 in Figure 6) as shown in Table 5. Only LUS conversions providing significant changes in livestock densities are allowed. Monogastrics are mainly found in croplands systems, therefore only these systems are influenced by changed in monogastrics densities (phase 5). On the other hand, bovines are found and influence both croplands and pastoral systems (phases 4 and 9). Small ruminants are mainly found in pastoral systems and influence only these systems (phase 10). Detailed conversion matrices are provided in 0.

Table 5 Conversion matrix for the allocation of livestock density changes.

From \ To		Rangelands		Croplands	
		Extensive	Intensive	Extensive	Intensive
Rangelands	Extensive	V	V	X	X
	Intensive	V	V	X	X
Croplands	Extensive	X	X	V	V
	Intensive	X	X	V	V

Where V represents feasible LUS conversions and X discarded conversions. Here the terms extensive and intensive are related to livestock density.

5 Simulation results

5.1 World development scenario: OECD Environmental Outlook to 2030

Projections of climatic, demographic, economic and more particularly agricultural production (see Annex 3 , Annex 7 and Annex 8) were used as drivers' inputs to simulate LUS changes over time. These projections are based on the scenario developed for the OECD environmental outlook to 2030 (Verburg, Stehfest *et al.*, 2009) which baseline assumes that the world development follows its current trends and no new policies are implemented to tackle current environmental pressures or regulate agricultural economy. According to this scenario, the global population will reach 9.1 billion persons by 2050 and its growth will be most important in developing countries whereas OECD countries only show a small increase.

Concerning the economical context, the scenario assumes a global increase of the GDP at a rate of 2.8% per year and 5% for BRIC countries (i.e. Brazil, Russia, India and China). Due to faster economic and demographic changes, agricultural production will increase more importantly in developing countries as compared to OECD countries which demand in land-based commodities should remain stable. Under these scenario assumptions, the agricultural production should increase by 50% in 2030 but croplands areas would only expand by 10% globally. Concerning climatic conditions and according to the greenhouse gases emissions from the baseline, temperature would increase between 1.7 and 2.4˚C by 2050. Due to global warming, hydrological cycles are affected with higher evaporation and, as a result, higher precipitations globally. Nonetheless, this global trends is expected to be unevenly distributed and water limited areas would become dryer whereas areas receiving currently high level of precipitations may have to face water drainage and flooding problems.

Climatic, demographic and economic projections data originated from multiple specific models. Socio-economic data projections were retrieved from PHOENIX (Hilderink, 2000) for population density and GTAP (Hertel, 1997) GDP. These projections are provided at regional scale. In order to be consistent with the simulation resolution, population and GDP growth have been downscaled to a resolution of 5 arc-minute based on the population density in each grid-cell according to:

$$POPd_{(i)(t+1)} = POPd_{(i)(t)} + g_{popd_{(t)}} * \ln(POPd)_{(i)(t)} * \left[\sum POPd_{(i)(t)} \Big/ \sum (POPd_{(i)(t)} * \ln(POPd)_{(i)(t)}) \right]$$

(Equation 4: Population density at t+1**)**

Where POPd is the population density, g_{popd} is the population growth at the regional scale, i is the ith cell in the raster, t is the time-step.

According to Equation 4 densely populated places have a higher population growth rate than places with marginal human presence. The natural logarithm of population density is used instead of the actual population density to limit the effect of extreme population density values. Based on the same rationale, growth in GDP was downscaled according to:

$$GDP_{(i)(t+1)} = GDP_{(i)(t)} + g_{GDP_{(t)}} * \ln(POPd)_{(i)(t)} * \left[\sum POPd_{(i)(t)} \Big/ \sum (POPd_{(i)(t)} * \ln(POPd)_{(i)(t)}) \right]$$

(Equation 5: GDP at t+1**)**

Where GDP is the gross domestic product, g_{popd} is the population growth at the regional scale, i is the ith cell in the raster, t is the time-step.

GTAP provided as well macro-economic projections where the demands in land-based commodities are expressed as required changes in land cover on one hand and regional production on the other hand for croplands, rice crops and pastures. Concerning animal products, demands are expressed as regional increase in livestock densities. Projections of macro-economic demands are provided at regional scale whereas climatic data are provided by the IMAGE climate model, at 0.5 degree resolution, and expressed as annual average temperatures and precipitations (Strengers *et al.*, 2006).

5.2 Model simulation

Based on this baseline scenario, Map 2 represents the various LUS map of Nigeria over one time-step between 2000 and 2005. Map 3 displays LUS maps over several world regions between the years 2000 and 2050 showing various LUS changes within different macro-economic contexts.

5.2.1 Land use systems changes over one time-step

Map *2* shows the result of various LUS allocation phases over one time-step in Latin America. Frame 1 shows the starting LUS map for the year 2000. Frame 2 shows the map once adaptive land use changes have been allocated. During this phase, the effects of population growth and environmental changes on landscape are allocated (Map 2). As shown in area A, systems of urban areas have expanded over dense settlements systems due to population growth within the area. Considering the landscape of a LUS, built-up areas expand over croplands which are becoming a marginal land use type within the system land cover composition. We can also note in area B that villages systems expand or appear in agricultural or wild systems, as observed in South of Brazil. In this case however, croplands remain the main land use type within the considered LUS landscape. These LUS conversions are related to the necessary expansion of built-up areas within the landscape so that housing capabilities are provided. Besides, these conversions are also linked to a local increase in PPP.

Frame 3 shows the land use map once macro-economic inputs affecting croplands systems and their productivity as well as animal production have been allocated. In this case, economic inputs request an expansion of croplands and a production increase of agricultural commodities as well as an increase in monogastric and grazing livestock breeding. An expansion of croplands can result in LUS conversions implying that deforestation occurs to use previously forested land as cultivated areas or that grazing areas become croplands. Considering a LUS, it means that the landscape will be covered by larger areas of croplands. Thus, in area C, pastoral, mosaic and populated systems with forests providing suitable, demographic, economic and biophysical conditions for crop cultivation are converted to cropland systems. During this allocation phase, mosaic systems can be considered as intermediary LUS in locations facing landscape changes induced by agricultural economy and moving between forested, pastoral and croplands systems. Apart from changes in land cover, such LUS conversions implies that population density and accessibility have increased so that agricultural labor force and technological improvements required to develop cultivated areas are provided. Croplands intensification can be observed in area D where croplands productivity increases. Such LUS changes represent a change in land management and do not change the LUS landscape. However, it also implies a limited gain in livestock density mainly monogastrics and/or bovines as well as population density and PPP. In Argentina, the macro-economic demand in animal products induces an increase in livestock densities within croplands systems (area E). Again, this type of LUS conversion does not influence the landscape.

Frame 4 shows the land use map once macro-economic inputs affecting pastoral areas and grazing livestock have been allocated. Area F shows an expansion of grazing areas through the conversion of mosaic and forested systems into pastoral systems. The expansion of grazing areas induces forest clearing and implies a small increase in population density and PPP within the considered LUS.

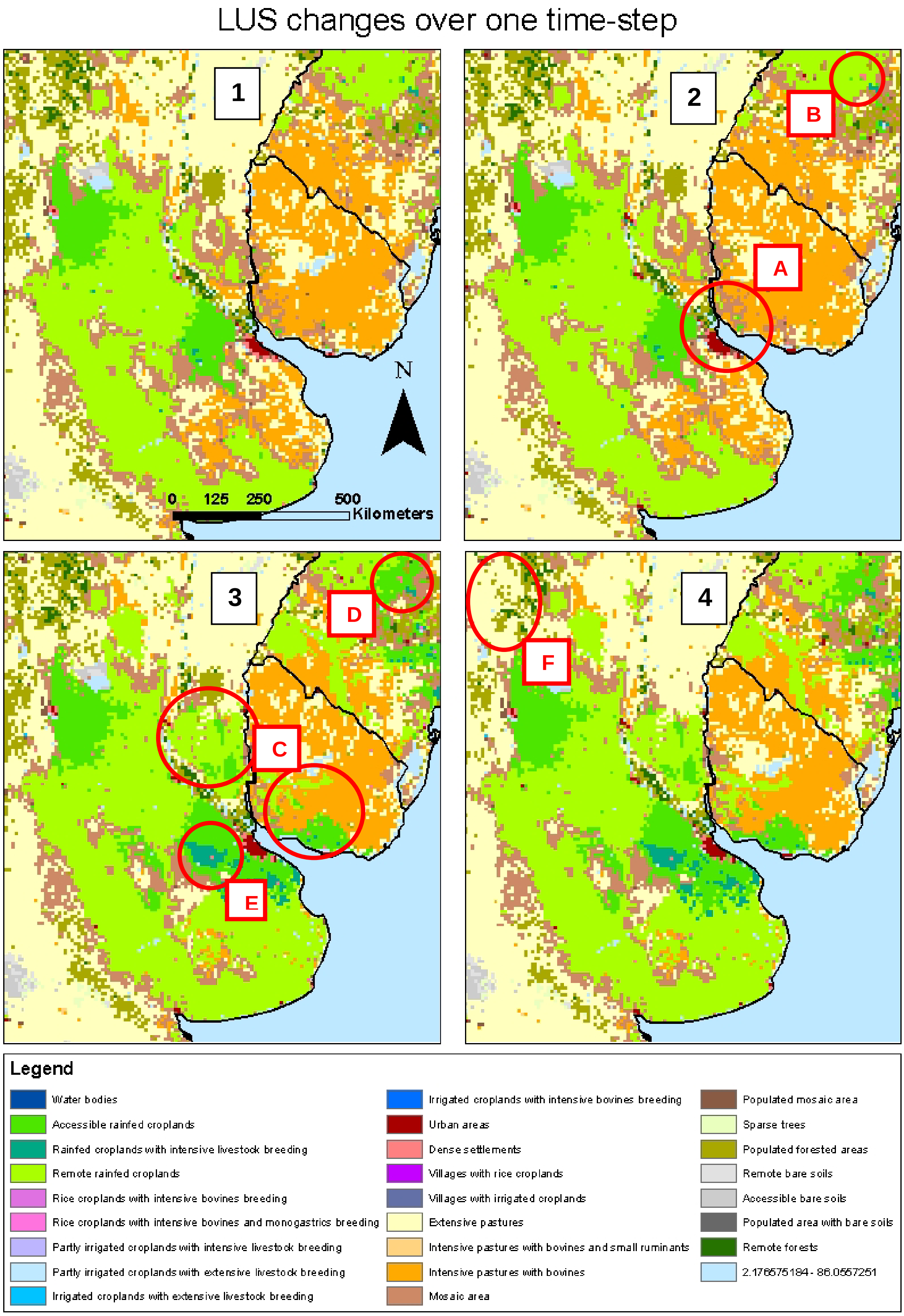
5.2.2 Land use systems changes in various macro-economic contexts

Map 3 provides LUS maps after ten time-steps for the year 2000 and 2050 and over several world regions. Comparing OECD countries and Russia, two different economical contexts are represented.

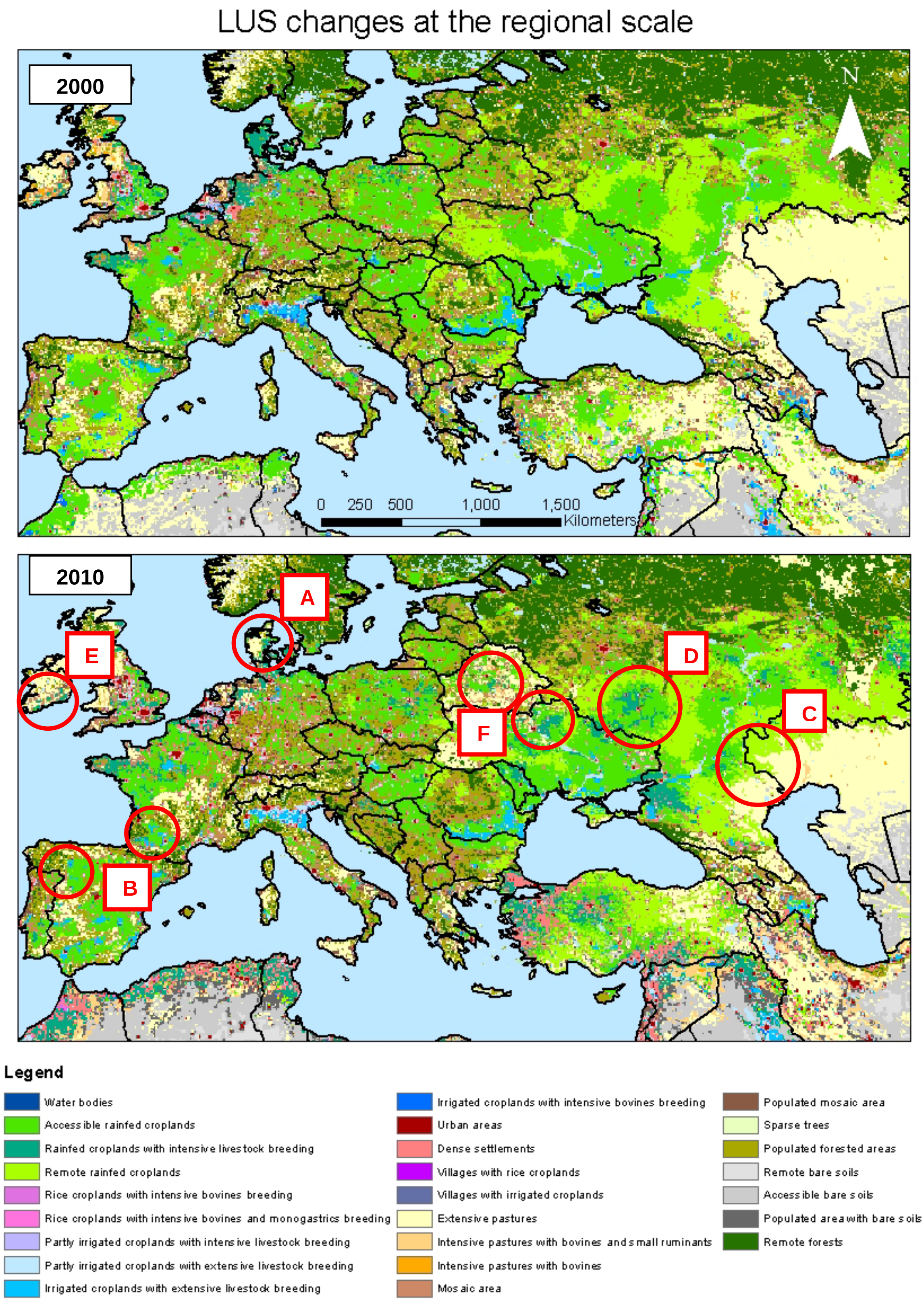
In OECD countries, croplands areas are projected to slightly decrease but their overall crop production should increase. Thus, we can note an abandonment of cultivated areas which are then used for grazing as observed in Denmark (area A) or reclaimed by natural vegetation. In the case of OECD countries, the use of limited cropland areas is intensified to reach the crop production demand by improving water supply through irrigation or by increasing the land productivity through management changes as shown in areas B in Northern Spain and Southern France. In Russia, both croplands areas and their total production of land-based commodities are projected to increase. Here the potential for expanding cultivated areas is projected to be high and LUS conversions induced by cropland expansion (area C) are sufficient to meet the demand in agricultural commodities production. Therefore, changes in croplands productivity related to land management will be very limited as illustrated in area D.

Concerning animal production and more particularly grazing livestock, OECD countries are projected to decrease their animal production whereas it is projected to increase in Eastern Europe. As a consequence, we can observe an extensification of pastoral systems in OECD countries as shown in Southern Ireland (area E). In Eastern Europe countries face an increase in grazing livestock density as observed in pastoral systems in Belarus and cropland systems in Ukraine (area F).

Global maps of LUS simulation for each time-step from year 2000 up to the year 2050 are available in Annex 14 .



Map 2 Land use systems changes over one time-step.



Map 3 land use system map after allocation of croplands and pastures land cover changes.

5.2.3 Model outcomes

Figure 7 shows absolute changes in areas for various categories of LUS. On the right hand side, changes in areas of croplands, pastoral and forested LUS are given for 6 world regions. On the right hand side, insight is given on land management changes for the same regions through changes in areas of rainfed and irrigated croplands systems. In addition, changes in areas of extensive and dense pastoral systems are also provided.

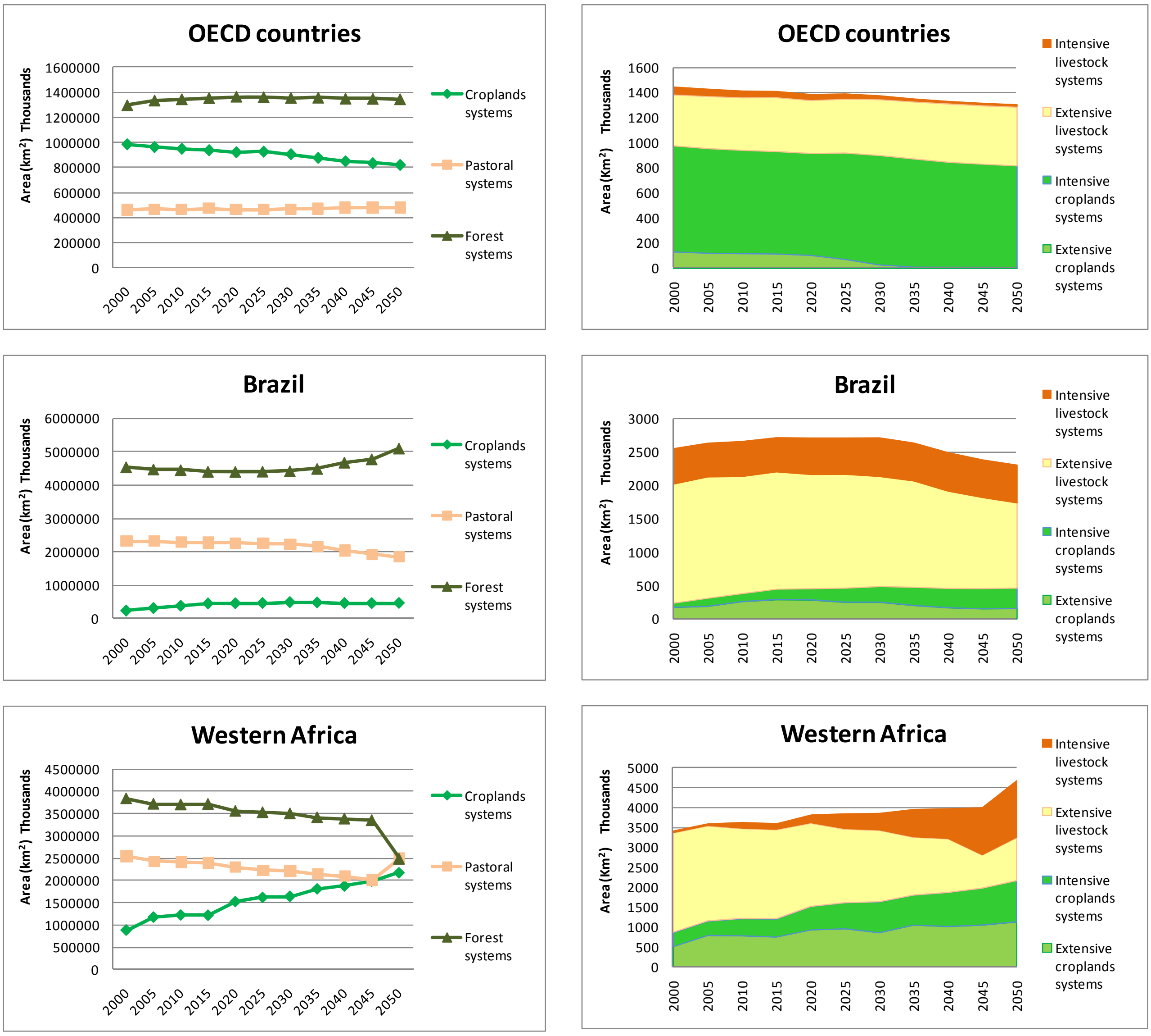


Figure 7 LUS changes in LUS area over various world regions.

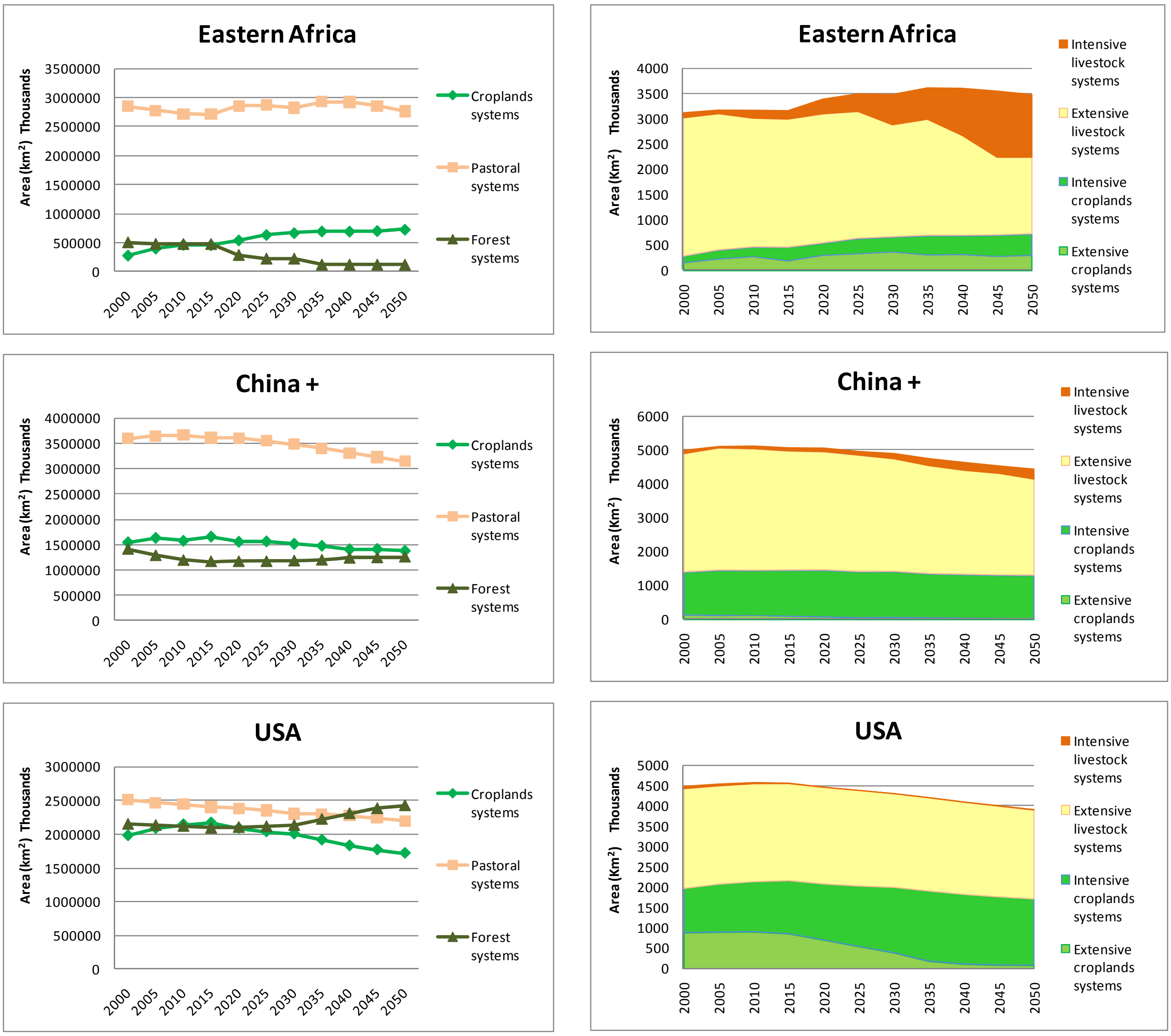
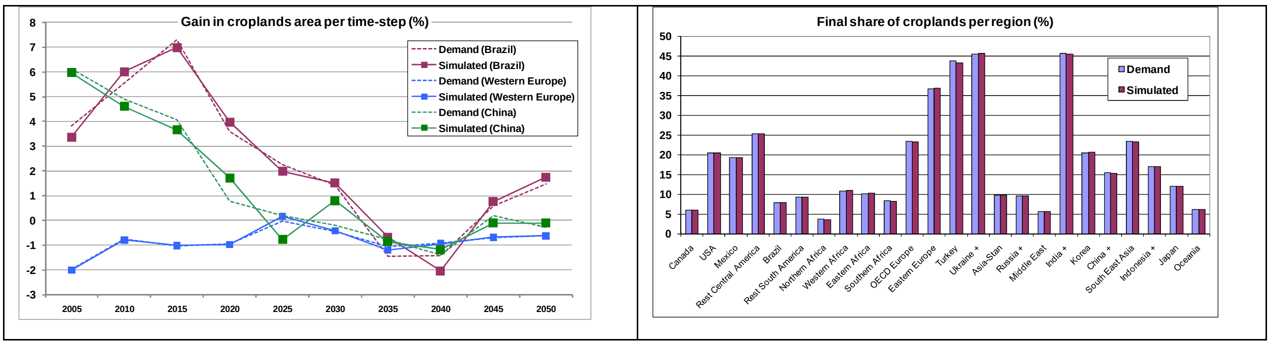


Figure 7 LUS changes in LUS area over various world regions (continued).

Figure 8 provides the relative changes in percentage of croplands areas and their productivity as well as changes in pastoral areas and livestock densities as requested by the macro-economic inputs. A comparison is made with the model outputs. Left hand graphs provide detailed changes for each time-step for Brazil, OECD Europe and China. Right hand histograms provide the final changes after 10 time-steps for the 24 IMAGE world regions.



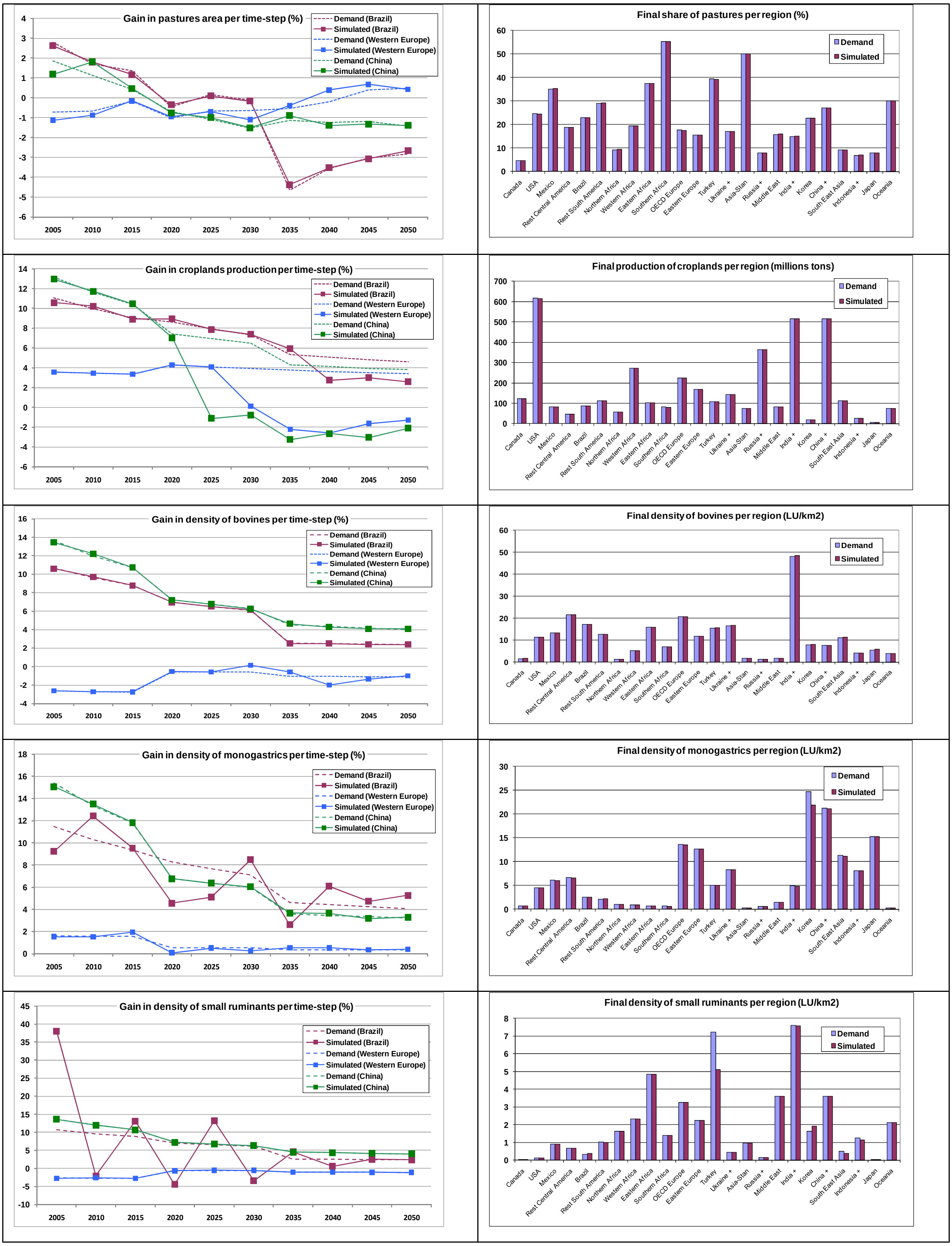


Figure 8 Model outcomes over 10 time-steps.

6 General discussion

6.1 Model code verification

The model code was checked in order to ensure the consistency between the conceptual framework and the simulation procedure. The various macro-economic demands retrieved from the OECD scenario are region specific and offers an appropriate framework to test the model outcomes with multiple macro-economic inputs. Annex 17 provides the detailed verification procedure to ensure that the model appropriately allocates LUS conversions at the grid-cell level according to the conceptual framework and that land use changes occur at the expected locations according to the various macro-economic demands.

In addition, Figure 8 shows that the simulation of future LUS patterns is resulting in the expected changes in land cover, croplands productivity and livestock densities as requested by the multiple OECD macro-economic inputs. However, the model tends to over or under estimate land use change processes over a single time-step as shown on right hand side of Figure 8 for croplands productivity in China or small ruminants density in Brazil. These deviations from the macro-economic demands were expected due to the multiple aspects of a LUS. Therefore, they are accounted for over each time-step so that the model is able to allocate the appropriate amount of land use changes in croplands production over time.

6.2 Model behavior

Describing land use as a system of human populations structuring the landscape provides an appropriate framework to simulate various land use change processes such as urbanization, deforestation/aforestation, desertification, croplands and pastoral expansion and land use intensification.

LUS make an explicit link between the landscape composition (i.e. land use and land cover) and the socio-economic context so that land use change does not implies solely a change in land use area but a change of the landscape composition consistent with the socio-economic and environmental local context as observed in the year 2000. Therefore, the competition of the various land use types in a considered LUS and their interactions within the landscape remains consistent with the local human population and livestock needs as well as the environmental context. Besides, LUS as units of simulation enables us to keep track of marginal land use and land cover types within the landscape. Marginal land cover types are important aspects of the landscape when aggregated at higher scale. Indeed, Zomer, 2009 noted that at the global scale, trees in croplands areas cover as much land as the Amazon forest.

Nonetheless the model is limited to account for regional specificities as LUS have been identified globally. It is a limiting aspect of the model more particularly for mosaic systems which landscape composition as well as socio-economic characteristics are expected to differ depending of the region considered. Apart from land cover changes, LUS offers the possibility to simulate changes in land management related to human inputs and pressures to the ecosystems, such as irrigation. Integrating land use with its socio-economic context is a step towards better addressing land use intensification since land use intensification is a function of managing natural resources in the context of prevailing socio-economic drivers (Lambin, Rounsevell *et al.*, 2000). Although assessing land use intensity based on agricultural efficiency of three crop types is a simplified approach due to lack of more detailed relevant data.

Moreover, global land use patterns are the result of agricultural macro-economic developments constrained by local biophysical and socio-economic conditions. LUS as unit of land use change simulation enables to combine top-down and bottom-up land use change processes and is a step towards better addressing land use change as the result of land use type competitions and interactions at various scales. Based on simple conversion rules, various land use change processes are related to their relevant drivers in each phase of the LUS allocation procedure so that the allocation is path dependent and the result of a trade-off between different land use change processes occurring simultaneously but driven by different specific drivers operating at various scales. Discriminating local adaptive land use changes from agricultural expansion and land management changes enables the model to account for local constraints to the development of agricultural activities and simulate land management decisions deviating from economical incentives.

Thus, the LUS competition and interactions is considered during the allocation phase at regional scale. The prevalence of adaptive land use changes enables to account for local pressures on decisions related to land use planning by identifying areas which previously were suitable for agriculture but become unsuitable due to changes in the socio-economic and/or climatic context. Consequently, the development of agricultural activities is not occurring where it is the most suitable but where it is the most feasible due the socio-economic and climatic contexts at the regional scale. This is relevant to urbanization processes, where the expansion of built-up areas reclaims arable lands decreasing land availability for agricultural activities (Dewan and Yamaguchi, 2009).

It is also relevant to global change effects such as land carrying capacity decrease in arid regions. Besides, allocating land use intensification offers the possibility to simulate various "strategies" aiming at fulfilling regional to global agricultural production demand but which cannot be captured if the model only account for land use and land cover areas. In Western Africa, where land availability is high, croplands tend to expand in order to increase the production of land-based commodities. In contrast, Europe will face an intensification of the land use in order to meet agricultural production demand since land availability for agricultural production is low but the economical context is favorable to technological developments aiming at improving croplands productivity.

Considering impact assessments, the integrated representation of land use makes the model highly suitable for integrative assessment of human impacts on the environment as it can be related to specific economic, climatic, demographic models as well as impact models such as GLOBIO.

6.3 Sensitivity analysis

Cluster analysis and definition of LUS

In this conceptual framework, land use change is simulated through the conversion of LUS. Thus, the magnitude of land use changes during the simulation are determined by the relative differences between LUS and the amount of LUS conversions allocated. However, LUS classes have been defined at the global scale by clustering method based on multiple land use aspects. For that reason, each grid-cell may deviate more or less from the centroids of its LUS class. As a consequence, the magnitude of land use change occurring at a considered location may be over or underestimated. Thus, levels of croplands and pastures land cover, land management of croplands and rice cultivation as well as livestock density have been defined within each LUS class using univariate clustering method. These levels enable the model to limit the over or underestimation of land use changes at local scale, by accounting for the deviation of each grid-cell from its LUS class centroids.

Thresholds for adaptive land use changes
In the current model implementation, thresholds are used during the allocation of adaptive land use changes in order to determine significant changes in local demographic, economic and biophysical conditions triggering the relevant LUS conversions. Especially, the threshold for population density triggering the shift towards systems with a larger cover of built-up areas proved to be a very sensitive parameter. In Africa and Asia where population growth is high, we can note urban sprawling and dense settlements (i.e. villages surrounded by rainfed croplands) spreading over large areas. On the other hand, in Europe, urbanization is very limited due to a low population growth as input. The same remark stands for the thresholds define for effect of climate change on wild systems.

Sensitivity to local drivers Logistic regressions
The various standardized coefficients obtained from the multiple binary logistic regressions (Table 1, Annex 9 and Annex 10) provide the contribution of local factors (i.e. demographic and biophysical conditions) to the occurrence of each LUS as well as the location of land use change. Thus, these coefficients provide an insight of the model sensitivity to various dynamic local drivers (i.e. population density, PPP and climate) as well as static (i.e. accessibility, soil properties and world regions).

Accessibility is influencing the occurrence of most LUS and more particularly the occurrence of croplands systems, except for rice systems which occurrence is also greatly influenced by soil drainage and the world region. On the other hand, the occurrence of wild systems is greatly influenced by population density, and apart from accessibility, climate and soil drainage also have a significant contribution.

The sensitivity of the model regarding the location of land use change is also provided by the various standardized coefficients available in Table 1 and Annex 10 . These tables show that accessibility plays, again, a significant role in the likelihood of most land use change processes. Besides, biophysical conditions expressed by the climate, terrain and soil conditions are more contributing than socio-economic conditions. Indeed, population density barely drives location of land use change and PPP is equally important in this regard. More particularly, the choice between expansion versus intensification of croplands is influenced by PPP which is positively correlated to the likelihood of intensifying croplands management or increasing livestock density.

Overall, we can note that the time-travel to reach the nearest market place has high influence on the location of land use change as well as type LUS conversions since it highly influences the occurrence of all LUS classes. Apart from croplands systems, population density also pays a significant role in the occurrence of dense settlements, pastoral and wild systems as well as the likelihood for pastures expansion. As a consequence, the model outcome is rather sensitive to the quality of future population density and accessibility maps.

Sensitivity to macro-economic drivers
Figure 8 shows that the model is able to handle multiple economical inputs since the required land cover, land management and livestock densities changes are fulfilled consistently by allocating land use changes within LUS and LUS conversion. With many land-based commodities demands to be fulfilled simultaneously, the model might have run the risk to be

unstable, or not being able to find a solution where all the macro-economic demands are fulfilled consistently. Moreover, the detailed results for Brazil, OECD countries and China show that over a single time-step, the model can allocate various economic demands appropriately.

The amount of LUS conversions are related to the macro-economic demand in crop production, pastoral areas and livestock densities. Global maps of LUS provided in Annex 14 over the period 2000-2050 as well as Figure 8 show that very high demands for crop production and livestock density induce LUS conversions over large scale. It can be observed in Africa where large areas are converted to dense pastoral systems in order to reach the requested demand in animal products. More particularly, in Western Africa, the surface covered by intensive pastoral systems equals the area covered by extensive pastoral system after 10 time-steps. A similar remark stands for India where most the cropland systems with low livestock density are converted into croplands with intensive monogastrics and bovines livestock systems. The extent of LUS conversions may be over estimated in some cases. It may be caused by the implicit assumption that LUS classes, as defined for the year 2000, will remain constant over time. Indeed, the model only allows limited changes within the systems while allocating land use changes and it does not account for improvement of crop productivity over time nor for new type of LUS having different land use components profile, following future technological improvements and land management.

6.4 Validation

Review of the land use systems identification

The map of land use systems for the year 2000 was reviewed by the IMAGE model team. Some remarks were made concerning errors in the influence of the accessibility layer in some regions such as the Nantes region in France which is classified as remote croplands whereas it is rather accessible. On the other hand the Namibian coast is considered accessible although it is not in reality. Concerns were also expressed about the high importance of the accessibility factor during the classification and its potential influence over land use system change. Besides, doubts were raised concerning some areas classified as irrigated croplands such as in North America and the Danube delta.

Concerning bare soils and grazing areas, it was noted that some regions are classified as pastures instead of bare soils like in the Andes and the Kalahari Desert. Sometimes it is the opposite such as in the center of Australia. It was also noted that some forests regions are in reality mosaic or sparse trees like in South-East China and Rondonia in Brazil. Besides, some populated forested areas should rather be classified as sparse trees or cropland use systems like in North Argentina, North Surinam and Iceland. One remark concerned densely populated croplands which do not appear in Indian rural areas. Finally, some areas are wrongly classified as land use systems with extensive livestock whereas it is intensive like in the Northern part of the Netherlands and in Northern Italy.

The remarks as well as a map locating these remarks are available in Annex 15 .

Validation of model outcomes

Due to lack of historical calibration and input data, historical validation of the model is impossible at the moment. We therefore chose to validate the location of land use change and the type of LUS conversions based on expert judgment and by comparing the model outcomes with recent literature on deforestation hotspots, and typical conversion patterns per region. The implicit assumption of the scenario used to simulate LUS changes over time is that there are no fundamental changes in recent macro-economic and demographic trends and policies. Therefore, the land use change processes observed over the last two decades should be observed as well in the model outcomes.

Lambin, Geist *et al.*, 2003 reported major land use change processes over the past two decades, observed in various regions of the world as well as hotspots of deforestation. Besides, Hansen *et al.* (2008) reported tropical forest clearing during the period 2000-2005 using remotely sensed data. Thus their findings are used to validate the simulation outcomes. Lambin, Geist *et al.*, 2003 reported that forested areas in Latin America gave way predominantly to pastures and this land use change process is adequately simulated by the model, in Northern Argentina and Paraguay as shown in the global maps of LUS (Annex 14).

Nonetheless, the model fails to locate hotspots of deforestation in the arc of deforestation of the Brazilian Amazon. As simulated by the model, forests were predominantly replaced by croplands in Africa and Asia. More particularly for Africa, patterns of deforestation as reported in literature can be found in the model outcomes in Madagascar, Cote d'Ivoire, Nigeria, Liberia, Cameroon and Congo basin. Concerning South-East Asia, deforestation hotspots reported to be located in Sumatra, Borneo, Vietnam, Cambodia and Myanmar can be observed in the model simulations (Annex 14). However, simulated patterns deviate from the hotspots of deforestation reported by Lambin, Geist *et al.*, 2003 and Hansen *et al.* (2008). Besides, as reported by Lambin, Geist *et al.*, 2003, the model simulations shows that most Latin America and Africa increased food production through expansion and intensification of croplands areas, except Western Africa where intensification was limited (see Figure 7). In Western Europe, croplands areas have decreased and this land use change process is properly simulated as shown in Figure 7. In Eastern Africa, pastoral areas are supposed to have decreased even though census data revealed that head of cattle highly increased in the same period, and the densification of livestock in pastoral systems can be observed in global maps of LUS over time as well as in Figure 7.

The model is able to allocate the appropriate amount of land use changes projected by the OECD scenario, at regional scale. Despite remaining concerns regarding the localization of future land use change hotspots, the model also simulates appropriately the type of land use change processes reported in literature. Increasing the spatial resolution of future population and climatic data to 10 km^2 is expected to improve the accuracy of future land use change hotspots, more particularly forest clearing areas.

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Annex 1 Technical description of the model

Technical description of the model	
Model name	IMAGE land allocation module
Version	1.0
Release date	15-11-2009
Simulated processes	Land use change
Domain of applicability	Global environmental assessments
Temporal scale	5 years time-step
Time horizon	2000-2050
Reference system	WGS 1984
Spatial projection	World Eckert IV
Spatial extent	Upper bound:8460600.961 Lower bound:16930490.570 Eastern bound:-8460518.965 Western bound:-16921202.422
Spatial resolution	9.453.139 km / 3581 columns x 1790 rows
User interface	None
Programming language	Python
Platform	Windows
Software requirements	- ArcGIS 9.3.1 - PASW 17.0.1 - SPSS-python integration plugin
Redistribution to third parties	Not applicable
Price	Not applicable

Annex 2 Datasets: sources and references

Dataset name	Organization	Project	Date of acquisition	Date of creation	Resolution	Time-frame	Regular update	Input data	Image substitution	Download	Reference
Population data											
LandScan	ORNL	Global Population Project		2005		2000	Y	Census counts, roads, slope, land cover, nighttime lights, populated places, P-95 circles and rural cells.	Y		http://www.ornl.gov/sci/landscan/landscan2005/
Land use/Land cover data											
Urban extent	NGDC	Global Impervious Surface Area : 2000-01	2000-2001		30 secondes	2000	N	Landsat imagery Night-time lights 2000-01 Landscan 2004	Y	http://www.ngdc.noaa.gov/dmsp/download_global_isa.html	http://www.ngdc.noaa.gov/dmsp/pubs/ISAglobal_20070921-1.pdf
Occurrence of trees and bare soils	GLCF	Vegetation Continuous Field (VCF)	2001	2003	15 secondes	2001	N	MODIS imagery	Y	http://glcf.umiacs.umd.edu/data/vcf/	Hansen M., DeFries R., Townshend J.R., et al. 2003. Vegetation continuous fields MOD44B, 2001 percent tree cover, collection 3. http://glcf.umiacs.umd.edu/data/treecover/. Viewed 25 April 2008.
Inland water bodies: Global Lake and Wetlands Database (GLWD)					30"					http://www.worldwildlife.org/science/data/item1877.html	Lehner, B. and P. Döll (2004): Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology 296/1-4: 1-22.
Global map of irrigated areas version 4.0.1	FAO/Frankfurt University		around 2000	2007	5arc-minutes	2000	N		N	http://www.fao.org/geonetwork/	http://www.geo.uni-frankfurt.de/ipg/ag/dl/f_publikationen/2005/Siebert_et_al_GMIA_HESS_2005.pdf
Global distribution of crops, croplands and pastures (175 in total)	SAGE		circa 2000	2007	5arc-minutes	2000	N	Agricultural inventory data (FAOSTAT) Administrative boundaries Global Agroecological Zone Assessment Multiple-cropping potential Irrigated areas	Y	http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html	Monfreda, C., N. Ramankutty, and J.A. Foley. Farming the planet. Part 2: The geographic distribution of crop areas, yields, physiological types, and npp in the year 2000. Accepted to Global Biogeochemical Cycles.
Global distribution of croplands and pastures	PAGE		circa 2000	2008	5arc-minutes	2000	N	Agricultural inventory data (FAOSTAT) MODIS land cover GLC2000		http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html	Monfreda, C., N. Ramankutty, and J.A. Foley. Farming the planet. Part 1: The geographic distribution of crop areas, yields, physiological types, and npp in the year 2000. Accepted to Global Biogeochemical Cycles.
Livestock											
Livestock density (sheep)	FAO-AGA	GLW: The Gridded Livestock of the World Project		2005	3arc-minutes	2000	N	**Locational** Longitude, latitude **Anthropogenic** Distance to roads and Distance to city lights **Demographic** Human population **Topographic** Elevation **Land cover** Normalized difference vegetation index **Temperature** Land surface temperature, Air temperature and Middle-infrared **Water and moisture** Vapour pressure deficit, Distance to rivers, Cold cloud duration, Potential evapotranspiration **General climatic** Modelled length of growing period **Other** Tsetse distributions (for Africa)	N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (buffaloes)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (goats)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (poultry)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (pigs)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (cattle)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (small ruminant)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Livestock density (bovine)							N		N	http://www.fao.org/geonetwork/	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf
Climate and environmental conditions											
IMAGE climate model	PBL-IMAGE	IMAGE		2006		2000 - 2050	Y		Y	http://www.pbl.nl/en/themasites/image/index.html	Strengers B., Schaeffer M. and Eickhout B., 2006. Climate: Variability, predictability and interactions with land cover in: MNP (2006) (Edited by A.F. Bouwman, T. Kram and K. Klein Goldewijk), Integrated modelling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands, 153-170.2000. Accepted to Global Biogeochemical Cycles.
Net Primary Productivity (NPP)	PBL-IMAGE	IMAGE				2000 - 2050	Y		Y	http://www.pbl.nl/en/themasites/image/index.html	MNP (2006) (Edited by A.F. Bouwman, T. Kram and K. Klein Goldewijk), Integrated modelling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.
Agricultural productivity											
Actual crop yields (175 in total)			circa 2000	2007	5arc-minutes	2000	N	Agricultural census data (FAOSTAT) Administrative boundaries Global Agroecological Zone Assessment Multiple-cropping potential Irrigated areas	N	http://www.sage.wisc.edu/mapsdatamodels.html	Monfreda, C., N. Ramankutty, and J.A. Foley. Farming the planet. Part 2: The geographic distribution of crop areas, yields, physiological types, and npp in the year 2000. Accepted to Global Biogeochemical Cycles.
Potential crop yields (26 crop types incl. grass, 19 also exist as irrigated)	PBL-IMAGE	IMAGE			1/2°	2000 - 2050					
Accessibility											
Accessibility	Wageningen University	IMAGE	2008		5 arc-minutes	-		DCW: World major roads DCW: World railroads DCW: World rivers WorldClim elevation Global Lake and Wetlands Database Global Maritime Ports Database Urban agglomerations over 750,000 inhabitants			
DCW: World roads	ESRI	Digital Chart of the World (DCW)				-				www.esri.com	
DCW: World railroads	ESRI	Digital Chart of the World (DCW)				-				www.esri.com	
DCW: World rivers	ESRI	Digital Chart of the World (DCW)				-				www.esri.com	
Inland water bodies: Global Lake and Wetlands Database (GLWD)					30"	2000				http://www.worldwildlife.org/science/data/item1877.html	Lehner, B. and P. Döll (2004): Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology 296/1-4: 1-22.
Global Maritime Ports Database	General Dynamics Advanced Information Systems					2009				http://www.gd-ais.com//Capabilities/offerings/sr/GGD	http://www.gd-ais.com//Capabilities/offerings/sr/GGDP/GMPDDescription.html
Urban agglomerations over 750,000 inhabitants	UNEP		2000			2000		Census data		http://geodata.grid.unep.ch/index.php	
Soil characteristics											
Soil parameters estimates	ISRIC	RIVM project	-	2004	5 arc-minutes	-	N	Digital Soil Map of the World (DSMW)	N	http://www.pbl.nl/en/themasites/image/index.html	Batjes, N. H.(2004). "Developement of a 5 by 5 arc-minutes global dataset of soil parameter estimates for use with the IMAGE model'. Report 2004/05, ISRIC - World Soil Information, Wageningen.
GDP/PPP											
CIA World Factbook	Central Intelligence Agency	-	-	2008	National level	2000	Y	Census data	Y	https://www.cia.gov/library/publications/the-world-factbook/fields/2004.html	-
Boundaries											
IMAGE regions	PBL-IMAGE	IMAGE		-		2000 - 2050	N		Y	http://www.pbl.nl/en/themasites/image/index.html	

Annex 3 Model inputs - outputs

Inputs/Outputs	Scale	Factor	Units	Scale	Format	Updated at each time-step	Remark
Inputs	Grid-cell level	LUS global map	-	Nominal	GRID*	Yes	See annex 14
		LUS land cover level	-	Ordinal	GRID*	Yes	-
		LUS land use intensity level	-	Ordinal	GRID*	Yes	-
		LUS livestock density level	-	Nominal	GRID*	Yes	-
		Population density	Persons/km2	Ratio	GRID*	Yes	See annex 7
		Time-travel to nearest market place	Hours	Ratio	GRID*	No	-
		Purchasing power parity	$/capita	Ratio	GRID*	Yes	See annex 7
		IMAGE region	-	Nominal	GRID*	No	See annex 2
		Soil cation exchange capacity	-	Nominal	GRID*	No	See annex 2
		Soil clay content	-	Ordinal	GRID*	No	See annex 2
		Soil silt content	-	Ordinal	GRID*	No	See annex 2
		Soil sand content	-	Ordinal	GRID*	No	See annex 2
		Soils clay content	-	Ordinal	GRID*	No	See annex 2
		Soil pH	-	Ordinal	GRID*	No	See annex 2
		Soil drainage	-	Ordinal	GRID*	No	See annex 2
		Altitude	Meters	Ratio	GRID*	No	See annex 2
		Slope	°	Ratio	GRID*	No	See annex 2
		Average annual temperature	°C	Ratio	GRID*	Yes	See annex 2
		Average annual precipitations	mm	Ratio	GRID*	Yes	See annex 2
		Net Primary Productivity	kg/km2/year	Ratio	GRID*	Yes	See annex 2
	Regional level	Macro-economic demand for croplands land cover change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for pastures land cover change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for croplands production change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for rice croplands production change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for bovines density change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for monogastrics density change	%	Ratio	Text	Yes	See annex 8
		Macro-economic demand for small ruminants density change	%	Ratio	Text	Yes	See annex 8
Outputs	Grid-cell level	Likelihood of occurrence for each land use system	-	Ratio	GRID*	Yes	See annex 14
		Rank of land use systems likelihood of occurrence	-	Ratio	GRID*	Yes	See annex 14
		Likelihood of occurrence of croplands	-	Ratio	GRID*	Yes	See annex 14
		Likelihood of occurrence of pastures	-	Ratio	GRID*	Yes	See annex 14
		Likelihood of occurrence of intensive croplands	-	Ratio	GRID*	Yes	See annex 14
		Likelihood of occurrence of intensive rice croplands	-	Ratio	GRID*	Yes	See annex 14
		LUS Land cover levels at t=t+1	-	Ordinal	GRID*	Yes	-
		Land use efficiency levels at t=t+1	-	Ordinal	GRID*	Yes	-
		Livestock density levels at t=t+1	-	Nominal	GRID*	Yes	-
		Land use systems a t=t+1	-	Nominal	GRID*	Yes	-

* Spatial properties of GRID datasets must comply with the model spatial properties described in Annex 1

Text input data must be formatted as shown below, where each row are inputs for each time-step for 24 IMAGE world regions numbered from 1 to 24:

```
Reg_dmd_a_1='(1=10) (2=5) (3=4) (4=3) (5=4) (6=7) (7=3) (8=10) (9=11) (10=9) (11=-2) (12=0) (13=26) (14=-1) (15=2) (16=8) (17=1) (18=12) (19=3) (20=6) (21=8) (22=13) (23=-5) (24=4)'
Reg_dmd_a_2='(1=7) (2=4) (3=8) (4=7) (5=6) (6=7) (7=1) (8=6) (9=9) (10=7) (11=-1) (12=0) (13=18) (14=-1) (15=-1) (16=7) (17=0) (18=9) (19=1) (20=5) (21=8) (22=12) (23=1) (24=3)'
Reg_dmd_a_3='(1=7) (2=3) (3=5) (4=-1) (5=7) (6=5) (7=1) (8=5) (9=6) (10=5) (11=-1) (12=1) (13=12) (14=0) (15=0) (16=5) (17=1) (18=8) (19=-4) (20=4) (21=6) (22=9) (23=-5) (24=3)'
Reg_dmd_a_4='(1=1) (2=0) (3=-1) (4=-1) (5=4) (6=3) (7=-1) (8=9) (9=8) (10=4) (11=-1) (12=-2) (13=6) (14=1) (15=0) (16=1) (17=2) (18=4) (19=-8) (20=1) (21=2) (22=7) (23=-9) (24=3)'
Reg_dmd_a_5='(1=1) (2=1) (3=0) (4=-1) (5=2) (6=3) (7=-1) (8=7) (9=6) (10=3) (11=0) (12=0) (13=5) (14=1) (15=2) (16=2) (17=1) (18=3) (19=-6) (20=0) (21=1) (22=5) (23=-5) (24=3)'
Reg_dmd_a_6='('1=1) (2=0) (3=3) (4=-2) (5=1) (6=3) (7=-1) (8=5) (9=7) (10=2) (11=0) (12=-1) (13=5) (14=1) (15=7) (16=1) (17=2) (18=3) (19=-4) (20=0) (21=1) (22=5) (23=-6) (24=3)'
Reg_dmd_a_7='(1=-2) (2=-2) (3=0) (4=0) (5=-1) (6=0) (7=-1) (8=5) (9=5) (10=3) (11=-1) (12=0) (13=1) (14=0) (15=4) (16=1) (17=1) (18=0) (19=-5) (20=-1) (21=-2) (22=1) (23=-5) (24=2)'
Reg_dmd_a_8='(1=-1) (2=-2) (3=5) (4=1) (5=-1) (6=0) (7=-1) (8=4) (9=2) (10=2) (11=-1) (12=-1) (13=0) (14=0) (15=5) (16=0) (17=1) (18=0) (19=-4) (20=-1) (21=-2) (22=1) (23=-6) (24=1)'
Reg_dmd_a_9='(1=-1) (2=-2) (3=4) (4=4) (5=1) (6=1) (7=-1) (8=5) (9=1) (10=1) (11=-1) (12=1) (13=1) (14=0) (15=5) (16=1) (17=1) (18=0) (19=-3) (20=0) (21=1) (22=1) (23=-6) (24=1)'
Reg_dmd_a_10='(1=-1) (2=-2) (3=0) (4=0) (5=1) (6=1) (7=-1) (8=6) (9=1) (10=1) (11=-1) (12=-1) (13=0) (14=1) (15=38) (16=1) (17=-1) (18=1) (19=-3) (20=0) (21=1) (22=0) (23=-5) (24=2)'
Reg_dmd_a = [Reg_dmd_a_1 , Reg_dmd_a_2 , Reg_dmd_a_3 , Reg_dmd_a_4 , Reg_dmd_a_5 , Reg_dmd_a_6 , Reg_dmd_a_7 , Reg_dmd_a_8 , Reg_dmd_a_9 , Reg_dmd_a_10]
```

Annex 4 Data lineage

Dataset name	**Major market places**
Delivered by	Aurelien Letourneau
Date	4-4-2008
Location	

Dataset	Destinations
Factsheet filled in by	Aurelien Letourneau
Origin	GEODATA (UNEP/GRID) General Dynamics Advanced Information Systems
Description	Location of major market places (i.e. major cities and ports).
Calculation procedure	Selection cities with more than 750,000 inhabitants or capitals from the UNEP major urban agglomerations and conversion to grid. Select ports with harborsize = 'Large' and conversion to grid. Combine destinations.
Uncertainty	
Inputs	UNEP major urban agglomerations with more than 750k Inhabitants. Global Maritime Ports Database.
Outputs	Destinations
Other remarks	
References	http://geodata.grid.unep.ch/ http://www.gd-ais.com//Capabilities/offerings/sr/GGDP/GMPDDescription.html

Dataset name	**Friction map**
Delivered by	Aurelien Letourneau
Date	4-4-2008
Location	

Dataset	Time_vmap
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Friction surface based on the roads, railroads, river networks, the slope and wetlands.
Calculation procedure	Vmap_roads, railroads, rivers are converted to grid. The slope is interpolated from the altitude dataset. Highways with gravel are attributed a speed of 100 km/h. Primary/secondary roads with gravel are attributed a speed of 65 km/h. Tertiary roads with gravel are attributed a speed of 40 km/h. Railroads are attributed a speed of 70 km/h. Rivers are attributed a speed of 10 km/h. Canals are attributed a speed of 5 km/h. The cell off-roads are attributed a speed of 5 km/h. Seas and lakes are attributed a speed of 2 km/h. Gentle slopes (0-10deg) off-roads are attributed a speed of 5 km/h. Moderate slopes (10-30deg) off-roads are attributed a speed of 3 km/h. Steep slopes (>30deg) off-roads are attributed a speed of 1km/h. Marsh and swamps off-roads are attributed a speed of 1km/h. Crossing borders divides the speed by 4. Friction is obtained by attributing the maximum speed for each cell in h/km and converting the speed in m/h.
Uncertainty	
Inputs	DCW major roads of the World (Vmap0) (provided by MNP). DCW rivers (provided by MNP). DCW railroads. WorldClim altitude. Global Lakes and Wetlands Database.
Outputs	
Other remarks	
References	http://www.fao.org/geonetwork/srv/en/main.home http://www.worldclim.org/ http://www.worldwildlife.org/science/data/globallakes.cfm http://mapserver.mnp.nl/portal/ http://www.grid.unep.ch/data/data.php?category=human_related

Dataset name	**Accessibility**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	Accessp_vmap
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Cost in time for a considered location to reach the nearest major urban agglomeration or port.
Calculation procedure	A cost distance computation is used to determine the cost in time between any location on the globe and the nearest urban agglomeration over 750000 inhabitants or major port. The input data are the friction map and the destinations.
Uncertainty	
Inputs	Time_vmap. Destinations.
Outputs	
Other remarks	
References	

Dataset name	**Area covered by grid-cell at 5 arc-minute resolution**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Proj_backgrd
Factsheet filled in by	Aurelien Letourneau
Origin	-
Description	This dataset is the projection in Eckert IV of the cell area dataset in geographic projection. It is used to resample the newly projected data.
Calculation procedure	Cell_area_5m is projected to Eckert IV.
Uncertainty	
Inputs	Cell_area_5m
Outputs	
Other remarks	
References	-

Dataset name	**Mask**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Mask
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	This dataset is used to retrieve only the cells which have data in all the datasets sued for classification and simulation to allow a consistent analysis.
Calculation procedure	All input datasets are projected top Eckert IV and resampled to 9.45x9.45 km. All input datasets are reclassified to 1 where there is data and NoData where there is not. All reclassified datasets are multiplied together.
Uncertainty	
Inputs	Pop_density accessp_vmap Global_bare Global_tree glbgtd1f0503m (goats counts) Pastures Croplands Urban_isa GMIA_V401 Rice Alt
Outputs	
Other remarks	
References	_

Dataset name	**Grid-cell identification**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_cell_id
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	This dataset is used to identify the cells in each raster dataset.
Calculation procedure	Mask is converted to feature data (point). Cell_id.shp is converted to raster with the feature_id as value for the raster. The raster cell_id is multiplied by the mask.
Uncertainty	
Inputs	Mask.
Outputs	
Other remarks	
References	_

Dataset name	**Accessibility resampled**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_access
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Provides the time in hour to reach the nearest market place for each cell.
Calculation procedure	Accessp_vmap resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Accessp_vmap. Proj_backgrd Mask.
Outputs	
Other remarks	
References	

Dataset name	**Area covered by bare soils**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_bare
Factsheet filled in by	Aurelien Letourneau
Origin	Vegetation Continuous Fields (GLCF)
Description	Fraction of each cell covered with bare soils.
Calculation procedure	Global_bare is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Global_bare. Proj_backgrd Mask.
Outputs	
Other remarks	
References	http://glcf.umiacs.umd.edu/data/vcf/

Dataset name	**Areas covered by trees**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_tree
Factsheet filled in by	Aurelien Letourneau
Origin	Vegetation Continuous Fields (GLCF)
Description	Fraction of each cell covered with trees.
Calculation procedure	Global_trees is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Global_trees. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://glcf.umiacs.umd.edu/data/vcf/

Dataset name	**Area covered by pastures**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_pasture
Factsheet filled in by	Aurelien Letourneau
Origin	PAGE
Description	Fraction of each cell covered with pastures, defined as permanent pastures according to FAO.
Calculation procedure	Pastures is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Pastures Proj_backgrd Mask
Outputs	
Other remarks	
References	http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html

Dataset name	**Area covered by croplands**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_crop
Factsheet filled in by	Aurelien Letourneau
Origin	PAGE
Description	Fraction of each cell covered with croplands.
Calculation procedure	Cropland is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Cropland. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html

Dataset name	**Built-up area**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_urban
Factsheet filled in by	Aurelien Letourneau
Origin	NGDC
Description	Fraction of each cell which is built-up.
Calculation procedure	Urban_isa is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. NoData are reclassified to 0. The resampled and reclassified data are finally multiplied by the mask.
Uncertainty	
Inputs	urban_isa. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.ngdc.noaa.gov/dmsp/download_global_isa.html

Dataset name	**Irrigated areas**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_irrig
Factsheet filled in by	Aurelien Letourneau
Origin	FAO/Frankfurt University
Description	Fraction of each cell which is irrigated.
Calculation procedure	Gmia is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	GMIA_V401. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.geo.uni-frankfurt.de/ipg/ag/dl/f_publikationen/2005/Siebert_et_al_GMIA_HESS_2005.pdf

Dataset name	**Area covered by rice cultivation**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_rice
Factsheet filled in by	Aurelien Letourneau
Origin	SAGE
Description	Fraction of each cell covered with rice croplands.
Calculation procedure	Rice is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Rice. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html

Dataset name	**Population density**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_pop_d
Factsheet filled in by	Aurelien Letourneau
Origin	ORNL
Description	Global population density.
Calculation procedure	Popdens_ls05 is projected from geographic to Eckert IV. The projected data are resampled to 9.45x9.45 km resolution. The resampled data are finally multiplied by the mask.
Uncertainty	
Inputs	Pop_density Proj_backgrd Mask
Outputs	
Other remarks	
References	http://www.ornl.gov/sci/landscan/landscan2005/

Dataset name	**Bovines density**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_bovines
Factsheet filled in by	Aurelien Letourneau
Origin	FAO – Gridded livestock of the World
Description	This dataset provides the density of bovines per km2 in each grid-cell.
Calculation procedure	glbbvd1f0503m is resampled to 5 arc-minutes resolution. glbbvd1f0503m is projected to Eckert IV and resampled to 9.45x9.45 km resolution. glbbvd1f0503m is multiplied by the mask.
Uncertainty	
Inputs	glbbvd1f0503m. Proj_backgrd Mask.
Outputs	
Other remarks	
References	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf

Dataset name	**Sheep density**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_sheeps
Factsheet filled in by	Aurelien Letourneau
Origin	FAO – Gridded livestock of the World
Description	This dataset provides the density of sheeps per km2 in each grid-cell.
Calculation procedure	glbshd1f0503m is resampled to 5 arc-minutes resolution. glbshd1f0503m is projected to Eckert IV and resampled to 9.45x9.45 km resolution. glbshd1f0503m is multiplied by the mask.
Uncertainty	
Inputs	glbshd1f0503m. Proj_backgrd Mask.
Outputs	
Other remarks	
References	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf

Dataset name	**Goats density**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_goats
Factsheet filled in by	Aurelien Letourneau
Origin	FAO – Gridded livestock of the World
Description	This dataset provides the density of goats per km2 in each grid-cell.
Calculation procedure	glbgtd1f0503m is reclassified, values ≤ 0 are attributed the value 0. glbgtd1f0503m is resampled to 5 arc-minutes resolution. glbgtd1f0503m is projected to Eckert IV and resampled to 9.45x9.45 km resolution. glbgtd1f0503m is multiplied by the mask.
Uncertainty	
Inputs	glbgtd1f0503m. Proj_backgrd Mask.
Outputs	
Other remarks	
References	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf

Dataset name **Pigs density**
Delivered by Aurelien Letourneau
Date 20-10-2008
Location Wageningen

Dataset	Times_pigs
Factsheet filled in by	Aurelien Letourneau
Origin	FAO – Gridded livestock of the World
Description	This dataset provides the density of pigs per km2 in each grid-cell.
Calculation procedure	glbpgd1f0503m is resampled to 5 arc-minutes resolution. glbpgd1f0503m is projected to Eckert IV and resampled to 9.45x9.45 km resolution. glbpgd1f0503m is multiplied by the mask.
Uncertainty	
Inputs	glbpgd1f0503m. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf

Dataset name **Chicken density**
Delivered by Aurelien Letourneau
Date 20-10-2008
Location Wageningen

Dataset	Times_poultry
Factsheet filled in by	Aurelien Letourneau
Origin	FAO – Gridded livestock of the World
Description	This dataset provides the density of chickens per km2 in each grid-cell.
Calculation procedure	glbpod1f0503m is resampled to 5 arc-minutes resolution. glbpod1f0503m is projected to Eckert IV and resampled to 9.45x9.45 km resolution. glbpod1f0503m is multiplied by the mask.
Uncertainty	
Inputs	glbpod1f0503m. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	ftp://ftp.fao.org/docrep/fao/010/a1259e/a1259e00.pdf

Dataset name	**Average altitude**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_alt
Factsheet filled in by	Aurelien Letourneau
Origin	WorldClim University of Berkeley CIAT Rainforest CRC
Description	This dataset provides the altitude of each grid-cell.
Calculation procedure	alt is projected to Eckert IV. alt is resampled to 9.45x9.45 km resolution. alt is multiplied by the mask.
Uncertainty	
Inputs	alt. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.worldclim.org/methods.htm http://www.worldclim.org/worldclim_IJC.pdf

Dataset name	**Average slope**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_slope
Factsheet filled in by	Aurelien Letourneau
Origin	WorldClim University of Berkeley CIAT Rainforest CRC
Description	This dataset provides the slope in degrees of each grid-cell.
Calculation procedure	alt is projected to Eckert IV. Alt is resampled to 9.45x9.45 km resolution. The slope is derived in each grid-cell. Slope_alt_rs1 is multiplied by the mask.
Uncertainty	
Inputs	alt. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	http://www.worldclim.org/methods.htm http://www.worldclim.org/worldclim_IJC.pdf

Dataset name	**Average annual precipitation**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_precXXXX
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE
Description	This dataset provides the average annual precipitations in each grid-cell for the year XXXX ranging from 2000 up to 2050.
Calculation procedure	Prec_XXXX is projected to Eckert IV. Prec_XXXX is resampled to 9.45x9.45 km resolution. Prec_XXXX is multiplied by the mask.
Uncertainty	
Inputs	prec_XXXX. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Average annual temperature**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_tempXXXX
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE
Description	This dataset provides the average annual temperature in each grid-cell for the year XXXX ranging from 2000 up to 2050.
Calculation procedure	temp_XXXX is projected to Eckert IV. temp_XXXX is resampled to 9.45x9.45 km resolution. temp_XXXX is multiplied by the mask.
Uncertainty	
Inputs	temp_XXXX. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Average annual net primaty productivity (NPP)**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_nppXXXX
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE
Description	This dataset provides the average annual NPP in each grid-cell for the year XXXX ranging from 2000 up to 2050.
Calculation procedure	npp_XXXX is projected to Eckert IV. npp_XXXX is resampled to 9.45x9.45 km resolution. npp_XXXX is multiplied by the mask.
Uncertainty	
Inputs	npp_XXXX. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil cation exhange capacity (CEC)**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_cecs
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil cation exhange capacity in the subsoil of each grid-cell.
Calculation procedure	Cec_sub is projected to Eckert IV. Cec_sub is resampled to 9.45x9.45 km resolution. Cec_sub is multiplied by the mask.
Uncertainty	
Inputs	Cec_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil clay content**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_clays
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil clay content in the subsoil of each grid-cell.
Calculation procedure	Clay_sub is projected to Eckert IV. Clay_sub is resampled to 9.45x9.45 km resolution. Clay_sub is multiplied by the mask.
Uncertainty	
Inputs	Clay_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil drainage capacity**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_drain
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil drainage capacity of each grid-cell.
Calculation procedure	drainage is projected to Eckert IV. drainage is resampled to 9.45x9.45 km resolution. drainage is multiplied by the mask.
Uncertainty	
Inputs	drainage. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil organic carbon content**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_orgcs
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil organic carbon content in the subsoil of each grid-cell.
Calculation procedure	Carbon_sub is projected to Eckert IV. Carbon_sub is resampled to 9.45x9.45 km resolution. Carbon_sub is multiplied by the mask.
Uncertainty	
Inputs	Carbon_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil pH**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_ph_s
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil pH in the subsoil of each grid-cell.
Calculation procedure	pH_sub is projected to Eckert IV. pH_sub is resampled to 9.45x9.45 km resolution. pH_sub is multiplied by the mask.
Uncertainty	
Inputs	pH_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil sand content**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_sands
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil sand content in the subsoil of each grid-cell.
Calculation procedure	sand_sub is projected to Eckert IV. sand_sub is resampled to 9.45x9.45 km resolution. sand_sub is multiplied by the mask.
Uncertainty	
Inputs	sand_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Soil silt content**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_silts
Factsheet filled in by	Aurelien Letourneau
Origin	ISRIC/RIVM
Description	This dataset provides the soil silt content in the subsoil of each grid-cell.
Calculation procedure	Silt_sub is projected to Eckert IV. Silt_sub is resampled to 9.45x9.45 km resolution. Silt_sub is multiplied by the mask.
Uncertainty	
Inputs	Silt_sub. Proj_backgrd. Mask.
Outputs	
Other remarks	
References	

Dataset name	**Average purchasing power parity (PPP) per capita**
Delivered by	Aurelien Letourneau
Date	20-10-2008
Location	Wageningen

Dataset	Times_ppp
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	This dataset provides the average Purchasing Power Parity (PPP) per capita in each grid-cell.
Calculation procedure	Accessp_vmap and ppp_cia are resampled to 5 arc-minutes. ppp_cia is reclassified to 1=value exists and 0=NoData. ppp_cia_mask is used to mask accessp_vmap. The log of accessp_vmap is computed. The result is bound between 2 and -2 (con > 2 becomes 2 con < -2 becomes -2). The result is scaled between 0 and 1. The inverse of scaled accessibility is computed. The accessibility is multiplied with the PPP.
Uncertainty	
Inputs	Accessp_vmap. PPP_CIA. Mask.
Outputs	
Other remarks	Downscaled average national PPP per capita using accessibility.
References	

Dataset name	**Wheat potential productivity**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	potprod_w
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Potential productivity of wheat in tons per hectare.
Calculation procedure	The highest productivity between spring and winter wheat is allocated to each cell. Productivity is converted from kg/Ha to tons/ha.
Uncertainty	
Inputs	GPOTCP_45_27 (Irrigated spring wheat) GPOTCP_45_28 (Irrigated winter wheat)
Outputs	
Other remarks	
References	

Dataset name	**Rice potential productivity**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	potprod_r
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE crop model
Description	Potential productivity of rice in tons per hectare.
Calculation procedure	Productivity is converted from kg/Ha to tons/ha.
Uncertainty	
Inputs	GPOTCP_45_29 (Irrigated rice)
Outputs	potprod_r
Other remarks	
References	-

Dataset name	**Maize potential productivity**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	potprod_m
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE crop model
Description	Potential productivity of maize in tons per hectare.
Calculation procedure	The highest productivity between temperate and tropical maize is allocated to each cell. Productivity is converted from kg/Ha to tons/ha.
Uncertainty	
Inputs	GPOTCP_45_30 (Irrigated temperate maize) GPOTCP_45_31 (Irrigated temperate maize)
Outputs	potprod_m
Other remarks	
References	-

Dataset name	**Combined Wheat and Maize potential productivity**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	potprod_wm
Factsheet filled in by	Aurelien Letourneau
Origin	IMAGE crop model
Description	Potential productivity of wheat and maize in tons per hectare.
Calculation procedure	The total cover of wheat and maize crop is computed within each cell. The share of wheat and maize over the total cover is computed within each cell. The potential production of wheat and maize are multiplied by their respective shares and then summed.
Uncertainty	
Inputs	wheat maize potprod_w potprod_m
Outputs	potprod_wm
Other remarks	
References	

Dataset name	**Wheat production efficiency per land use system**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	eff_wheat
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Provides the ratio between actual and potential productivity for each grid-cell.
Calculation procedure	The actual productivity is divided by the potential productivity, providing the production efficiency within each grid-cell.
Uncertainty	
Inputs	potprod_w wheat_y
Outputs	eff_wheat
Other remarks	Production efficiencies are constrained between 0 and 1.
References	

Dataset name	**Maize production efficiency per land use system**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	eff_maize
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Provides ratio between actual and potential productivity for each grid-cell.
Calculation procedure	The actual productivity is divided by the potential productivity, providing the production efficiency within each grid-cell.
Uncertainty	
Inputs	potprod_m maize_y
Outputs	eff_maize
Other remarks	Production efficiencies are constrained between 0 and 1.
References	

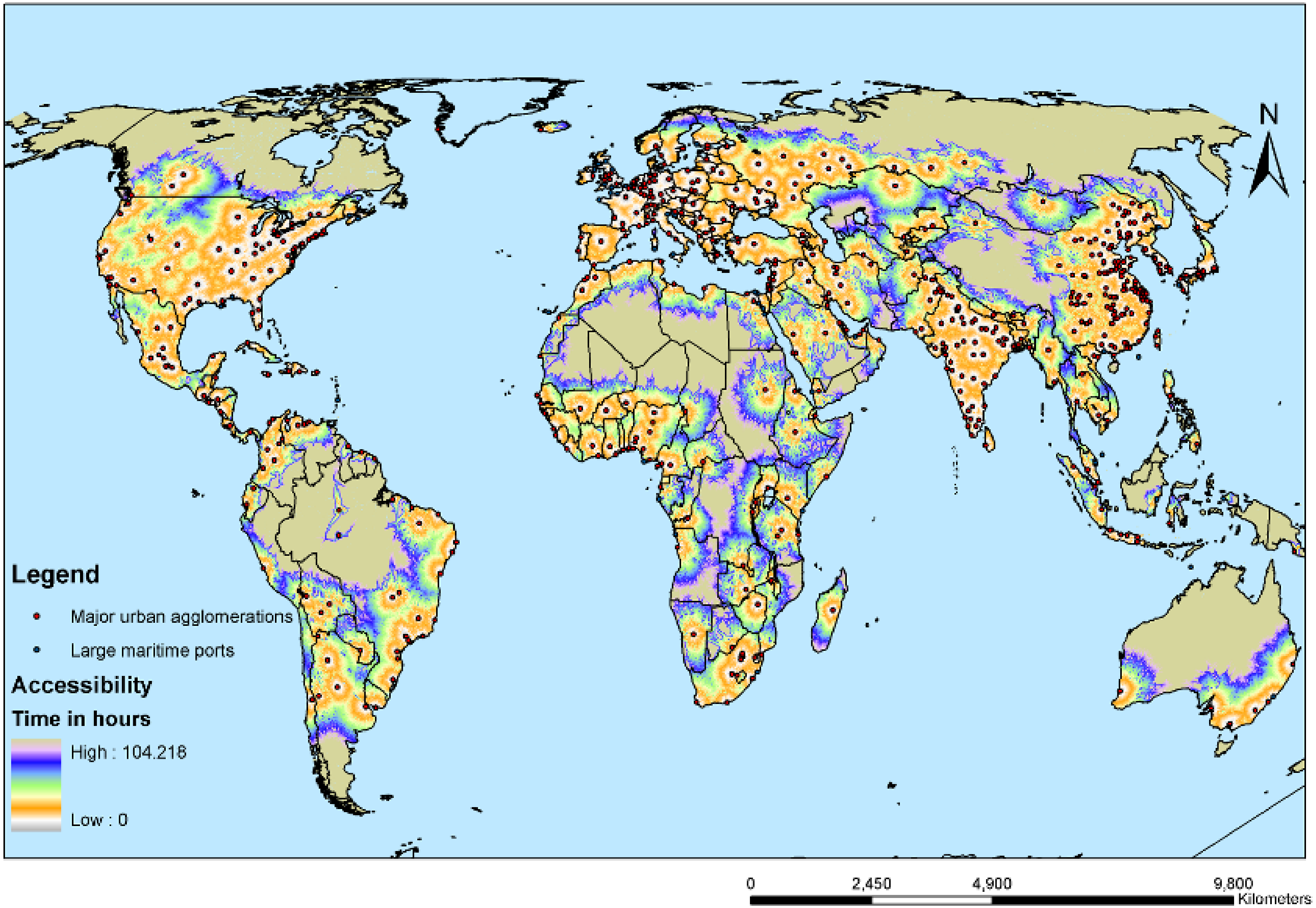
Dataset name	**Rice production efficiency per land use system**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	Eff_rice
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Provides the ratio between actual and potential productivity for each grid-cell.
Calculation procedure	The actual productivity is divided by the potential productivity, providing the production efficiency within each grid-cell.
Uncertainty	
Inputs	potprod_r rice_y
Outputs	Eff_rice
Other remarks	Production efficiencies are constrained between 0 and 1.
References	

Dataset name	**Combined production efficiency index for wheat and maize per LUS**
Delivered by	Aurelien Letourneau
Date	27-6-2008
Location	

Dataset	eff_WM
Factsheet filled in by	Aurelien Letourneau
Origin	Own calculation
Description	Provides the production efficiency index for wheat and maize for each grid-cell.
Calculation procedure	The total cover of wheat and maize crop is computed within each cell. The share of wheat and maize over the total cover is computed within each cell. The production efficiency of wheat and maize are multiplied by their respective shares and then summed.
Uncertainty	
Inputs	wheat maize eff_wheat eff_maize
Outputs	eff_WM
Other remarks	Production efficiencies are constrained between 0 and 1.
References	

Annex 5 Global accessibility map



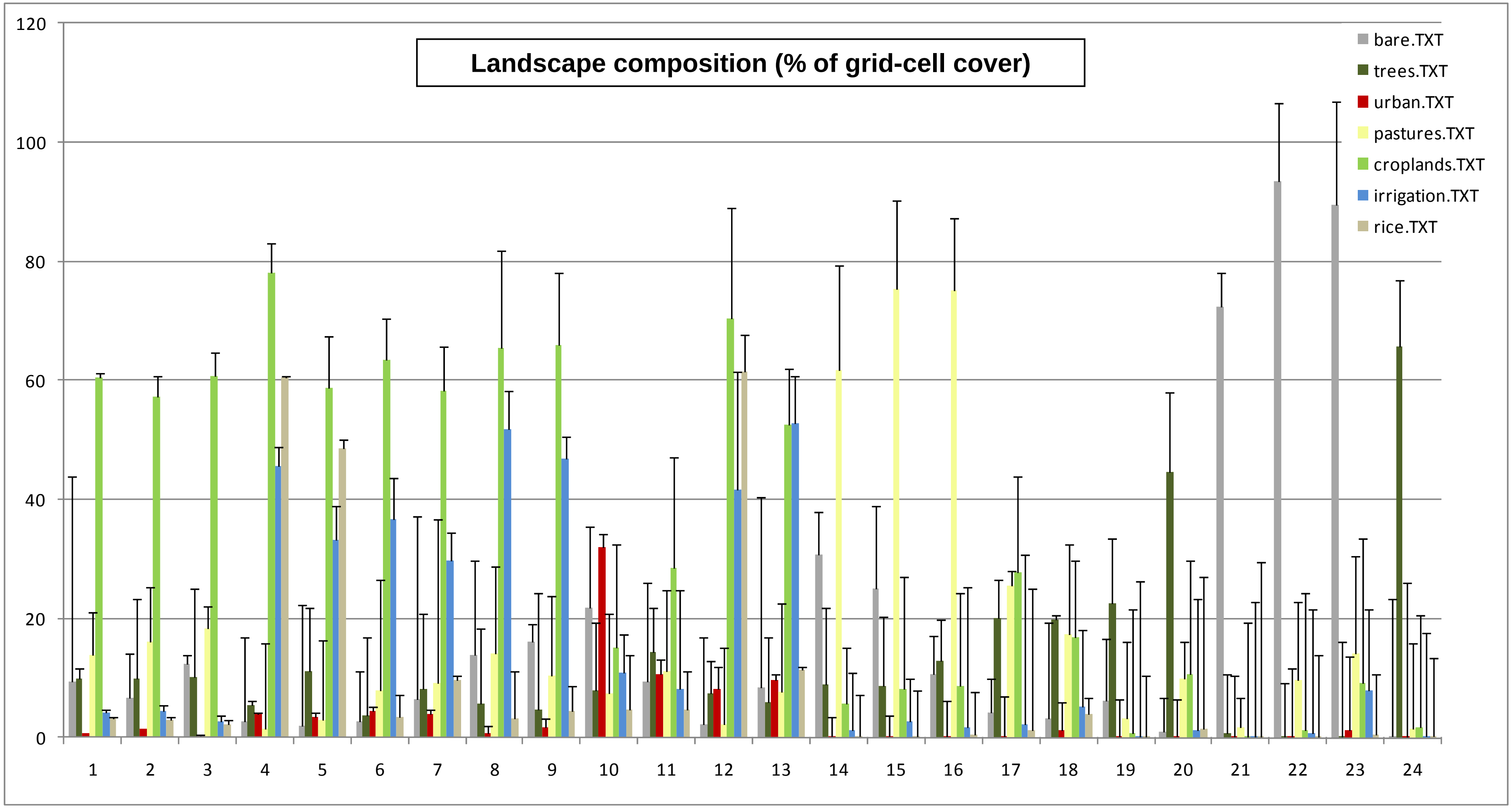
Annex 6 Land use systems profiles

Average parameters value per LUS

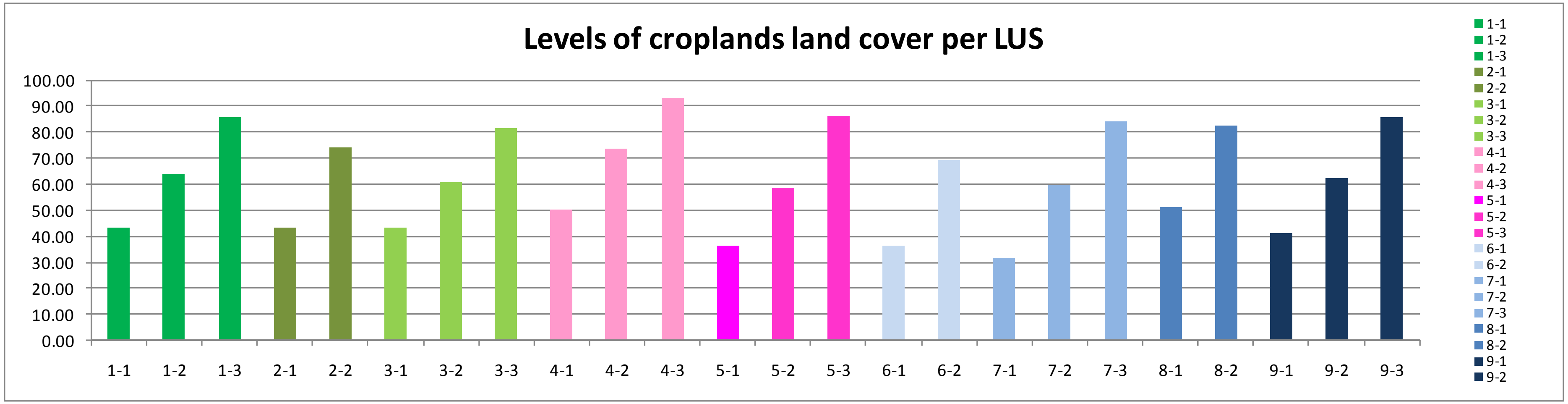
Major category	Label	LUS number	Population density	Accessibility	PPP	Bare soils	Tree cover	Urban	Pastures	Croplands	Irrigated	Rice	Efficiency (wheat and maize)	Efficiency (rice)	Bovines	Small ruminants	Monogastrics
			Persons/km2	Time travel (hours)	$ per capita	% cell cover							Actual prod/Potential prod		LU/km2		
Croplands	Accessible rainfed croplands	1	103.436	2.715	4869.806	9.371	9.830	.815	13.827	60.592	4.113	3.317	.414	.185	19.978	3.015	8.627
	Rainfed croplands with intensive livestock breeding	2	156.490	3.130	6780.586	6.573	9.901	1.365	16.027	57.159	4.577	2.908	.478	.176	49.874	7.582	57.986
	Remote rainfed croplands	3	33.215	6.900	1164.487	12.447	10.205	.206	18.317	60.701	2.686	2.147	.284	.159	12.407	1.405	4.343
	Rice croplands with intensive bovines breeding	4	585.069	3.233	615.904	2.834	5.443	4.006	1.401	78.169	45.543	60.519	.658	.311	98.011	13.345	6.981
	Rice croplands with intensive bovines and monogastrics breeding	5	491.505	3.699	985.065	1.913	11.164	3.420	3.012	58.777	33.175	48.658	.365	.506	20.602	2.985	35.059
	Partly irrigated croplands with intensive livestock breeding	6	623.018	2.188	3428.364	2.709	3.596	4.523	7.958	63.407	36.627	3.386	.624	.423	62.454	26.845	120.927
	Partly irrigated croplands with extensive livestock breeding	7	525.067	2.136	2587.095	6.556	8.293	3.919	9.266	58.161	29.755	9.687	.477	.403	36.282	5.810	29.409
	Irrigated croplands with extensive livestock breeding	8	91.500	3.599	4883.952	13.869	5.780	.799	14.025	65.513	51.856	3.161	.504	.325	19.972	2.538	13.563
	Irrigated croplands with intensive bovines breeding	9	224.084	3.384	1601.428	16.034	4.685	1.814	10.315	66.037	46.933	4.496	.527	.243	44.042	6.394	5.065
Dense settlements	Urban areas	10	3829.793	4.529	10658.280	21.849	7.987	31.947	7.461	15.050	10.913	4.749	.234	.198	11.734	2.065	7.844
	Dense settlements	11	944.435	2.390	8789.006	9.534	14.285	10.661	11.274	28.466	8.272	4.725	.357	.244	16.411	2.661	15.805
	Villages with rice croplands	12	1202.484	2.678	942.730	2.134	7.344	8.205	2.275	70.417	41.672	61.567	.560	.421	65.990	12.093	31.478
	Villages with irrigated croplands	13	1246.246	2.015	3059.088	8.328	6.002	9.594	7.688	52.639	52.746	11.526	.516	.438	31.790	6.867	33.362
Pastures	Extensive pastures	14	13.513	10.220	837.492	30.767	8.951	.060	61.858	5.757	1.120	.156	.125	.139	6.799	1.821	1.509
	Intensive pastures with bovines and small ruminants	15	35.386	10.965	3594.152	25.020	8.601	.234	75.257	8.269	2.613	.107	.219	.138	55.683	39.594	12.269
	Intensive pastures with bovines	16	20.463	7.690	1074.618	10.541	12.966	.086	75.027	8.675	1.753	.421	.306	.239	50.914	4.999	2.696
Mosaic	Mosaic area	17	28.822	5.652	2809.883	4.329	19.975	.164	25.491	27.715	2.328	1.290	.299	.193	16.452	1.863	5.609
	Populated mosaic area	18	186.011	4.321	2557.870	3.133	19.800	1.345	17.276	16.954	5.204	4.039	.333	.313	20.792	2.863	16.068
Sparse trees	Sparse trees	19	1.440	52.355	1.088	6.232	22.468	.005	3.156	.643	.036	.050	.012	.023	1.203	.216	.169
Forests	Populated forested areas	20	37.784	8.997	2250.759	.878	44.552	.275	10.010	10.744	1.138	1.540	.205	.194	9.068	1.085	6.242
Bare soils	Remote bare soils	21	.340	60.093	20.083	72.478	.676	.000	1.846	.035	.016	.001	.004	.012	.187	.094	.073
	Accessible bare soils	22	4.244	10.325	569.926	93.482	.077	.020	9.793	1.140	.646	.027	.040	.045	1.163	1.305	.561
	Populated area with bare soils	23	162.189	5.826	1639.128	89.427	.098	1.357	14.035	9.193	7.924	.375	.144	.104	7.600	5.933	1.972
Forests	Remote forests	24	4.742	23.124	837.023	.204	65.806	.024	1.378	1.725	.126	.198	.049	.075	2.063	.249	1.290

Standard deviation of each parameter per LUS class

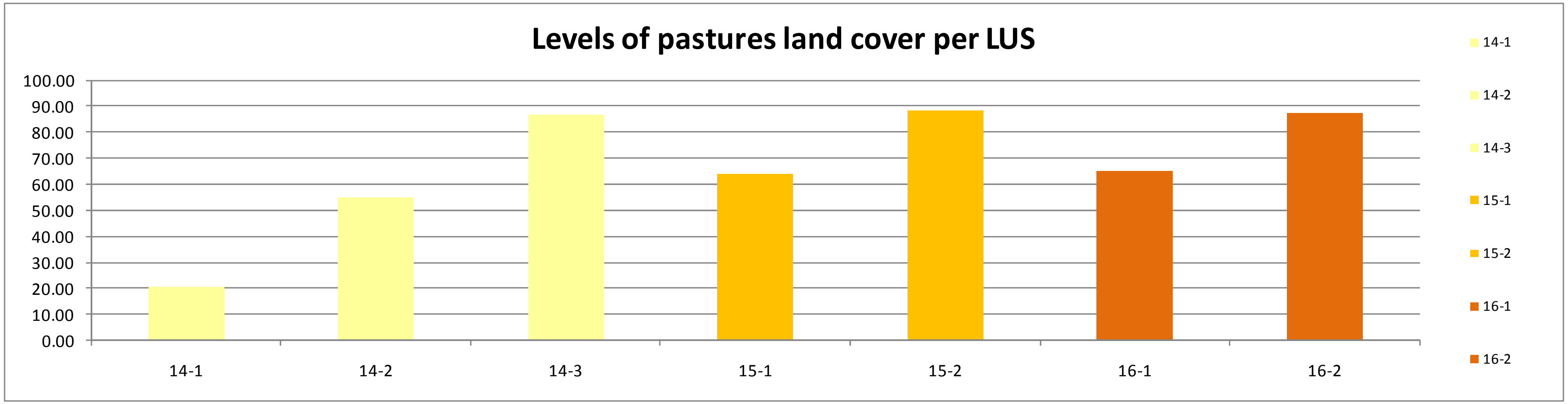
Major category	Label	LUS number	Population density	Accessibility	PPP	Bare soils	Tree cover	Urban	Pastures	Croplands	Irrigated	Rice	Efficiency (wheat and maize)	Efficiency (rice)	Bovines	Small ruminants	Monogastrics
			Persons/km2	Time travel (hours)	$ per capita	% cell cover							Actual prod/Potential prod		LU/km2		
Croplands	Accessible rainfed croplands	1	6.026	74.959	254.245	34.400	1.737	.038	7.155	.566	.562	.043	.105	.055	1.784	1.464	1.537
	Rainfed croplands with intensive livestock breeding	2	14.473	36.115	61.018	7.677	13.303	.143	9.317	3.487	.809	.579	.086	.086	6.438	2.123	1.322
	Remote rainfed croplands	3	14.790	23.477	2643.450	1.324	14.939	.305	3.723	4.072	1.057	.932	.171	.172	8.547	2.099	5.667
	Rice croplands with intensive bovines breeding	4	21.989	15.941	1832.417	13.936	.772	.304	14.498	4.825	3.398	.238	.185	.153	26.450	6.781	5.432
	Rice croplands with intensive bovines and monogastrics breeding	5	36.350	3.807	2458.807	20.421	10.548	.673	13.350	8.651	5.701	1.327	.245	.351	31.142	9.650	7.198
	Partly irrigated croplands with intensive livestock breeding	6	37.573	3.742	4504.468	8.534	13.323	.776	18.692	7.085	7.029	3.897	.256	.290	59.500	5.781	14.486
	Partly irrigated croplands with extensive livestock breeding	7	41.885	11.891	2254.752	30.728	12.413	.671	27.473	7.558	4.823	.756	.252	.229	23.924	4.613	7.864
	Irrigated croplands with extensive livestock breeding	8	64.396	3.871	1678.999	15.889	12.496	1.123	14.622	16.406	6.293	8.039	.243	.239	39.057	4.367	10.146
	Irrigated croplands with intensive bovines breeding	9	85.150	20.045	4439.113	3.154	19.634	1.508	13.364	12.102	3.724	4.111	.258	.298	17.882	4.528	16.229
Dense settlements	Urban areas	10	123.976	1.122	5558.822	13.717	11.425	2.321	13.242	17.523	6.461	9.215	.275	.293	20.233	4.742	13.456
	Dense settlements	11	126.999	1.969	5453.894	16.587	7.581	2.412	13.636	18.702	16.607	6.511	.336	.278	32.491	7.209	31.641
	Villages with rice croplands	12	134.369	1.547	3082.672	14.742	5.591	3.722	12.838	18.621	19.750	6.184	.237	.267	39.819	5.559	11.559
	Villages with irrigated croplands	13	151.006	10.162	5652.890	32.202	10.773	1.162	14.855	9.251	7.955	.419	.276	.351	85.163	48.321	53.403
Pastures	Extensive pastures	14	174.659	3.983	5109.990	7.181	12.942	3.386	17.383	9.387	9.899	6.920	.292	.324	26.023	5.675	28.372
	Intensive pastures with bovines and small ruminants	15	185.403	1.767	6930.845	13.967	11.619	3.582	15.112	18.676	7.201	7.859	.294	.359	49.817	17.835	68.557
	Intensive pastures with bovines	16	219.668	1.076	5523.352	6.647	6.957	6.091	12.340	15.664	23.461	7.186	.365	.194	67.001	22.882	90.225
Mosaic	Mosaic area	17	255.335	1.577	376.903	5.579	6.676	6.811	2.641	16.129	28.399	23.855	.119	.326	36.134	14.528	9.755
	Populated mosaic area	18	265.627	4.028	3577.775	16.271	.674	4.608	15.141	12.855	12.878	2.569	.230	.246	28.624	16.521	4.547
Sparse trees	Sparse trees	19	267.424	.995	4457.676	10.374	10.975	6.396	12.996	20.884	26.319	10.297	.318	.286	34.992	6.003	38.623
Forests	Populated forested areas	20	273.832	1.962	1138.854	5.751	13.407	6.222	6.168	18.897	22.223	25.582	.223	.328	24.291	5.348	39.410
Bare soils	Remote bare soils	21	484.277	1.552	850.417	5.533	9.946	10.489	4.803	19.220	22.802	29.434	.210	.390	55.668	15.469	55.524
	Accessible bare soils	22	770.745	1.467	4377.207	13.110	9.202	11.595	12.898	23.166	21.035	13.790	.302	.300	45.771	10.264	57.050
	Populated area with bare soils	23	821.051	4.683	10236.750	17.507	16.070	12.302	16.506	24.217	13.614	10.336	.306	.341	31.839	6.600	33.546
Forests	Remote forests	24	3968.514	11.911	12536.189	23.144	11.156	26.022	14.568	18.859	17.579	13.169	.275	.329	46.870	8.442	21.886

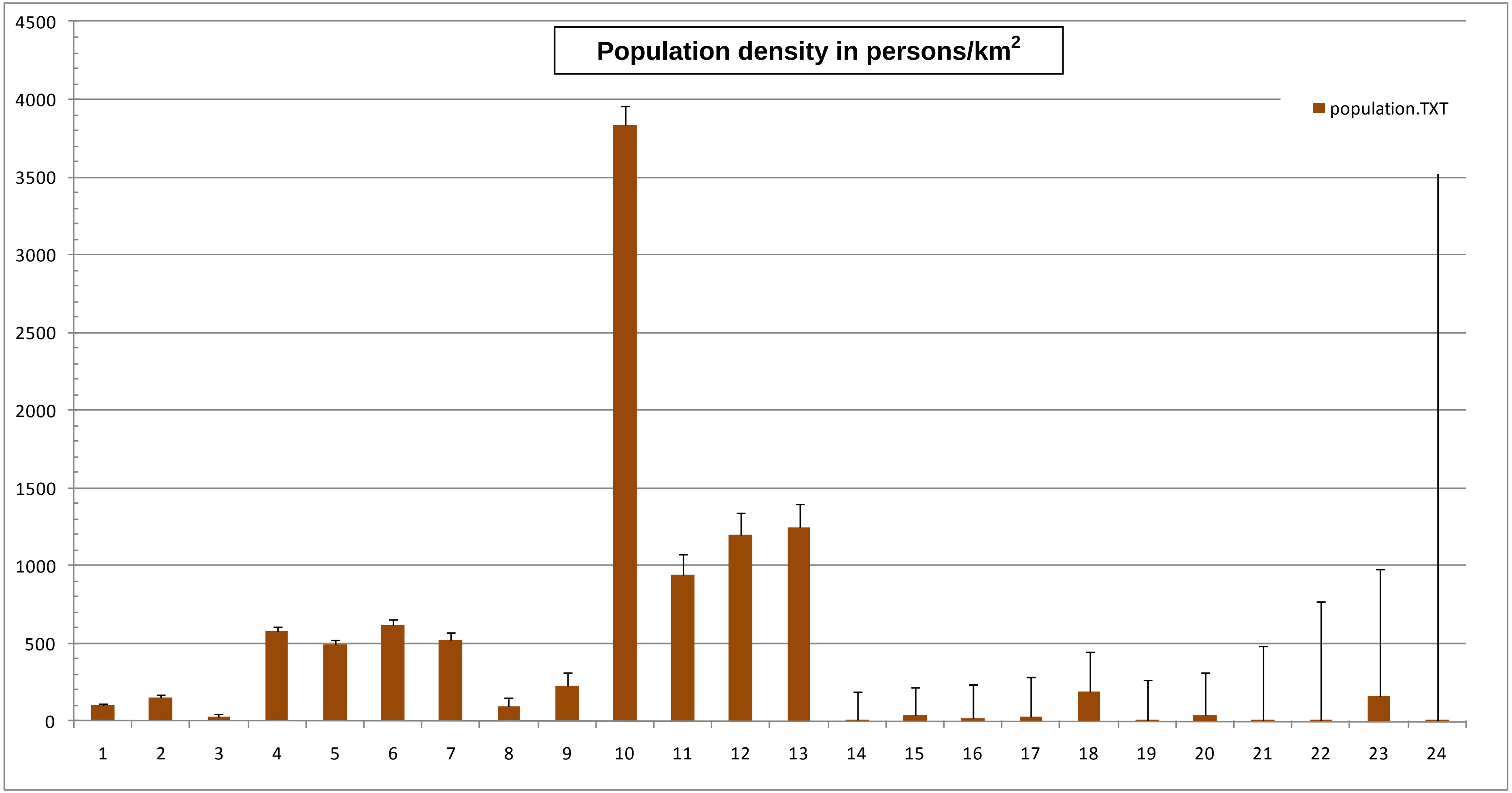

Landscape composition (% of grid-cell cover)
bare.TXT
trees.TXT
urban.TXT
pastures.TXT
croplands.TXT
irrigation.TXT
rice.TXT
0
20
40
60
80
100
120
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

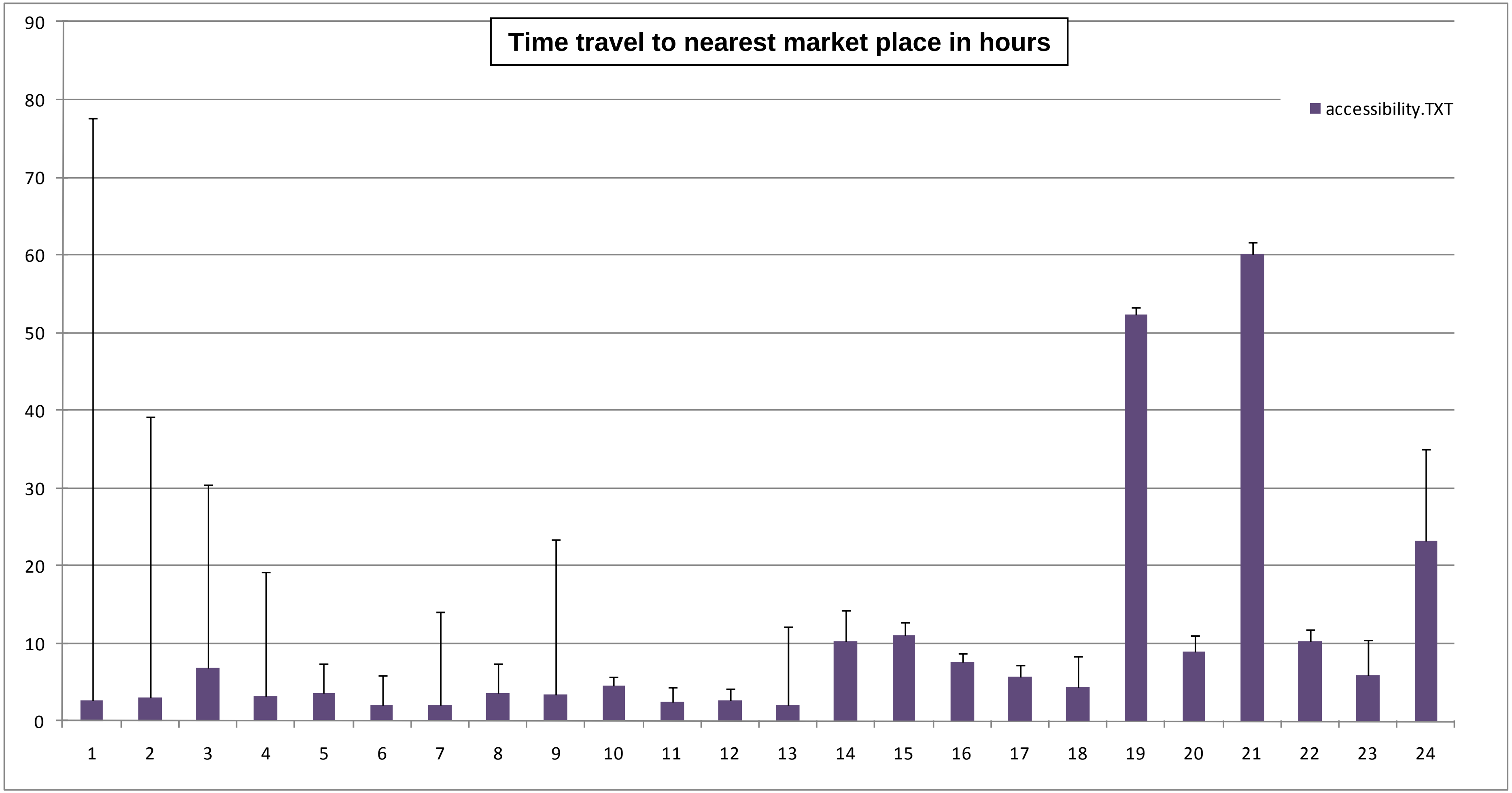
Levels of croplands land cover per croplands systems

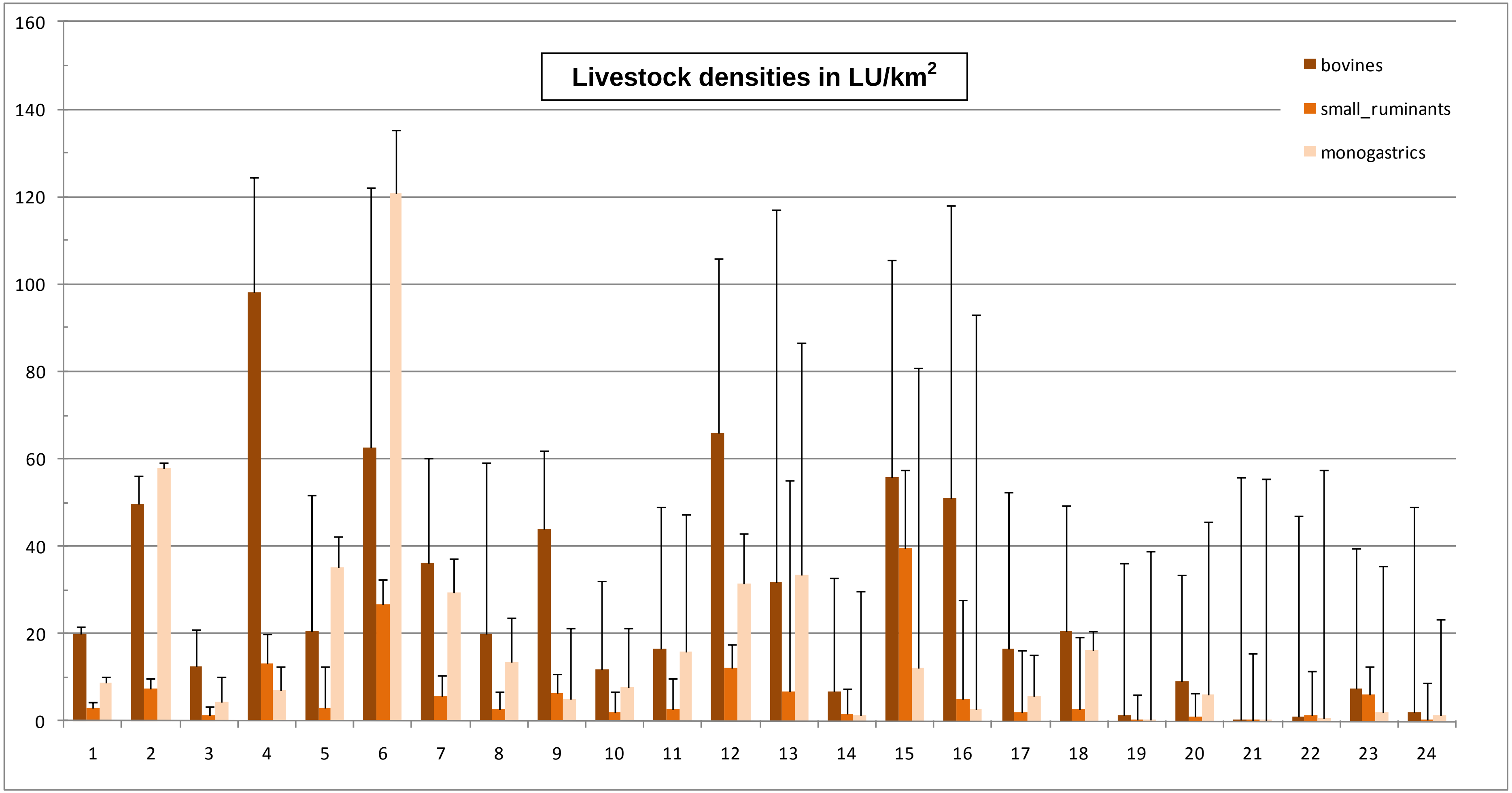


Levels of pastures land cover per pastoral systems

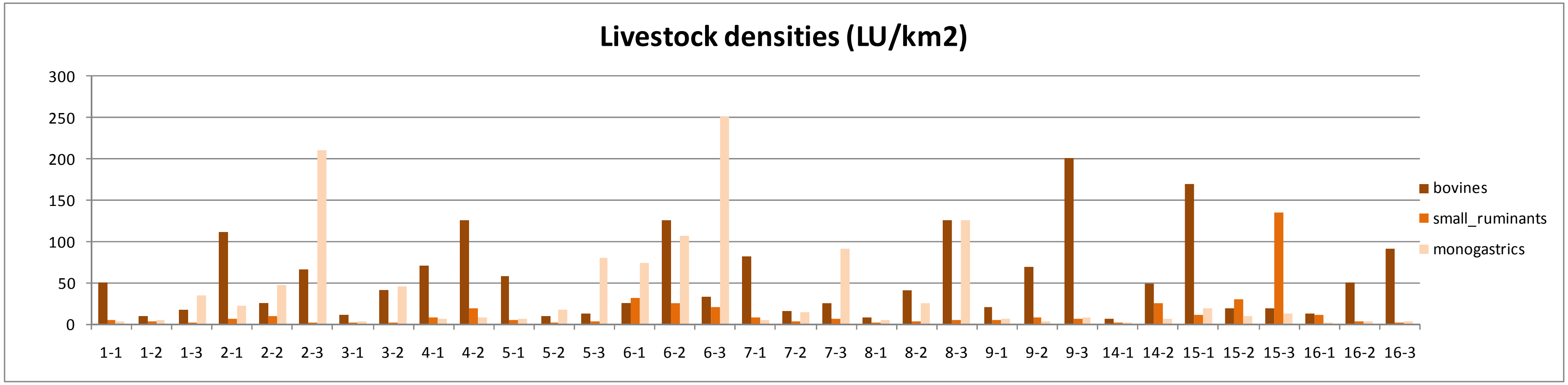


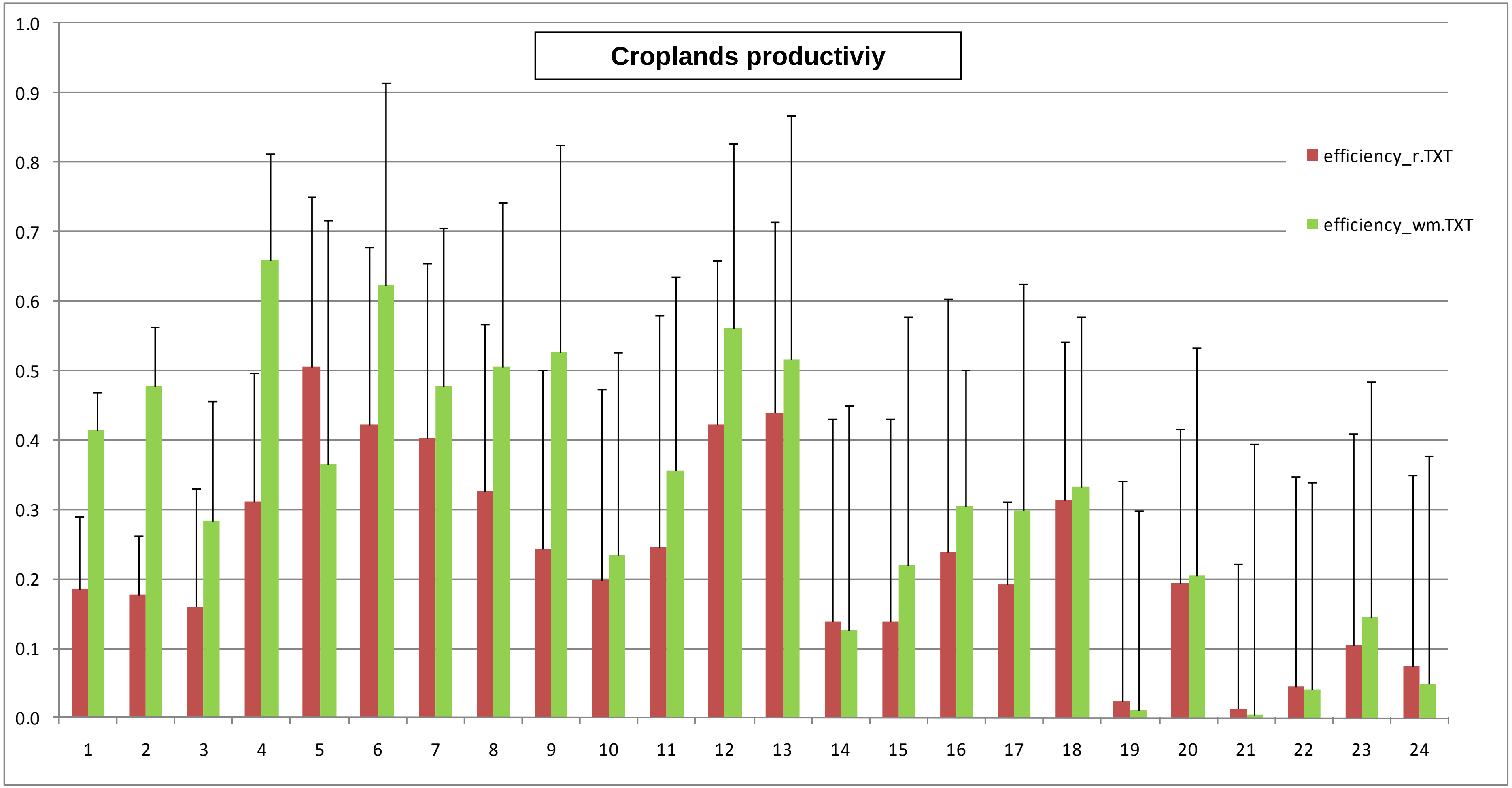

Population density in persons/km2
population.TXT
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24


Time travel to nearest market place in hours
accessibility.TXT
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

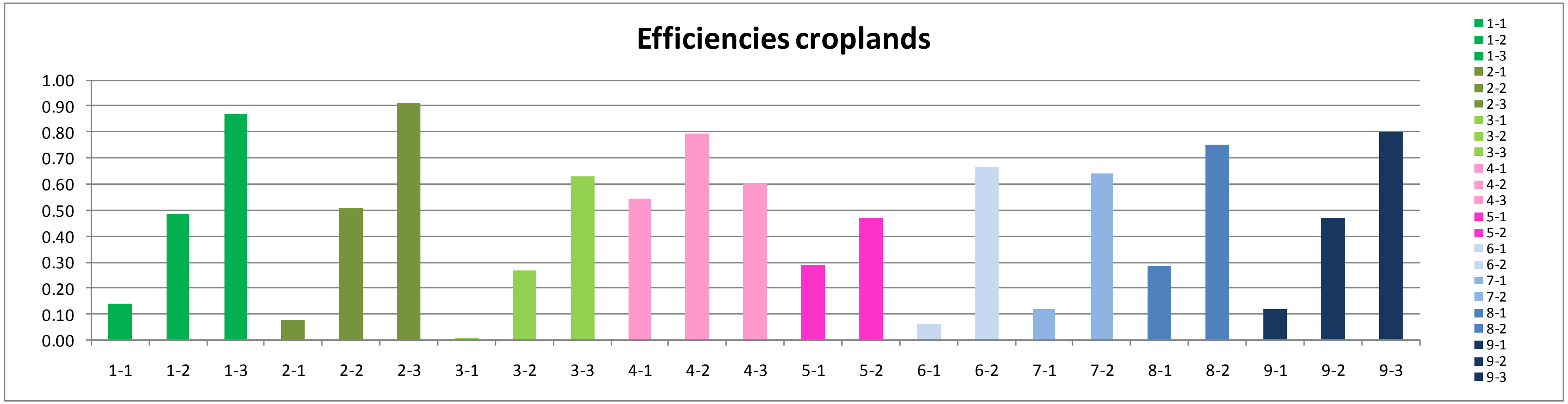


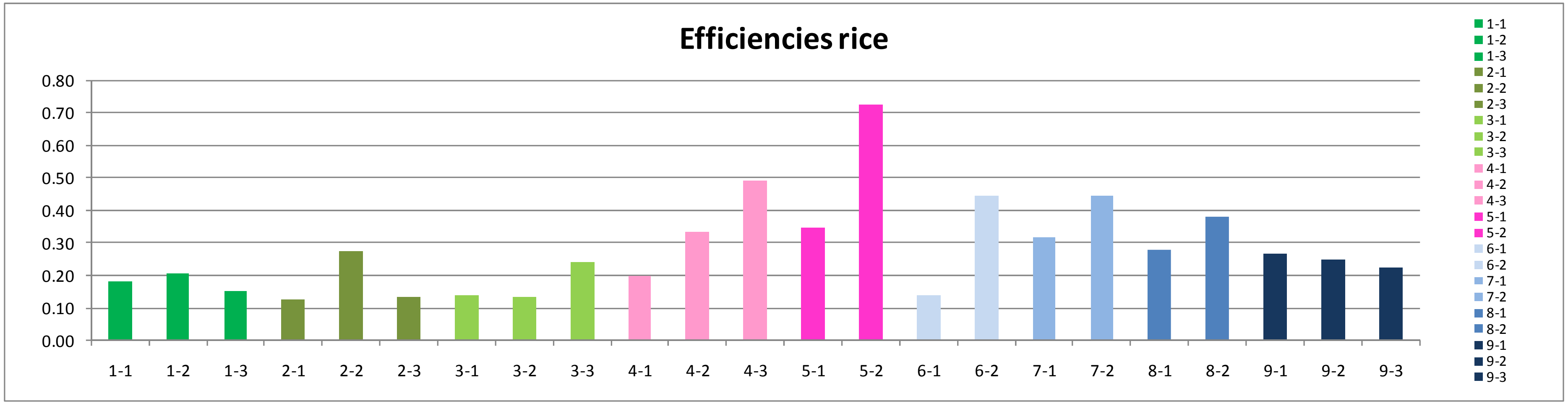
Levels of livestock density per LUS.

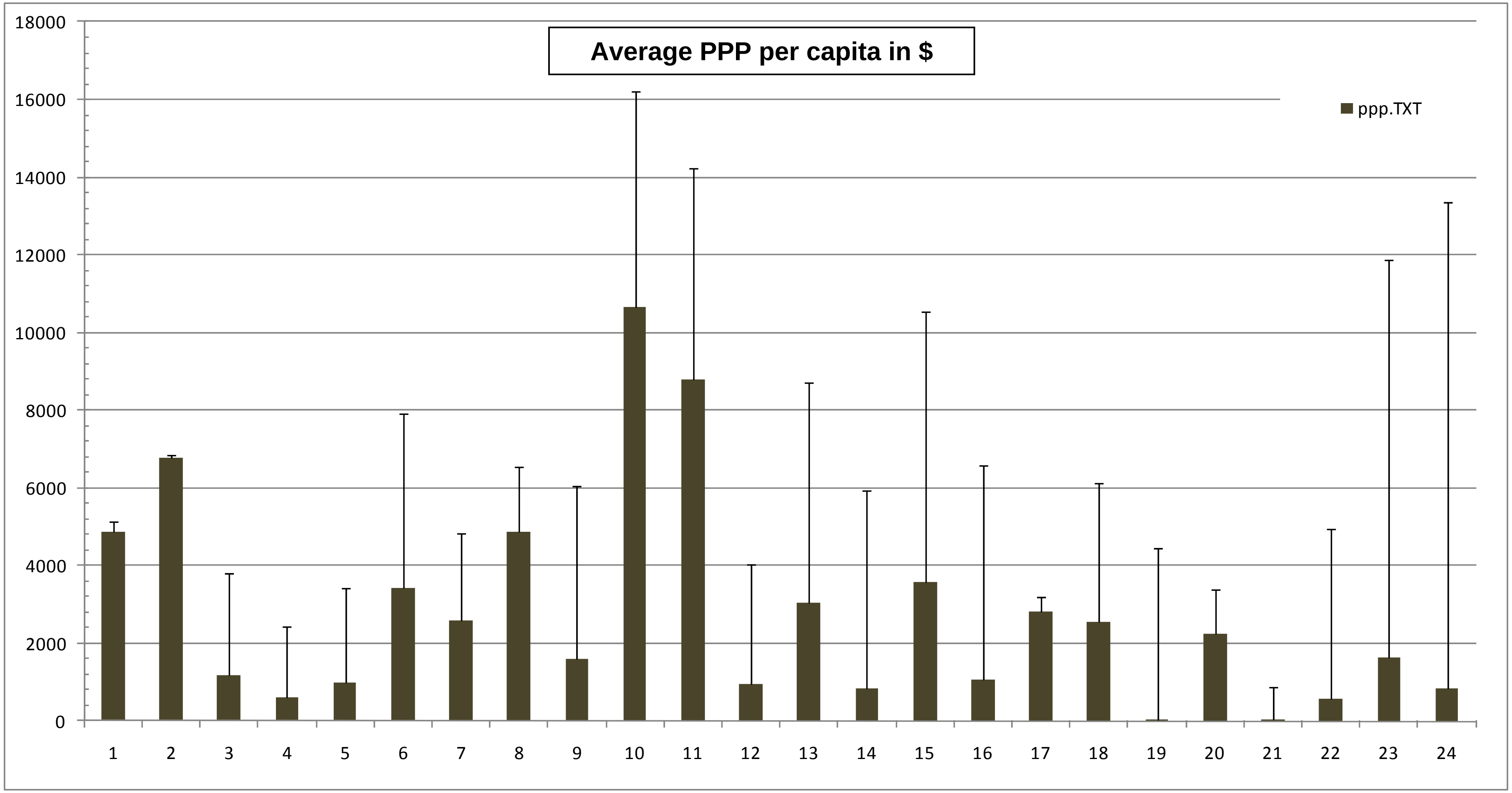

Livestock densities (LU/km2)
300
250
200
150
100
50
0
1-1
1-2
1-3
2-1
2-2
2-3
3-1
3-2
4-1
4-2
5-1
5-2
5-3
6-1
6-2
6-3
7-1
7-2
7-3
8-1
8-2
8-3
9-1
9-2
9-3
14-1
14-2
15-1
15-2
15-3
16-1
16-2
16-3
bovines
small_ruminants
monogastrics


Croplands productiviy
efficiency_r.TXT
efficiency_wm.TXT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Levels of land use intensity per cropland system.






Average PPP per capita in $
ppp.TXT
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Annex 7 Socio-economic drivers inputs

IMAGE World region	Population density (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	3.801	4.376	4.071	3.966	3.721	3.320	2.822	2.428	2.135	1.993
USA	3.801	4.708	4.314	3.900	3.450	3.082	2.720	2.383	2.104	1.921
Mexico	6.927	5.832	5.187	4.621	3.794	2.968	2.217	1.458	0.697	-0.078
Rest Central America	7.728	7.365	6.672	5.927	5.155	4.397	3.640	2.940	2.304	1.678
Brazil	6.458	6.487	5.493	4.676	3.986	3.323	2.642	2.085	1.542	1.011
Rest South America	8.065	7.027	6.375	5.666	4.916	4.187	3.437	2.768	2.135	1.590
Northern Africa	10.861	8.517	7.827	6.843	5.867	5.021	4.319	3.652	2.974	2.286
Western Africa	15.174	12.618	12.161	11.350	10.583	9.900	9.236	8.526	7.776	7.024
Eastern Africa	15.174	12.618	12.161	11.350	10.583	9.900	9.236	8.526	7.776	7.024
Southern Africa	15.174	8.495	8.507	8.453	8.240	7.889	7.416	6.894	6.356	5.827
OECD Europe	1.060	1.101	0.668	0.455	0.280	0.086	-0.143	-0.365	-0.553	-0.711
Eastern Europe	-0.267	-0.851	-1.091	-1.413	-1.844	-2.292	-2.639	-2.887	-3.067	-3.225
Turkey	7.283	6.678	5.839	5.002	4.369	3.656	2.873	2.152	1.559	1.017
Ukraine +	-1.642	0.394	0.745	0.453	-0.163	-0.687	-1.002	-1.276	-1.624	-2.059
Asia-Stan	5.897	0.394	0.745	0.453	-0.163	-0.687	-1.002	-1.276	-1.624	-2.059
Russia +	-0.649	-2.216	-2.380	-2.630	-2.908	-3.022	-2.909	-2.749	-2.735	-2.907
Middle East	12.331	10.774	10.438	9.307	8.046	7.023	6.271	5.609	4.909	4.142
India +	8.461	8.107	7.392	6.613	5.733	4.862	4.154	3.653	3.095	2.477
Korea	3.278	1.566	1.083	0.613	0.130	-0.599	-1.446	-2.157	-2.730	-3.214
China +	3.963	2.932	2.821	2.206	1.218	0.339	-0.221	-0.635	-1.117	-1.692
South East Asia	6.466	6.363	5.753	5.118	4.418	3.616	2.869	2.264	1.714	1.174
Indonesia +	5.213	5.824	4.690	3.663	3.085	2.691	2.218	1.575	0.905	0.312
Japan	1.027	0.290	-0.361	-1.000	-1.495	-1.805	-1.979	-2.097	-2.243	-2.422
Oceania	1.766	4.921	4.647	4.482	4.059	3.481	2.855	2.373	2.082	1.931

IMAGE World region	Purchasing Power Parity (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	9.189	9.431	6.513	5.341	4.583	4.653	7.373	7.786	7.786	7.605
USA	8.514	13.228	8.400	8.186	8.477	8.400	9.806	9.539	9.463	9.472
Mexico	-1.620	28.717	18.837	16.398	15.097	15.047	11.308	10.970	10.498	10.162
Rest Central America	-0.127	6.255	6.274	7.415	8.371	9.392	9.054	9.076	8.881	8.644
Brazil	4.101	9.599	8.891	10.039	9.969	9.650	9.097	8.911	8.660	8.338
Rest South America	2.736	15.762	10.194	11.014	12.281	13.615	12.968	12.589	12.085	11.499
Northern Africa	16.014	24.124	19.088	20.547	21.393	21.356	17.574	16.481	15.742	15.401
Western Africa	7.059	23.236	14.062	17.013	19.526	21.681	19.605	18.921	18.401	17.936
Eastern Africa	9.031	23.236	14.062	17.013	19.526	21.681	19.605	18.921	18.401	17.936
Southern Africa	11.511	15.910	8.324	11.212	13.970	18.021	18.342	19.933	20.966	21.488
OECD Europe	6.323	9.138	11.031	10.065	9.020	8.622	9.402	9.472	9.346	9.218
Eastern Europe	30.183	29.512	25.294	20.260	18.003	17.316	18.475	17.350	16.133	15.351
Turkey	15.995	48.832	45.510	30.366	22.351	19.045	13.987	13.592	12.885	12.139
Ukraine +	87.542	40.416	24.951	23.728	23.937	23.994	21.709	19.286	17.302	16.410
Asia-Stan	67.751	40.416	24.951	23.728	23.937	23.994	21.709	19.286	17.302	16.410
Russia +	60.266	38.975	35.023	34.820	34.573	32.556	27.813	24.335	22.213	21.749
Middle East	11.933	13.214	7.835	10.380	13.800	16.254	13.961	12.814	12.140	12.092
India +	31.498	36.650	28.943	26.915	25.596	24.701	22.500	20.551	18.715	17.457
Korea	27.222	28.393	26.995	18.281	14.020	12.739	17.552	16.925	15.612	14.115
China +	54.701	53.313	36.682	32.060	30.586	30.024	27.476	24.641	22.299	21.042
South East Asia	22.267	26.680	20.931	18.827	17.259	16.808	15.972	15.185	14.031	13.052
Indonesia +	24.933	32.931	27.639	27.396	25.134	22.331	19.674	18.669	18.006	17.030
Japan	3.451	-0.202	8.747	8.554	7.058	6.041	7.811	7.629	7.769	8.192
Oceania	11.809	12.943	8.730	7.168	6.908	7.346	10.136	10.255	9.808	9.248

Annex 8 Macro-economic drivers inputs

IMAGE World region	Croplands area (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	10.496	7.453	6.884	1.426	0.645	0.770	-1.913	-0.898	-1.026	-0.994
USA	4.593	3.762	3.359	0.047	0.579	0.210	-2.396	-2.011	-1.543	-1.550
Mexico	3.955	7.913	4.667	-0.694	0.343	3.399	-0.440	4.980	3.924	0.422
Rest Central America	2.887	6.749	-1.360	-1.485	-0.889	-1.937	-0.402	0.823	3.834	0.415
Brazil	3.815	5.542	7.308	3.595	2.249	1.417	-1.445	-1.435	0.597	1.485
Rest South America	7.224	6.656	4.863	2.640	3.008	3.485	-0.445	0.249	0.759	1.477
Northern Africa	3.242	1.192	0.646	-1.480	-0.990	-0.607	-1.447	-0.642	-0.932	-1.253
Western Africa	10.288	6.448	4.631	9.025	6.711	4.803	5.486	3.943	5.259	5.587
Eastern Africa	10.936	8.723	5.590	8.111	5.683	7.081	4.648	1.522	0.733	0.807
Southern Africa	9.245	7.419	5.399	3.565	2.955	2.265	3.235	1.903	1.189	1.199
OECD Europe	-1.967	-0.747	-1.043	-0.939	-0.016	-0.434	-1.070	-0.918	-0.694	-0.604
Eastern Europe	0.451	0.479	0.854	-1.827	-0.111	-0.628	-0.421	-0.784	0.501	-1.336
Turkey	26.368	18.103	12.389	6.184	5.095	4.752	0.885	0.453	0.513	0.496
Ukraine +	-1.210	-0.804	-0.479	1.255	1.174	1.447	0.170	0.141	-0.162	0.961
Asia-Stan	1.871	-1.176	0.344	0.489	2.089	6.650	4.242	5.313	5.274	38.424
Russia +	7.732	7.075	5.407	1.417	1.917	0.668	1.349	0.453	0.984	1.177
Middle East	1.404	0.056	0.822	2.074	1.046	1.735	0.828	0.756	1.388	-0.692
India +	12.188	9.378	7.727	4.131	3.277	2.725	0.437	0.482	0.047	0.624
Korea	2.787	0.827	-4.050	-7.576	-5.663	-3.995	-5.410	-4.194	-3.133	-3.178
China +	6.127	4.911	4.067	0.793	0.181	-0.196	-0.769	-1.401	0.192	-0.266
South East Asia	7.996	7.698	6.455	1.628	1.276	0.513	-1.925	-2.125	0.907	1.497
Indonesia +	12.776	11.861	8.960	6.755	5.453	4.697	0.988	0.607	0.542	0.456
Japan	-4.814	0.966	-5.127	-9.037	-5.031	-6.199	-5.311	-5.561	-5.718	-5.188
Oceania	3.970	2.953	3.241	2.812	3.363	2.795	1.800	1.401	0.961	1.513

IMAGE World region	Rice area (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
USA	1.722	1.038	0.160	-2.273	-1.245	-1.515	-3.192	-3.011	-2.673	-2.726
Mexico	6.465	3.314	3.649	-0.188	1.160	0.287	-2.418	-2.357	-2.228	-2.432
Rest Central America	0.095	-1.221	2.992	0.488	0.291	0.299	-0.693	-0.299	-0.890	-0.580
Brazil	2.328	1.821	1.777	-1.043	-1.297	-1.309	-4.961	-4.602	-4.164	-3.976
Rest South America	4.504	3.644	4.713	1.047	1.291	0.517	-2.470	-1.901	-2.374	-0.151
Northern Africa	6.737	6.378	1.356	2.790	0.377	-0.145	-0.158	0.791	-0.930	0.854
Western Africa	6.971	4.685	3.224	6.415	4.920	3.515	2.787	1.869	1.752	1.289
Eastern Africa	6.914	5.536	3.649	5.896	3.440	2.990	4.412	2.572	1.154	1.261
Southern Africa	5.461	4.853	3.705	2.154	3.597	1.084	4.478	2.499	1.761	-2.488
OECD Europe	-6.359	-5.593	-6.475	-4.321	-2.709	-3.185	-3.489	-1.527	-2.803	-2.977
Eastern Europe	8.142	5.249	5.215	3.888	6.625	6.881	-6.013	-6.426	-6.520	-6.327
Turkey	18.540	26.493	18.799	4.386	4.587	4.859	2.205	1.625	0.746	1.736
Ukraine +	0.456	0.559	-0.339	1.464	1.439	1.362	-0.561	-0.199	-0.001	0.844
Asia-Stan	-0.780	0.050	-0.676	0.014	3.092	-0.394	-1.671	-0.033	2.941	0.913
Russia +	7.093	5.168	10.141	-0.156	-3.249	-9.923	1.878	2.044	1.464	2.519
Middle East	9.022	12.962	1.276	0.281	-0.229	0.765	0.586	1.713	-1.587	2.193
India +	9.636	8.702	7.414	3.698	3.373	2.892	0.221	-0.010	0.470	0.408
Korea	-2.379	-0.970	-3.679	-8.901	-6.059	-5.671	-6.453	-4.510	-4.108	-0.783
China +	2.996	2.668	2.490	-0.544	-0.197	-0.789	-0.795	-1.643	-1.346	-1.247
South East Asia	7.581	5.639	4.976	0.549	0.130	0.161	-2.520	-2.767	-2.297	-2.347
Indonesia +	10.820	8.947	9.223	4.299	4.507	4.021	1.007	0.413	0.840	0.182
Japan	-5.734	-4.768	-6.304	-5.482	-4.077	-7.998	-5.410	-5.825	-6.146	-6.263
Oceania	-1.284	-1.451	-1.093	-0.006	-0.008	0.069	0.768	0.449	0.199	0.403

IMAGE World region	Production all crops (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	12.636	11.218	10.087	6.236	5.870	5.544	4.318	4.140	3.975	3.823
USA	8.826	8.110	7.502	6.413	6.027	5.684	5.108	4.860	4.635	4.430
Mexico	11.014	9.921	9.026	8.890	8.164	7.548	3.465	3.349	3.240	3.138
Rest Central America	7.754	7.196	6.713	6.517	6.119	5.766	4.566	4.367	4.184	4.016
Brazil	11.059	9.958	9.056	8.601	7.920	7.339	5.350	5.078	4.833	4.610
Rest South America	9.789	8.917	8.187	6.959	6.507	6.109	6.110	5.758	5.445	5.164
Northern Africa	14.609	12.746	11.305	10.577	9.565	8.730	8.357	7.712	7.160	6.682
Western Africa	21.687	17.822	15.126	19.537	16.344	14.048	15.141	13.150	11.621	10.412
Eastern Africa	21.852	17.933	15.206	18.702	15.755	13.611	14.656	12.783	11.334	10.180
Southern Africa	10.640	9.617	8.773	10.893	9.823	8.945	11.418	10.248	9.296	8.505
OECD Europe	3.583	3.459	3.344	4.267	4.092	3.932	3.775	3.637	3.510	3.391
Eastern Europe	3.983	3.831	3.689	1.937	1.900	1.864	2.295	2.243	2.194	2.147
Turkey	34.801	25.817	20.519	14.125	12.377	11.013	6.502	6.105	5.753	5.440
Ukraine +	8.757	8.052	7.452	4.924	4.692	4.482	2.802	2.726	2.653	2.585
Asia-Stan	7.885	7.309	6.811	4.452	4.262	4.088	2.442	2.384	2.328	2.275
Russia +	8.641	7.953	7.367	6.090	5.740	5.429	3.847	3.704	3.572	3.449
Middle East	15.759	13.613	11.982	10.625	9.604	8.763	8.068	7.466	6.947	6.496
India +	18.637	15.710	13.577	12.452	11.073	9.969	9.627	8.782	8.073	7.470
Korea	3.206	3.107	3.013	1.776	1.745	1.715	0.475	0.473	0.471	0.468
China +	13.139	11.613	10.405	7.441	6.926	6.477	4.294	4.117	3.954	3.804
South East Asia	12.442	11.065	9.963	7.481	6.960	6.507	4.737	4.523	4.327	4.148
Indonesia +	18.204	15.401	13.345	12.656	11.234	10.099	6.449	6.059	5.713	5.404
Japan	1.514	1.491	1.469	-0.294	-0.295	-0.296	-0.646	-0.651	-0.655	-0.659
Oceania	13.134	11.609	10.402	9.584	8.746	8.042	7.258	6.767	6.338	5.960

IMAGE World region	Production rice (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
USA	3.654	3.525	3.405	2.178	2.132	2.087	0.394	0.392	0.391	0.389
Mexico	7.251	6.761	6.332	3.722	3.589	3.464	0.112	0.111	0.111	0.111
Rest Central America	5.174	4.919	4.689	6.111	5.759	5.445	5.660	5.357	5.084	4.838
Brazil	8.544	7.871	7.297	5.592	5.296	5.030	1.941	1.904	1.869	1.835
Rest South America	8.107	7.499	6.976	5.761	5.447	5.166	2.475	2.415	2.358	2.304
Northern Africa	6.131	5.777	5.461	8.489	7.825	7.257	5.358	5.086	4.840	4.616
Western Africa	15.790	13.637	12.001	15.504	13.423	11.834	14.588	12.731	11.293	10.147
Eastern Africa	15.785	13.633	11.997	15.506	13.425	11.836	14.592	12.734	11.296	10.149
Southern Africa	10.368	9.394	8.587	14.580	12.725	11.288	21.438	17.654	15.005	13.047
OECD Europe	-7.440	-8.038	-8.741	-4.781	-5.021	-5.286	-3.009	-3.102	-3.201	-3.307
Eastern Europe	13.008	11.511	10.323	5.848	5.525	5.236	-2.612	-2.682	-2.756	-2.834
Turkey	23.218	18.843	15.855	7.666	7.120	6.647	4.363	4.180	4.013	3.858
Ukraine +	6.306	5.932	5.600	2.652	2.583	2.518	2.368	2.314	2.261	2.211
Asia-Stan	6.506	6.108	5.757	2.488	2.428	2.370	2.496	2.436	2.378	2.322
Russia +	9.637	8.790	8.080	-2.099	-2.144	-2.191	3.525	3.405	3.292	3.188
Middle East	10.532	9.528	8.699	8.103	7.496	6.973	7.554	7.024	6.563	6.159
India +	11.545	10.350	9.379	7.664	7.118	6.645	4.287	4.111	3.948	3.798
Korea	0.171	0.170	0.170	-2.734	-2.811	-2.893	-0.877	-0.884	-0.892	-0.900
China +	3.220	3.119	3.025	0.241	0.240	0.239	-1.679	-1.708	-1.737	-1.768
South East Asia	8.020	7.425	6.911	3.959	3.808	3.668	0.209	0.208	0.208	0.208
Indonesia +	7.680	7.132	6.657	5.039	4.798	4.578	4.013	3.858	3.715	3.582
Japan	-3.115	-3.216	-3.322	-4.374	-4.574	-4.793	-4.202	-4.387	-4.588	-4.808
Oceania	1.006	0.996	0.986	-1.048	-1.059	-1.070	-0.461	-0.463	-0.465	-0.467

IMAGE World region	Pastoral areas (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	5.061	4.799	4.601	0.582	0.739	0.063	-1.536	-1.059	-0.951	-1.334
USA	0.273	-0.037	-0.020	-1.154	-0.974	-1.251	-1.757	-1.587	-1.695	-1.702
Mexico	2.407	1.771	0.974	-1.355	-1.351	-0.969	-3.692	-2.631	-2.873	-2.187
Rest Central America	-4.504	-2.746	-2.153	-2.017	-1.920	-2.108	-3.810	-3.623	-3.269	-2.996
Brazil	2.800	1.697	1.358	-0.474	0.170	-0.129	-4.650	-3.555	-3.035	-2.828
Rest South America	3.913	3.032	2.917	1.368	0.922	0.309	-1.252	-1.902	-1.891	-1.934
Northern Africa	0.791	-0.865	-0.548	-0.155	0.075	0.253	-0.143	0.262	0.030	0.189
Western Africa	1.744	-0.231	-1.718	5.401	2.636	1.201	2.930	1.360	-0.103	-0.803
Eastern Africa	4.349	1.379	0.043	7.610	4.578	2.231	4.660	2.516	0.686	0.164
Southern Africa	9.501	7.862	6.560	3.588	2.782	1.895	2.262	1.856	0.928	-0.348
OECD Europe	-0.717	-0.672	-0.170	-1.007	-0.683	-0.651	-0.539	-0.194	0.388	0.484
Eastern Europe	-0.015	-1.310	1.015	-2.705	-1.520	-1.649	-3.319	-3.286	-3.103	-3.016
Turkey	16.240	6.858	3.796	4.245	2.083	0.916	0.271	2.912	-0.058	2.637
Ukraine +	6.122	5.878	6.167	7.259	9.071	6.699	6.112	6.119	5.307	5.322
Asia-Stan	1.896	0.422	-0.381	0.637	0.415	0.929	0.716	0.335	-0.258	0.018
Russia +	8.648	8.828	7.633	-1.548	-1.152	-1.603	2.798	1.330	0.970	0.788
Middle East	-9.309	-1.777	0.014	0.587	-0.767	0.146	-0.789	0.166	-0.125	0.131
India +	-0.320	-0.161	-0.430	-1.882	-1.076	-0.645	-2.908	-1.353	-0.020	0.193
Korea	19.782	93.201	-15.428	-7.508	-6.768	-7.593	-6.667	-5.128	29.827	-29.386
China +	1.857	1.116	0.424	-0.710	-1.100	-1.521	-1.138	-1.240	-1.204	-1.421
South East Asia	2.531	-0.077	10.080	-5.054	8.576	2.248	-7.384	0.148	-4.171	-2.748
Indonesia +	10.876	3.726	5.201	4.578	6.052	3.148	-2.337	0.372	-0.341	-0.360
Japan	-3.445	-3.265	2.998	-5.354	-5.129	-5.247	-5.364	-5.317	-5.286	-5.285
Oceania	0.764	0.771	0.685	0.430	0.483	0.511	0.661	0.647	0.292	0.438

IMAGE World region	Production monogastrics (gain in %)									
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Canada	10.923	9.848	8.965	5.591	5.295	5.029	4.776	4.558	4.359	4.177
USA	7.137	6.661	6.245	3.996	3.842	3.700	2.430	2.373	2.318	2.265
Mexico	11.746	10.511	9.511	6.383	6.000	5.660	1.393	1.373	1.355	1.337
Rest Central America	10.244	9.292	8.502	8.710	8.012	7.418	5.063	4.819	4.597	4.395
Brazil	11.482	10.299	9.338	8.292	7.657	7.112	4.644	4.438	4.249	4.076
Rest South America	12.785	11.336	10.181	8.678	7.985	7.395	4.303	4.125	3.962	3.811
Northern Africa	22.496	18.365	15.515	14.576	12.722	11.286	8.577	7.899	7.321	6.822
Western Africa	28.581	22.228	18.186	24.573	19.726	16.476	18.427	15.560	13.465	11.867
Eastern Africa	28.579	22.227	18.185	24.580	19.730	16.479	18.417	15.553	13.460	11.863
Southern Africa	18.510	15.619	13.509	14.851	12.931	11.450	10.629	9.608	8.766	8.059
OECD Europe	1.606	1.581	1.556	0.534	0.531	0.528	0.373	0.372	0.371	0.369
Eastern Europe	4.410	4.224	4.053	-0.020	-0.020	-0.020	-0.614	-0.617	-0.621	-0.625
Turkey	30.002	23.078	18.751	11.082	9.976	9.071	2.051	2.010	1.970	1.932
Ukraine +	6.870	6.428	6.040	3.503	3.385	3.274	1.806	1.774	1.743	1.713
Asia-Stan	6.944	6.494	6.098	3.448	3.333	3.226	1.780	1.748	1.718	1.689
Russia +	7.748	7.191	6.708	1.567	1.543	1.519	-0.411	-0.413	-0.414	-0.416
Middle East	17.794	15.106	13.123	12.627	11.212	10.081	8.201	7.579	7.045	6.582
India +	30.871	23.589	19.087	18.163	15.371	13.323	10.895	9.825	8.946	8.211
Korea	8.507	7.840	7.270	0.850	0.843	0.836	-1.748	-1.779	-1.812	-1.845
China +	15.416	13.357	11.783	6.775	6.345	5.966	3.587	3.463	3.347	3.239
South East Asia	16.874	14.438	12.616	10.180	9.240	8.458	4.823	4.601	4.399	4.214
Indonesia +	35.305	26.093	20.693	17.168	14.653	12.780	7.720	7.167	6.688	6.268
Japan	-1.609	-1.635	-1.662	-2.602	-2.671	-2.745	-3.121	-3.221	-3.328	-3.443
Oceania	11.071	9.968	9.064	6.935	6.485	6.090	7.501	6.978	6.523	6.123

IMAGE World region	Production bovines (gain in %)									
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Canada	6.550	6.147	5.791	4.473	4.281	4.105	4.782	4.564	4.365	4.182
USA	2.828	2.751	2.677	1.697	1.669	1.641	1.629	1.602	1.577	1.553
Mexico	10.993	9.905	9.012	5.541	5.250	4.988	0.216	0.216	0.215	0.215
Rest Central America	10.536	9.532	8.702	8.503	7.837	7.267	4.595	4.393	4.208	4.038
Brazil	10.667	9.639	8.791	6.960	6.507	6.110	2.545	2.482	2.422	2.365
Rest South America	13.221	11.677	10.456	9.222	8.443	7.786	5.034	4.793	4.574	4.374
Northern Africa	22.362	18.275	15.451	14.888	12.959	11.472	7.825	7.257	6.766	6.337
Western Africa	32.572	24.570	19.724	28.404	22.121	18.114	23.026	18.716	15.766	13.619
Eastern Africa	32.565	24.566	19.721	28.399	22.118	18.112	23.031	18.720	15.768	13.620
Southern Africa	18.958	15.936	13.746	17.123	14.620	12.755	14.191	12.428	11.054	9.954
OECD Europe	-2.622	-2.693	-2.767	-0.564	-0.568	-0.571	-1.064	-1.075	-1.087	-1.099
Eastern Europe	8.952	8.216	7.593	-0.526	-0.529	-0.532	-2.188	-2.237	-2.288	-2.341
Turkey	24.521	19.692	16.452	9.823	8.945	8.210	4.156	3.990	3.837	3.695
Ukraine +	10.888	9.819	8.941	6.389	6.005	5.665	4.720	4.508	4.313	4.135
Asia-Stan	10.885	9.817	8.939	6.417	6.030	5.687	4.696	4.486	4.293	4.116
Russia +	8.471	7.809	7.244	1.175	1.162	1.148	-0.505	-0.508	-0.510	-0.513
Middle East	20.147	16.768	14.360	15.982	13.780	12.111	10.301	9.339	8.541	7.869
India +	11.055	9.955	9.054	6.353	5.974	5.637	3.799	3.660	3.531	3.410
Korea	8.896	8.169	7.552	1.523	1.500	1.478	-0.728	-0.733	-0.739	-0.744
China +	13.619	11.987	10.704	7.227	6.740	6.314	4.542	4.345	4.164	3.998
South East Asia	21.470	17.675	15.020	13.435	11.844	10.590	7.016	6.556	6.153	5.796
Indonesia +	24.267	19.528	16.338	15.262	13.241	11.693	8.915	8.185	7.566	7.034
Japan	-3.819	-3.970	-4.135	-4.898	-5.150	-5.429	-5.334	-5.635	-5.971	-6.350
Oceania	3.438	3.323	3.217	-0.566	-0.569	-0.572	0.387	0.386	0.384	0.383

IMAGE World region	Production small ruminants (gain in %)									
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Canada	6.667	6.250	5.882	5.556	5.263	5.000	3.571	3.448	3.333	3.226
USA	2.703	2.632	2.564	1.944	1.907	1.872	1.575	1.550	1.527	1.504
Mexico	10.798	9.746	8.880	5.674	5.369	5.096	0.227	0.227	0.226	0.226
Rest Central America	10.526	9.524	8.696	8.000	7.407	6.897	4.839	4.615	4.412	4.225
Brazil	10.653	9.627	8.782	7.031	6.569	6.164	2.581	2.516	2.454	2.395
Rest South America	13.188	11.652	10.436	9.242	8.460	7.800	5.061	4.817	4.596	4.394
Northern Africa	22.349	18.267	15.445	14.899	12.967	11.479	7.821	7.254	6.763	6.335
Western Africa	32.542	24.552	19.713	28.416	22.128	18.119	23.032	18.721	15.769	13.621
Eastern Africa	32.593	24.581	19.731	28.390	22.112	18.108	23.013	18.708	15.759	13.614
Southern Africa	18.933	15.919	13.733	17.177	14.659	12.785	14.184	12.422	11.049	9.950
OECD Europe	-2.613	-2.683	-2.757	-0.561	-0.564	-0.567	-1.069	-1.081	-1.093	-1.105
Eastern Europe	8.913	8.183	7.564	-0.563	-0.566	-0.569	-2.146	-2.193	-2.242	-2.294
Turkey	24.518	19.690	16.451	9.841	8.960	8.223	4.136	3.972	3.820	3.679
Ukraine +	10.526	9.524	8.696	6.667	6.250	5.882	5.000	4.762	4.545	4.348
Asia-Stan	10.925	9.849	8.966	6.381	5.998	5.659	4.704	4.493	4.300	4.122
Russia +	8.539	7.867	7.293	1.176	1.163	1.149	-0.568	-0.571	-0.575	-0.578
Middle East	20.138	16.762	14.356	15.997	13.791	12.120	10.288	9.329	8.533	7.862
India +	11.063	9.961	9.058	6.339	5.961	5.626	3.811	3.671	3.541	3.420
Korea	8.889	8.163	7.547	1.754	1.724	1.695	-1.250	-1.266	-1.282	-1.299
China +	13.616	11.984	10.702	7.225	6.738	6.313	4.546	4.349	4.167	4.001
South East Asia	21.739	17.857	15.152	13.158	11.628	10.417	7.075	6.608	6.198	5.837
Indonesia +	24.242	19.512	16.327	15.351	13.308	11.745	8.896	8.170	7.553	7.022
Japan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oceania	3.443	3.328	3.221	-0.570	-0.573	-0.576	0.397	0.395	0.394	0.392

Annex 9 Logit models: standardized coefficients and goodness of fit (ROC) for LUS

Variables	lus1	lus2	lus3	lus4	lus5	lus6	lus7	lus8	lus9	lus10	lus11	lus12	lus13	lus14	lus15	lus16	lus17	lus18	lus19	lus20	lus21	lus22	lus23	lus24
Intercept	-7.818	-2.434	-0.954	-11.497	-7.442	-10.029	-7.128	-3.999	-4.899	13.060	1.377	-9.780	-5.307	-0.570	-1.527	-1.344	-1.166	-1.620	-6.593	-0.312	-3.556	-2.136	-4.030	1.075
Population density	-0.277	0.471	-0.261		1.311	1.951	2.147		0.354	30.011	6.611	4.310	4.679	-1.369		-0.484	-1.026	0.536	-1.551	-0.493	-26.356	-3.940	1.175	-10.003
Time travel	-27.723	-9.388	-5.679	-18.503	-6.656	-25.935	-24.849	-11.037	-17.035		-3.818	-11.602	-15.841	-2.353	-0.622	-4.272	-5.600	-6.192		-1.278	2.642	-2.504	-6.188	-0.732
PPP	-0.296	-0.344	-0.979	-4.098	-0.788		-0.190	-0.415	-0.574		0.732	-0.952	-0.436	-0.319		-0.192		0.239	-23.005	0.082	-1.487	-0.082		-0.135
Atitude	-0.321	-0.293	-0.573	-3.229	-1.858		-0.204	-0.524	-0.392			-1.437		0.229	-0.257	-0.120	-0.316	0.121	-0.234	-0.154	0.346	0.621		-0.135
Slope	-0.186		-0.189		0.319			-0.151			0.090			0.045	0.360		0.075	0.339		0.359		0.157	0.298	0.186
Annual temperature	-0.561		-0.549	-2.300	0.741		0.379	0.786	0.844			2.095	0.908		-0.739		-0.203	0.568	-1.099	0.240	0.587	0.574		-0.487
Annual precipitations	0.114			1.244	0.786	-0.897	-0.419	-0.719	-0.844	-0.417	0.173		-0.833	-0.268			0.257	0.450	0.473	0.374	-1.089	-3.170	-2.866	1.044
NPP	-0.258		-0.262		-0.222		0.180	-0.238			0.163			-0.164			-0.119	0.270	-0.198	0.135	-1.302			1.882
Cation exchange	0.491							0.600	0.833					0.269					0.346	-0.088	-0.287	-0.536		-0.063
Clay content	0.112	0.158		-0.572										0.208		0.252	0.156	0.466		0.191		-0.201		
Soil pH	0.112		0.118		-0.308			0.516	0.327	-0.389				0.327			-0.135	-0.166	-0.178	-0.347	0.407	0.432		
Sand content			-0.479			0.459		0.208	0.286					0.315			-0.122	0.566	-0.208	0.285	0.476	-0.159		
Silt content	-0.189													-0.055	0.199	0.323		0.360	-0.401	0.224	0.468			
Drainage 0	-0.013		-0.140	0.179	2.317	-0.201	0.080	0.205	0.150		0.031	1.318		0.357	0.084	0.118	0.071	0.459	0.061	0.333	0.496	0.264		-0.043
Drainage 1	-0.365		-0.267	0.322	1.358	0.219	0.018	-0.411	-0.349		-0.156	1.609		0.015	0.142	0.008	0.151	0.147	0.263	0.543	0.099	0.268		0.270
Drainage 2	-0.130		-0.171	1.654	7.393	0.276	0.353	-0.001	0.118		-0.206	6.621		0.258	0.240	0.017	0.205	0.318	0.955	0.650	-0.105	0.052		0.348
Drainage 3	-0.041		-0.180	1.353	4.803	0.220	0.172	-0.228	0.026		-0.265	4.006		0.332	0.302	0.256	0.412	0.341	1.119	0.818	-0.382	0.071		0.481
Drainage 4	-0.125		-0.235	2.139	7.100	0.258	0.302	-0.346	-0.082		-0.168	6.324		0.409	0.653	0.313	0.604	0.562	0.841	1.144	-0.579	0.029		0.699
Drainage 5	-0.177		-0.312	2.495	8.953	0.012	0.425	-0.598	-0.110		-0.186	7.705		0.607	0.515	0.101	0.706	0.897	1.258	1.715	-0.874	-0.018		1.102
Drainage 6	-0.230		-0.193	1.377	6.169	-0.482	0.153	-0.774	-0.300		-0.238	5.041		0.599	0.420	0.455	0.654	0.602	1.460	1.409	-0.527	0.051		0.950
Canada	-0.054	0.204	0.079	-0.682	0.284	2.473	0.312	0.788	0.570	0.214	0.301	0.729	0.327	-0.769	-4.208	-0.319	-0.124	-0.206	-0.132	0.012	-0.539	0.153	0.542	0.667
USA	0.092	0.365	0.431	0.049	2.895	2.542	0.307	2.383	1.078	0.591	0.460	-2.008	3.402	-0.257	-0.791	-0.177	-0.001	-0.076	-0.156	0.200	-0.547	0.055	3.808	0.280
Mexico	0.064	-0.006	0.141	-0.071	-0.187	-0.299	0.207	0.928	0.371	0.169	0.178	-0.089	1.736	-0.142	-0.234	-0.317	0.144	0.035	-0.147	0.140	-0.269	0.086	1.948	0.040
Rest Central America	0.095	0.014	0.027	-0.213	-0.286	-0.110	0.161	0.338	0.237	0.440	0.084	-0.352	0.783	-0.069	-0.830	-0.105	0.067	0.065	-0.281	0.059	-0.698	-0.761	0.241	-0.156
Brazil	-0.068	-0.222	-0.010	-0.248	2.519	0.196	0.177	0.228	0.077	0.639	0.190	-0.363	2.153	-0.068	-0.034	0.955	0.194	0.182	-0.173	0.108	-0.002	-0.039	1.002	-0.108
Rest South America	-0.186	-0.396	-0.074	-0.605	-1.654	2.980	0.231	0.685	0.175	0.581	0.215	-0.522	2.968	-0.148	-0.265	0.227	-0.009	0.040	-0.415	0.188	-0.633	0.357	4.565	0.045
Northern Africa	0.074	-0.027	-0.371	2.257	2.475	2.209	0.365	0.275	0.484	0.339	0.277	2.140	4.158	-0.509	-0.603	-0.406	-0.443	-0.001	-3.087	-0.532	-0.224	0.385	7.483	-0.433
Western Africa	0.289	-0.048	0.185	2.111	3.459	4.115	0.378	-3.324	-0.293	0.374	0.192	-0.915	-1.982	-0.284	-0.519	-0.311	0.208	0.256	-0.446	0.137	-0.327	0.338	4.416	0.159
Eastern Africa	0.220	-0.054	0.005	-0.203	-1.648	2.255	0.430	0.078	0.099	0.279	0.179	-0.433	2.258	-0.083	-0.150	0.058	0.165	0.647	-0.123	0.038	-0.319	0.464	3.843	-0.072
Southern Africa	-0.143	-0.265	-0.310	-0.217	-1.323	2.200	0.075	0.128	-0.421	0.354	0.106	-0.194	2.307	0.158	-0.311	0.066	-0.038	0.274	-0.134	0.102	-0.237	0.086	3.152	-0.093
Western Europe	0.070	0.908	0.091	-0.347	-0.147	3.929	0.400	1.539	0.878	0.332	0.211	-0.068	2.521	-0.206	0.060	-0.064	0.009	0.233	-0.143	0.381	0.049	0.267	-0.871	0.228
Central Europe	0.232	0.131	-0.033	-0.204	-0.188	0.879	0.251	0.911	0.306	0.157	0.090	-0.181	0.988	-0.243	-2.128	-1.417	0.066	0.125	-1.195	0.239	-1.156	-0.158	-0.003	0.073
Turkey	0.123	0.036	0.142	0.001	-0.099	0.815	0.201	0.758	0.432	0.233	0.104	-1.870	1.450	-0.112	-1.416	-0.092	0.132	0.145	-1.075	0.050	-1.043	0.079	1.706	0.007
Ukraine	0.241	0.058	0.010	-0.366	-0.175	0.629	0.166	0.771	0.124	-0.473	0.064	-0.403	0.873	-0.294	-1.454	-1.254	-0.002	0.056	-1.156	0.133	-1.025	-1.083	-0.097	0.032
Asia-Stan	-0.312	-0.249	-0.278	-0.520	-0.037	-0.249	0.327	0.840	0.860	-0.081	0.096	-0.126	2.684	0.110	-0.496	-0.160	-0.038	0.190	-0.703	-0.189	-0.488	0.288	3.090	-0.234
Russia	-0.054	-0.299	-0.102	-1.311	-0.091	-0.317	0.556	1.174	0.657	0.457	0.279	0.264	3.665	-0.848	-1.546	-1.038	0.007	0.382	-0.305	0.339	-0.370	-0.148	4.453	0.810
Middle East	-0.138	-0.053	-0.199	-0.113	2.425	2.158	0.304	1.067	0.595	0.456	0.295	-0.587	2.999	-0.446	-0.038	-0.236	-0.275	0.085	-0.807	-0.387	-0.316	0.650	8.450	-0.205
South Asia	0.595	0.076	-0.166	9.843	6.326	3.421	1.181	0.586	2.232	-0.446	0.078	6.620	5.653	-0.482	-0.517	-0.345	-0.083	0.259	-0.601	0.008	-0.596	0.650	7.340	0.162
Korea	-0.049	-0.040	-0.077	-0.182	0.975		0.295	0.299	0.347	0.349	0.086	0.588	1.809	-0.103	-0.852	-0.512	-0.023	0.156	-0.109	0.147	-0.450	-0.466		0.080
China	0.008	0.192	-0.415	2.747	7.876	9.323	1.417	1.302	1.093	0.087	0.262	4.558	7.260	-0.357	-0.408	-0.161	-0.093	0.897	-0.701	0.333	-0.474	0.562	5.476	0.328
South-East Asia	0.257	-0.111	0.267	1.516	5.934	1.666	0.304	0.748	0.633	0.563	0.129	2.723	2.773	-0.415	-2.022	-2.200	0.025	0.278	-0.290	0.163	-0.030	-1.298	2.936	0.161
Indonesia	0.259	0.013	0.616	1.498	4.450	0.791	0.358	0.531	0.492	0.608	0.087	3.791	2.946	-0.583	-2.192	-1.630	0.083	-0.215	-0.150	0.270	-0.210	-0.842	0.838	-0.241
Japan	-0.085	-0.901	-0.068	0.008	1.699	-0.039	0.157	0.245	0.278	0.492	0.090	0.454	2.878	-0.123	-0.856	-0.663	-0.097	0.049	-0.705	0.191	-0.609	-0.505		0.117
Goodness-of-fit (ROC)	**0.948**	**0.921**	**0.880**	**0.996**	**0.987**	**0.993**	**0.985**	**0.943**	**0.965**	**0.994**	**0.984**	**0.997**	**0.994**	**0.868**	**0.882**	**0.896**	**0.828**	**0.910**	**0.917**	**0.822**	**0.963**	**0.952**	**0.952**	**0.937**

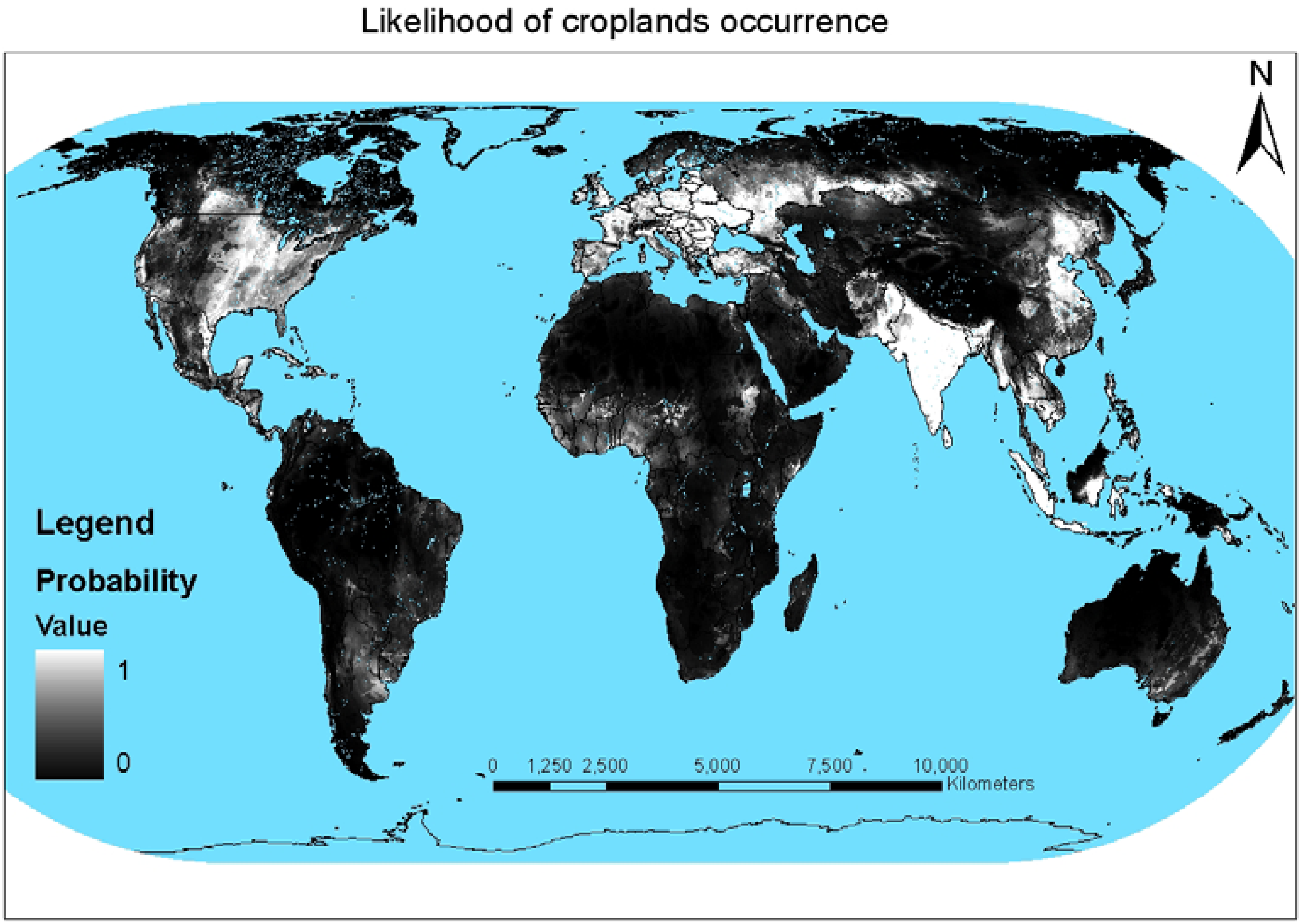
All coefficients siginificant at 0.01 level, except cells marked

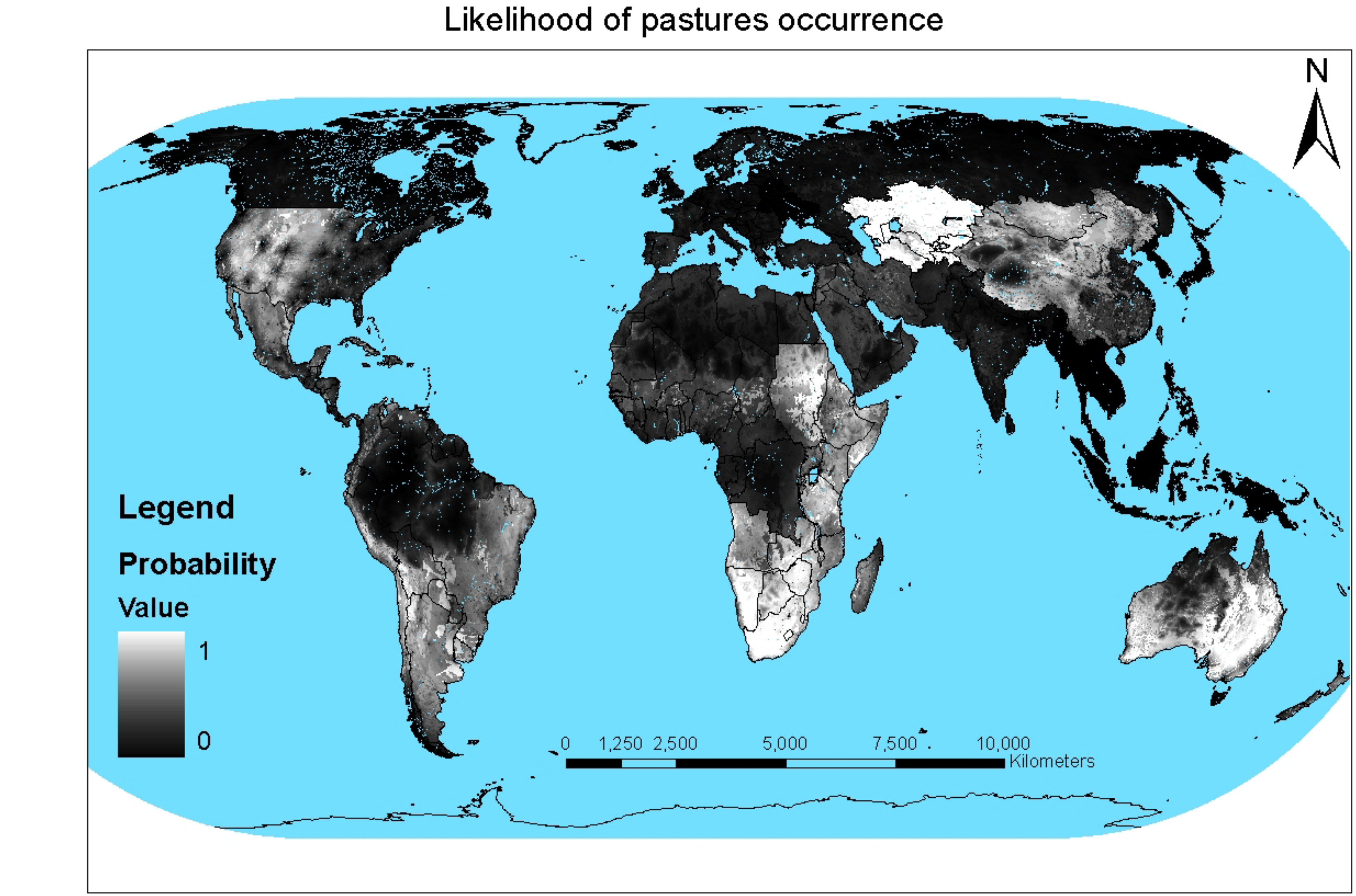
Annex 10 Logit models: standardized coefficients and goodness of fit (ROC) for location of land use change

Variables	Croplands expansion	Pastures expansion	Rice expansion	Croplands intensification	Rice intensification	Bovines intensification	Monogastrics intensification	Small ruminants intensification
Intercept	-4.209	-2.621	-13.730	-4.100	-6.103	-5.703	-8.379	-6.331
Population density	0.172	-0.817	0.147	0.046	0.028	0.041	0.058	0.072
Time travel	-6.755	-2.284	-4.322	-4.661	-4.658	-5.041	-8.142	-3.426
PPP	-0.086	-0.426	-0.261	0.178	-0.089	0.040	0.009	0.055
Atitude	-0.837	0.056	-2.387	-0.099	0.074	-0.441	-0.288	-0.100
Slope	-0.352	-0.080	0.071	0.018	0.236	-0.104	0.131	0.178
Annual temperature	-0.276	-0.163	2.146	0.105	0.336	0.048	1.277	-0.095
Annual precipitations	0.124	-0.238	0.709		-0.235	0.226	0.233	-0.014
NPP	-0.305	-0.174	-0.209	0.161	0.469	0.041	0.267	0.188
Cation exchange	0.214	0.290		0.031	0.075	0.239	-0.059	0.253
Clay content	0.115	0.307	0.252	0.138	0.356	0.604	0.586	-0.020
Soil pH	0.232	0.364	-0.330	-0.024	-0.093	-0.023	-0.218	-0.048
Sand content	-0.324	0.279	0.581	-0.344	-0.176	0.735	0.745	0.268
Silt content	-0.024	-0.091	0.484	-0.077		0.474	0.507	0.413
Drainage 0	0.011	0.338	0.548	-0.155	0.103	0.483	0.574	0.053
Drainage 1	-0.289	-0.033	0.190	-0.248	-0.080	-0.016	0.320	-0.117
Drainage 2	0.031	0.135	0.877	-0.110	0.233	0.333	0.685	0.152
Drainage 3	0.008	0.208	1.122	-0.136	0.116	0.482	0.700	0.176
Drainage 4	0.033	0.241	1.211	-0.191	0.126	0.565	1.040	-0.032
Drainage 5	0.006	0.388	1.702	-0.443	0.161	0.752	1.333	-0.113
Drainage 6	-0.072	0.400	1.191	-0.271	0.357	0.404	0.985	-0.052
Canada	0.364	-0.953	0.837	0.100	-4.076	-0.064	0.796	-4.733
USA	0.415	-0.158	3.858	0.453	-0.252	0.121	0.656	-1.694
Mexico	0.201	-0.140	-0.211	0.136	-0.074	0.040	0.245	-0.400
Rest Central America	0.126	-0.067	0.767	-0.096	-0.063	0.060	-0.013	-0.216
Brazil	0.139	-0.081	3.280	0.301	-0.317	0.565	0.299	-0.971
Rest South America	0.056	-0.177	2.985	0.545	0.221	0.327	0.029	-0.630
Northern Africa	0.003	-0.486	3.196	-0.202	-0.211	-0.140	0.109	-0.188
Western Africa	0.345	-0.401	3.625	-0.390	-0.756	-0.243	-0.460	-0.331
Eastern Africa	0.114	-0.087	2.818	0.177	-0.579	0.214	-0.323	-0.110
Southern Africa	-0.052	0.017	2.029	-0.115	-0.914	0.011	-0.141	-0.449
Western Europe	0.265	-0.345	2.323	0.367	0.185	0.258	0.659	-0.154
Central Europe	0.226	-0.370	-0.016	0.217	-0.191	-0.181	0.364	-0.228
Turkey	0.190	-0.197	-0.288	0.022	0.031	-0.031	0.081	-0.073
Ukraine	0.228	-0.547	-0.026	0.103	0.005	-0.093	0.233	-0.430
Asia-Stan	-0.055	0.083	0.198	0.037	0.166	-0.366	-0.212	-0.485
Russia	0.341	-1.174	0.533	-0.172	0.007	-1.264	0.221	-1.442
Middle East	0.014	-0.380	2.794	-0.006	-0.420	-0.331	0.124	-0.121
South Asia	0.593	-0.542	3.496	0.395	-0.172	0.660	-0.049	0.056
Korea	0.030	-0.855	0.823	0.045	0.165	-0.083	0.213	-0.203
China	0.294	-0.230	5.242	0.721	0.820	-0.018	1.635	-0.250
South-East Asia	0.307	-1.032	2.324	0.142	-0.182	-0.214	0.195	-0.501
Indonesia	0.766	-0.613	2.128	-2.365	0.045	-0.054	0.182	-0.256
Japan	-0.049	-1.050	0.953	0.056	0.192	-0.239	0.201	-1.087
Goodness-of-fit (ROC)	**0.891**	**0.844**	**0.978**	**0.893**	**0.918**	**0.920**	**0.944**	**0.874**

All coefficients siginificant at 0.01 level, except cells marked

Annex 11 Examples of suitability maps for various land use change processes




Likelihood of pastures occurrence
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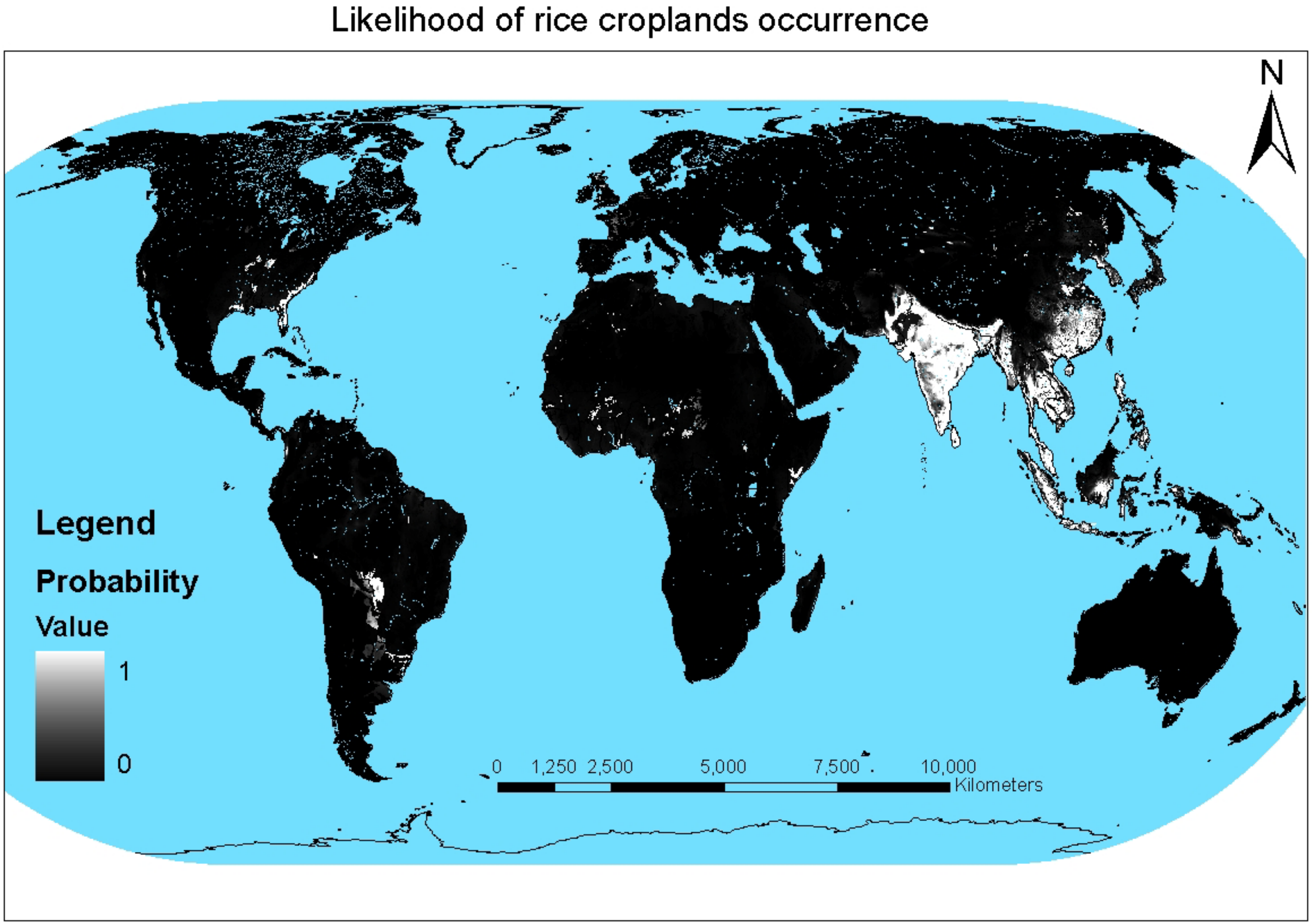
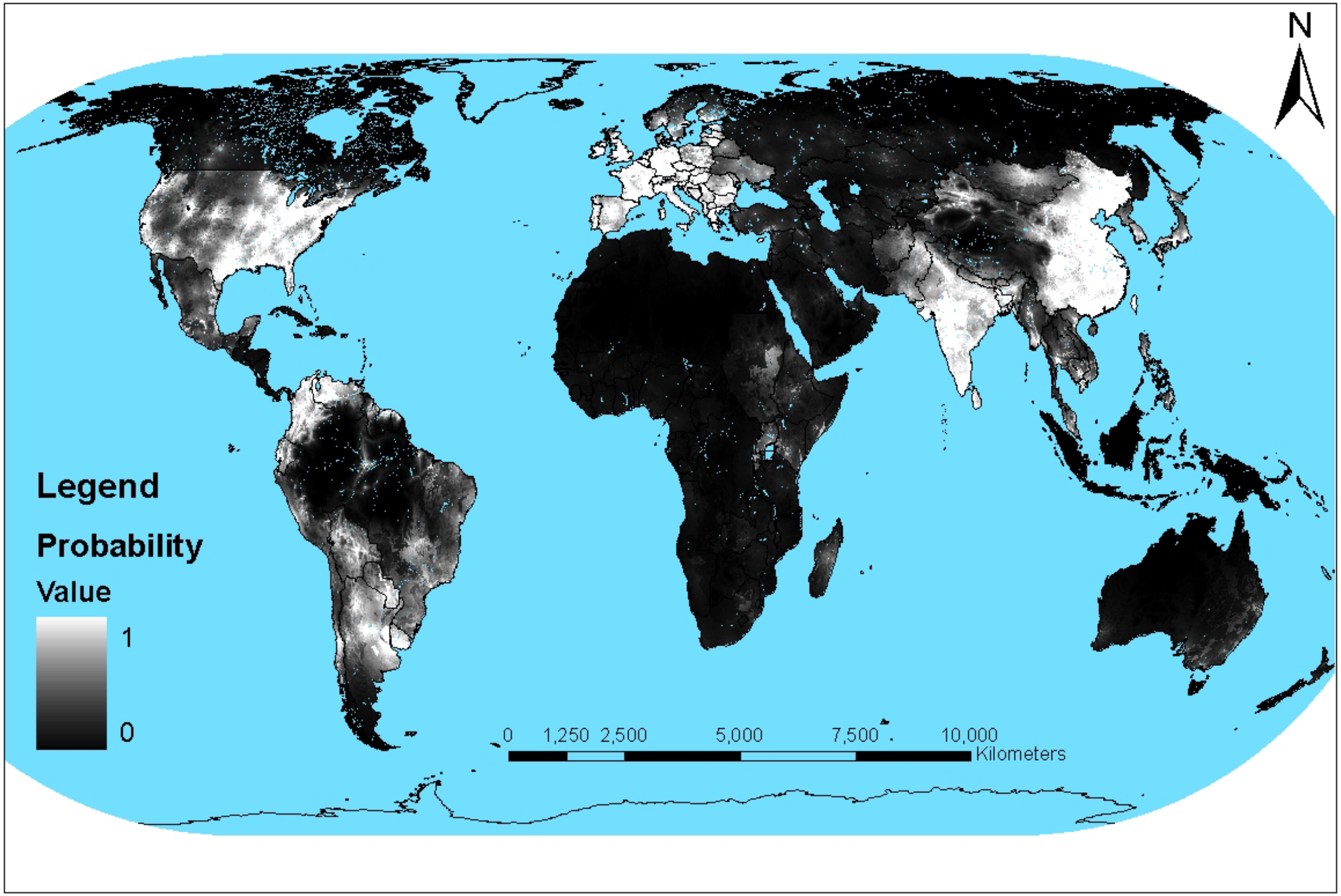
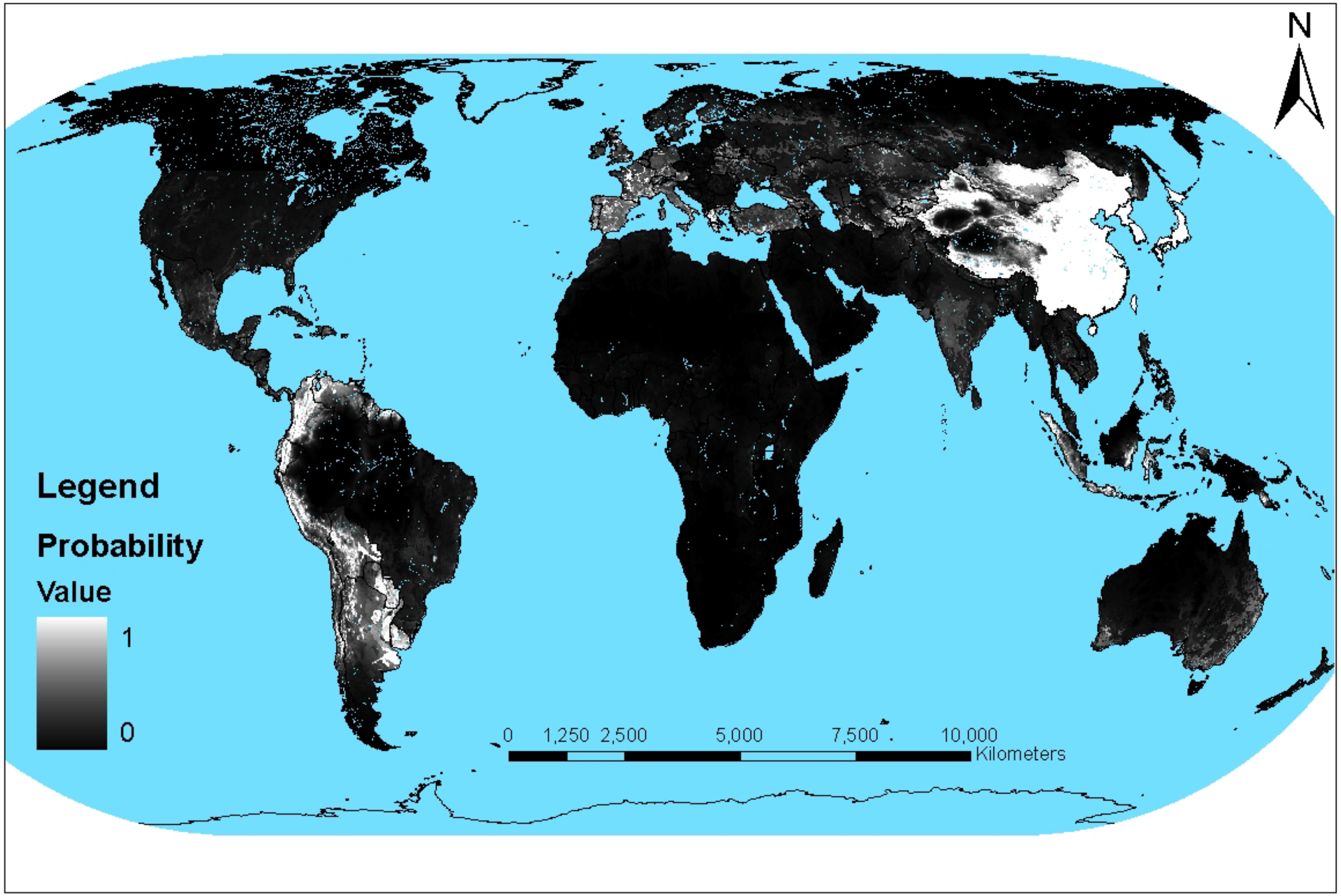
Legend
Probability
Value
1
0
0
1,250
2,500
5,000
7,500
10,000
Kilometers


Likelihood of rice croplands occurrence
N
Legend
Probability
Value
1
0
0 1,250 2,500 5,000 7,500 10,000
Kilometers

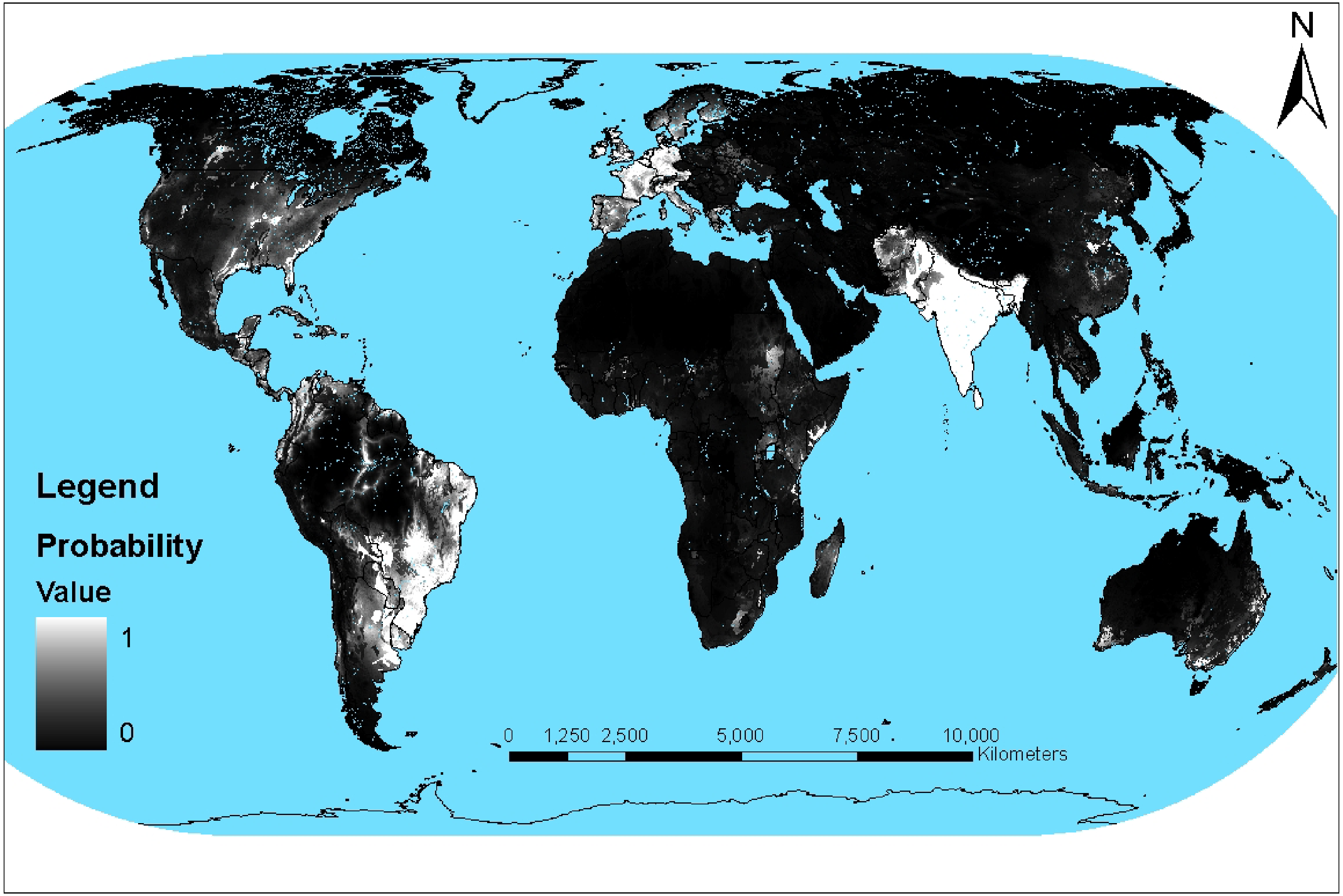
Likelihood of occurrence for intensive croplands



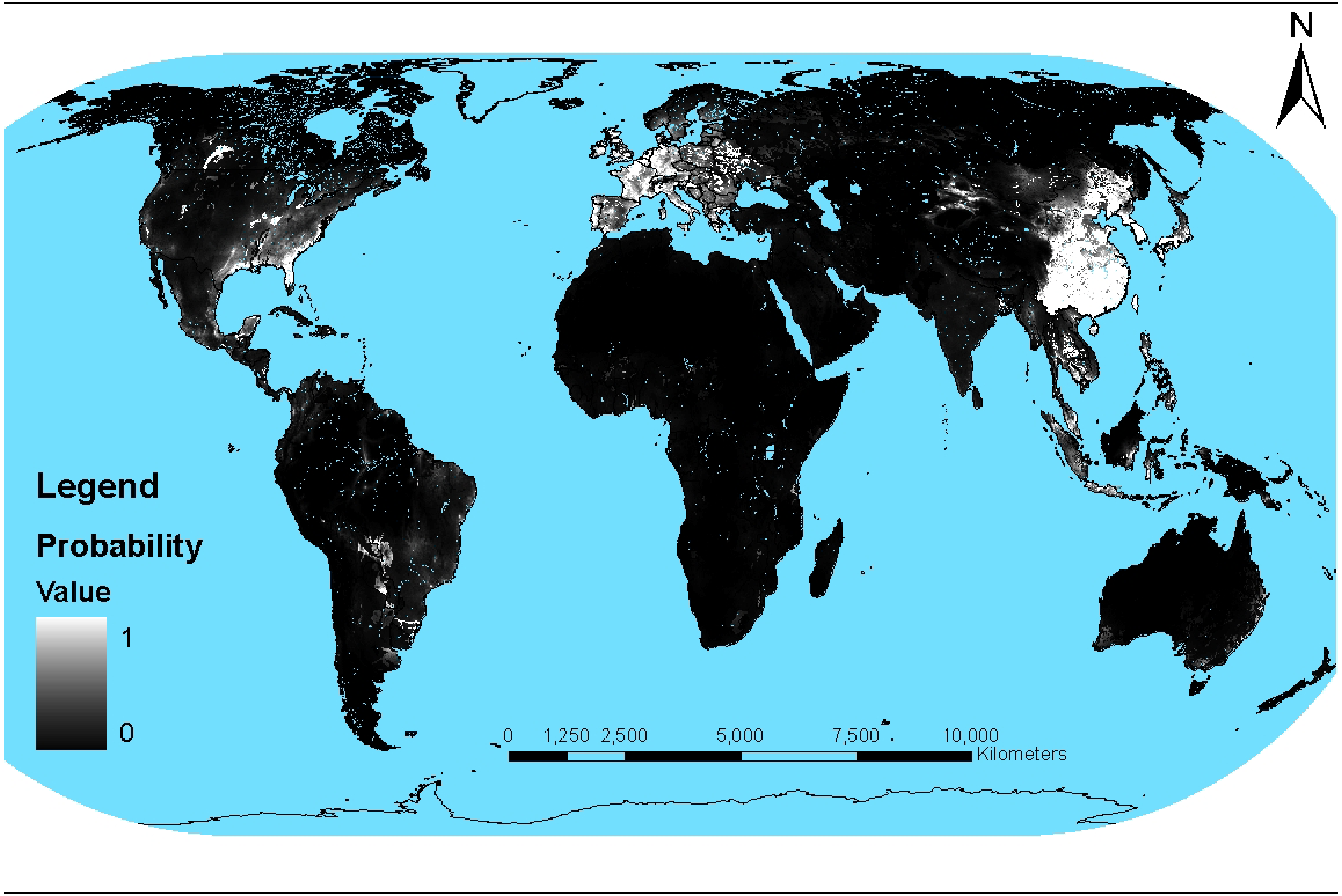
Likelihood of occurrence for intensive rice croplands



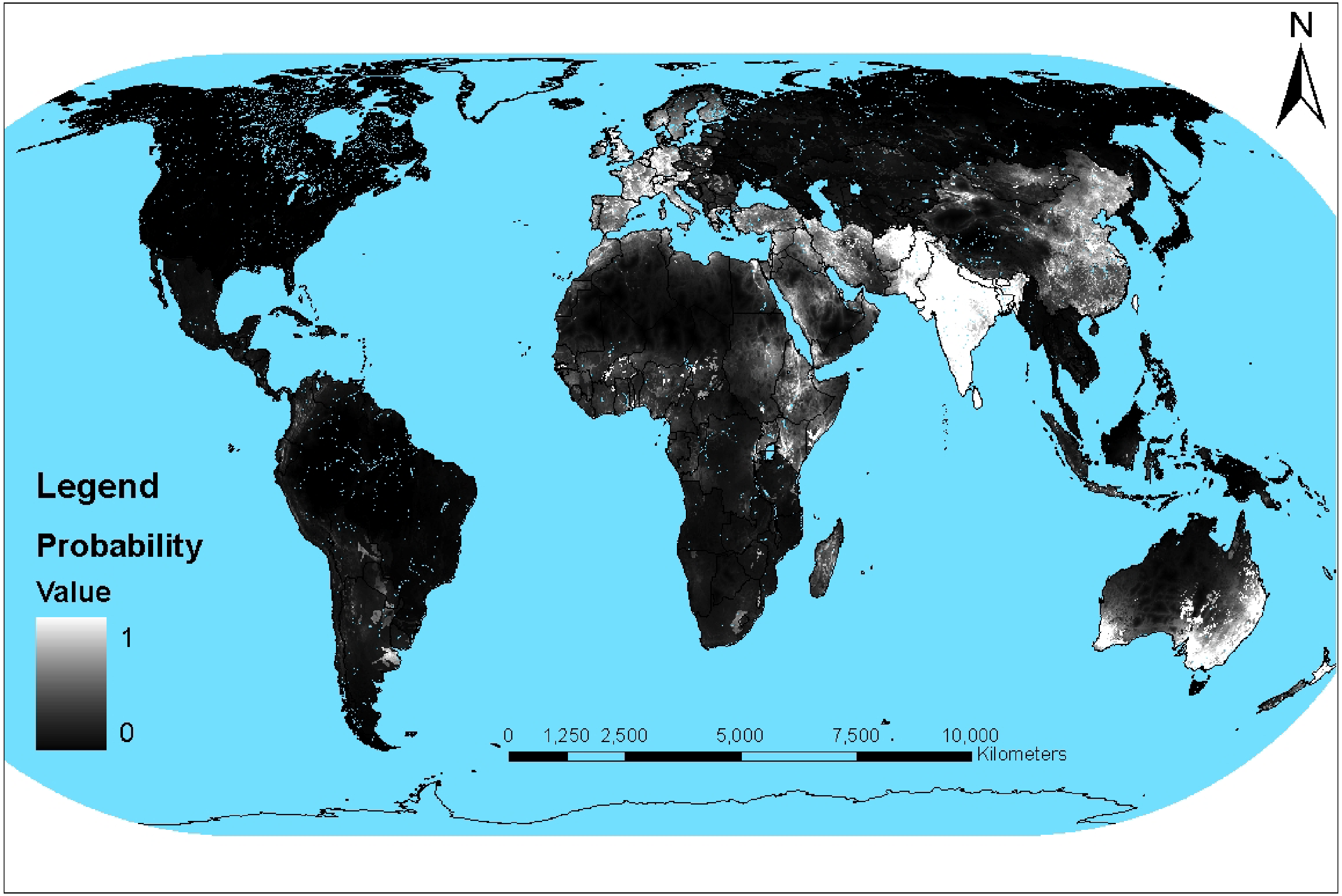
Likelihood of occurrence for intensive bovines systems



Likelihood of occurrence for intensive monogastrics systems

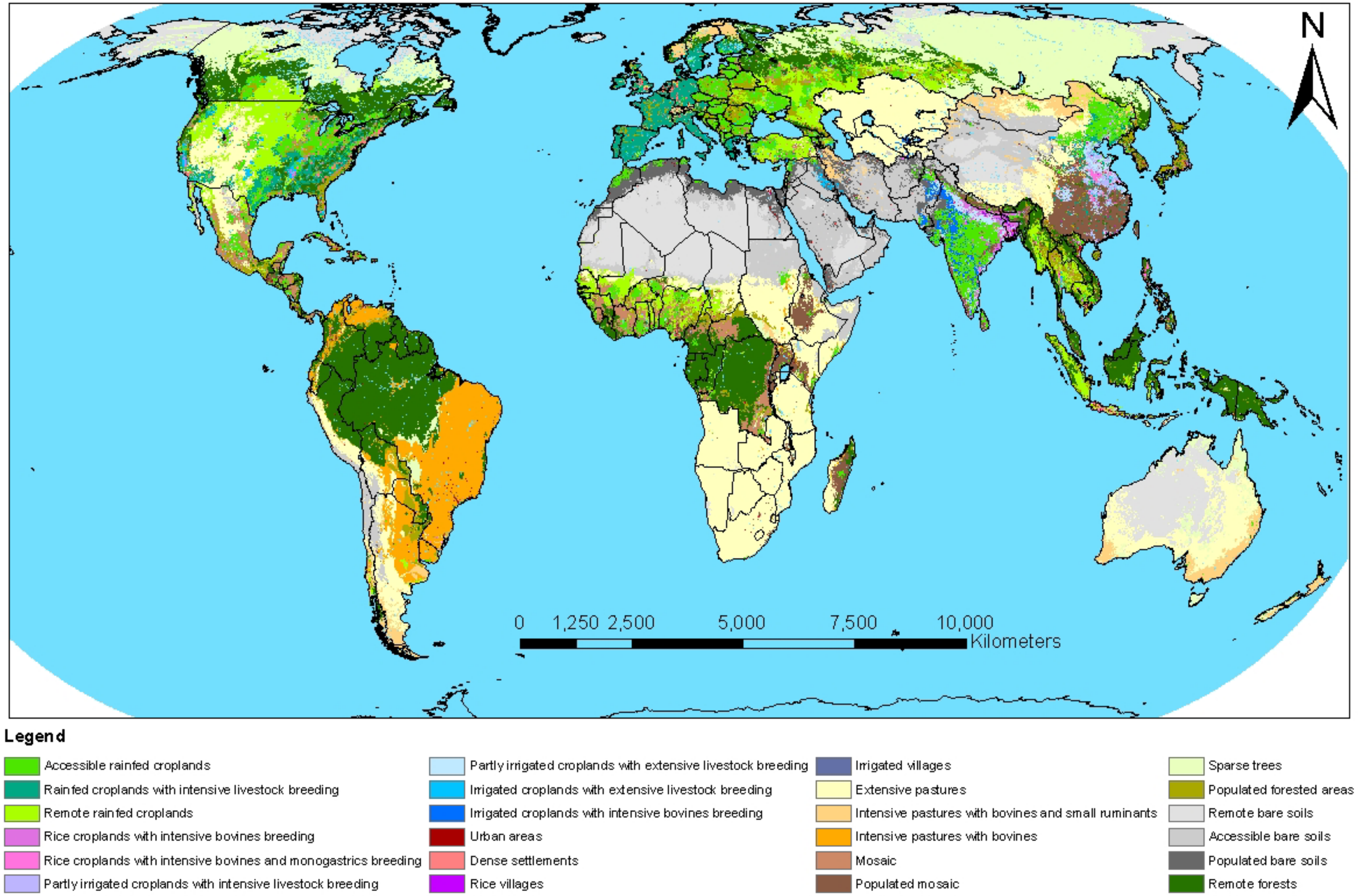


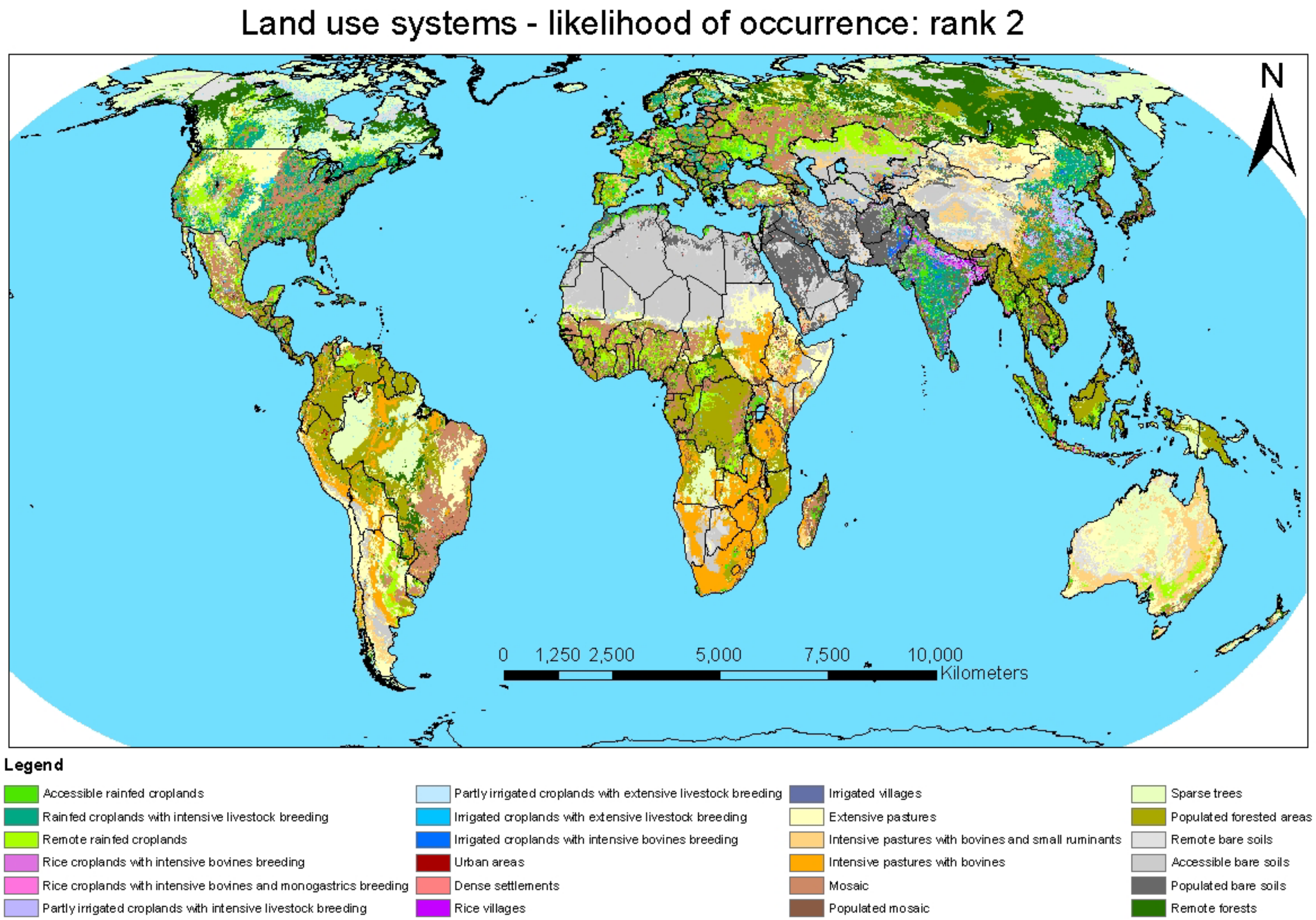
Likelihood of occurrence for intensive small ruminants systems



Annex 12 Land use systems most likely to occur

Land use systems - likelihood of occurrence: rank 1




Land use systems - likelihood of occurrence: rank 2
N
0
1,250
2,500
5,000
7,500
10,000
Kilometers
Legend
Accessible rainfed croplands
Rainfed croplands with intensive livestock breeding
Remote rainfed croplands
Rice croplands with intensive bovines breeding
Rice croplands with intensive bovines and monogastrics breeding
Partly irrigated croplands with intensive livestock breeding
Partly irrigated croplands with extensive livestock breeding
Irrigated croplands with extensive livestock breeding
Irrigated croplands with intensive bovines breeding
Urban areas
Dense settlements
Rice villages
Irrigated villages
Extensive pastures
Intensive pastures with bovines and small ruminants
Intensive pastures with bovines
Mosaic
Populated mosaic
Sparse trees
Populated forested areas
Remote bare soils
Accessible bare soils
Populated bare soils
Remote forests

Annex 13 Conversion matrices

Conversion matrices for local adaptive land use changes

	To	Croplands									Dense settlements				Pastures			Mosaic		Sparse trees	Forests	Barren			Forests
From	From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Accessible rainfed croplands	1	1	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Rainfed croplands with intensive livestock	2	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Remote rainfed croplands	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Rice croplands with intensive bovines	4	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines and monogastrics	5	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with intensive livestock	6	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with extensive livestock	7	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with extensive livestock	8	1	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with intensive bovines	9	0	1	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Urban areas	10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense settlements	11	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice villages	12	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated villages	13	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Extensive pastures	14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0
Intensive bovines and small ruminants pastures	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
Intensive bovines pastures	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0
Mosaic	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Populated mosaic	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
Sparse trees	19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1	0	1
Populated forests	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
Remote bare soils	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Accessible bare soils	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
Populated bare soils	23	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
Remote forests	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1

Conversion matrices for croplands, pastures and rice expansion

	To	Croplands									Dense settlements				Pastures			Mosaic		Sparse trees	Forests	Barren			Forests
From	From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Accessible rainfed croplands	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1
Rainfed croplands with intensive livestock	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Remote rainfed croplands	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1
Rice croplands with intensive bovines	4	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines and monogastrics	5	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with intensive livestock	6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with extensive livestock	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with extensive livestock	8	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with intensive bovines	9	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Urban areas	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense settlements	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice villages	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated villages	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extensive pastures	14	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1
Intensive bovines and small ruminants pastures	15	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Intensive bovines pastures	16	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Mosaic	17	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	1
Populated mosaic	18	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	1
Sparse trees	19	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Populated forests	20	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Remote bare soils	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accessible bare soils	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated bare soils	23	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote forests	24	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Where 1 are feasible LUS conversions and 0 discarded conversions.

Conversion matrices for land use intensification

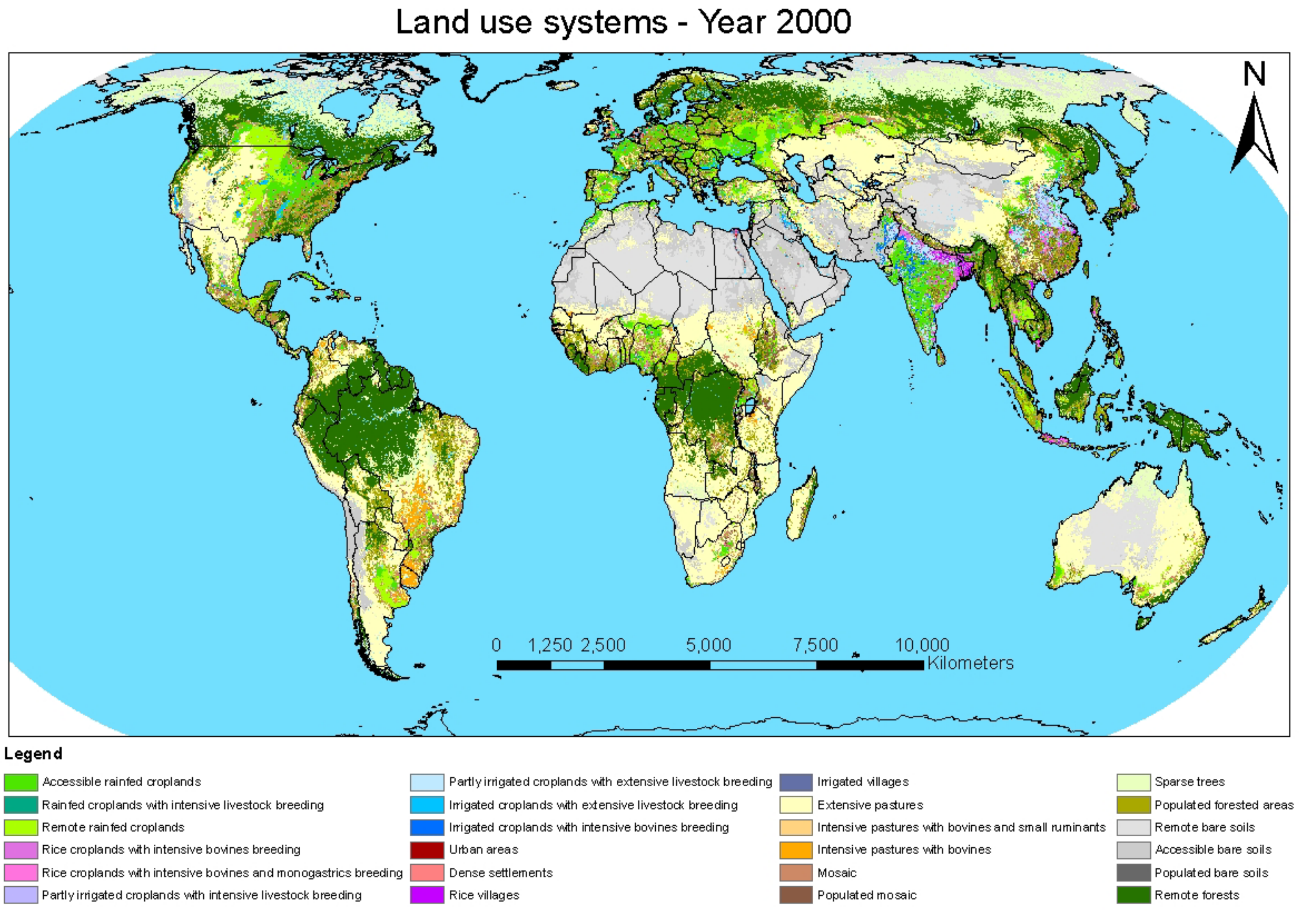
	To	Croplands									Dense settlements				Pastures			Mosaic		Sparse trees	Forests	Barren			Forests
From	From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Accessible rainfed croplands	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rainfed croplands with intensive livestock	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote rainfed croplands	3	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines and monogastrics	5	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with intensive livestock	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with extensive livestock	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with extensive livestock	8	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with intensive bovines	9	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban areas	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense settlements	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice villages	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated villages	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extensive pastures	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Intensive bovines and small ruminants pastures	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Intensive bovines pastures	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mosaic	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated mosaic	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparse trees	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated forests	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote bare soils	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accessible bare soils	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated bare soils	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote forests	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Conversion matrices for changes in livestock densities

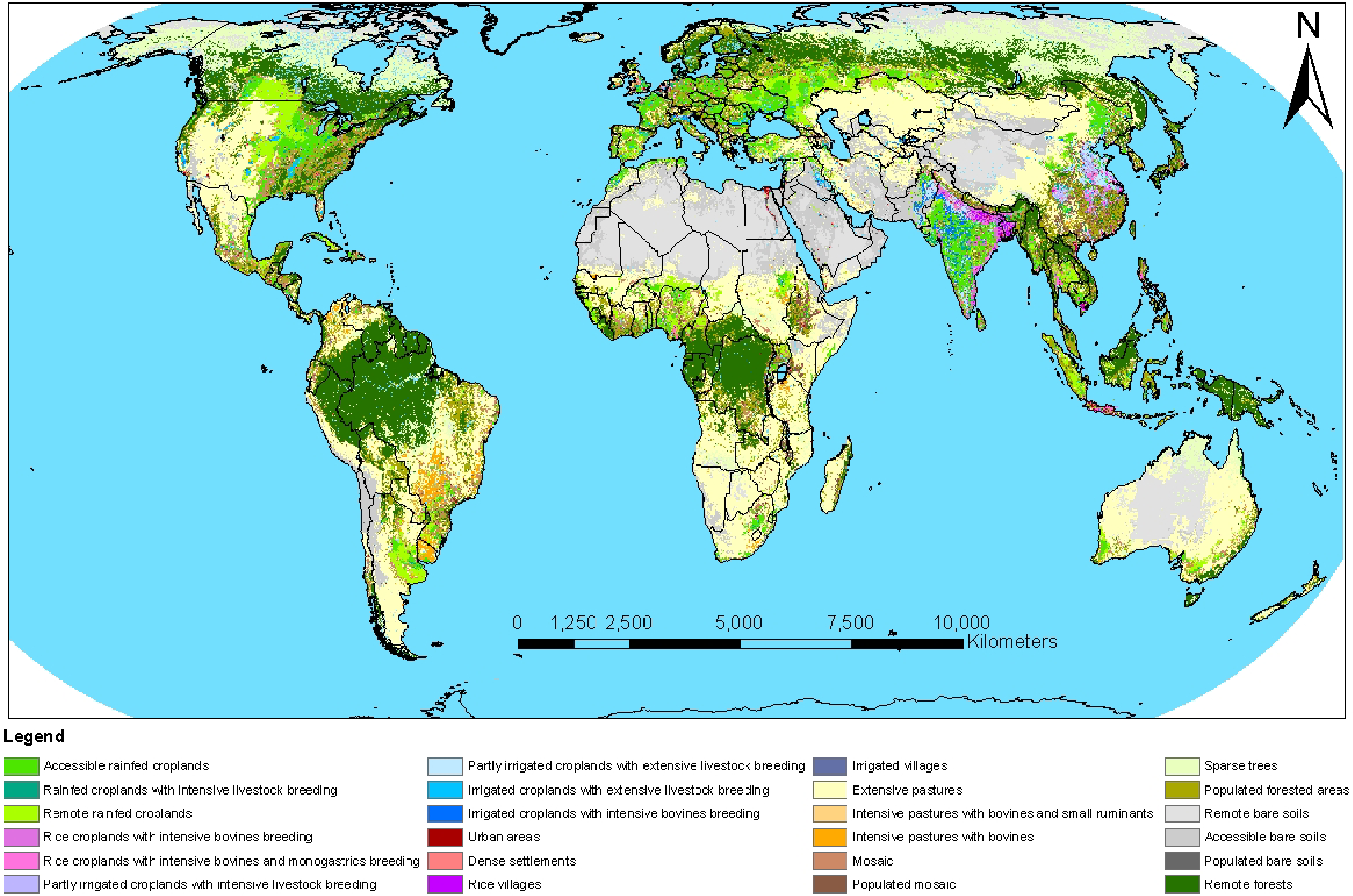
	To	Croplands									Dense settlements				Pastures			Mosaic		Sparse trees	Forests	Barren			Forests
From	From/to	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Accessible rainfed croplands	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rainfed croplands with intensive livestock	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote rainfed croplands	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice croplands with intensive bovines and monogastrics	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with intensive livestock	6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partly irrigated croplands with extensive livestock	7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with extensive livestock	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated croplands with intensive bovines	9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban areas	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dense settlements	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice villages	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Irrigated villages	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extensive pastures	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Intensive bovines and small ruminants pastures	15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Intensive bovines pastures	16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Mosaic	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated mosaic	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparse trees	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated forests	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote bare soils	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Accessible bare soils	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Populated bare soils	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remote forests	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Where 1 are feasible LUS conversions and 0 discarded conversions.

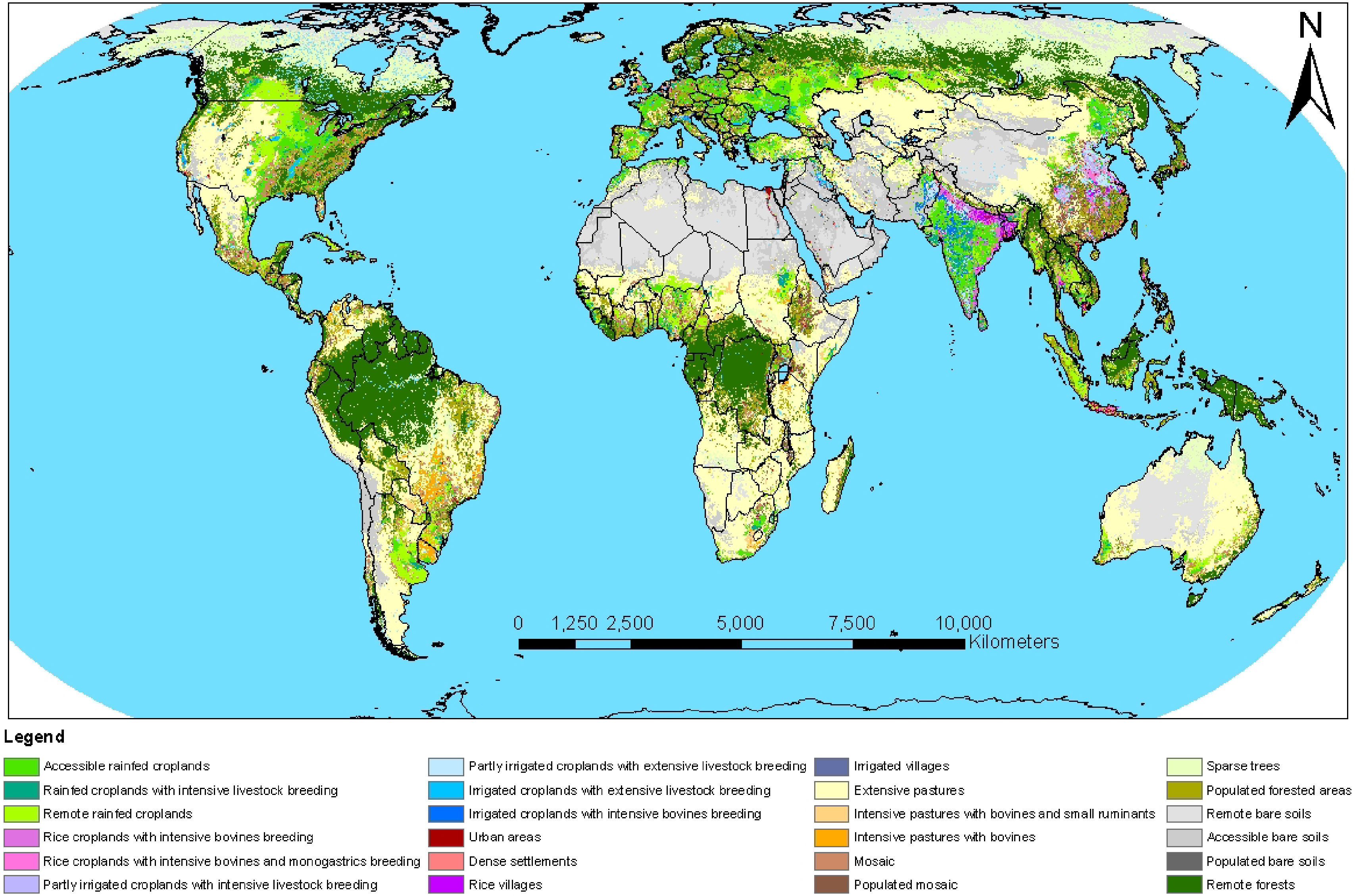
Annex 14 Simulated land use systems maps for the period 2000 – 2050



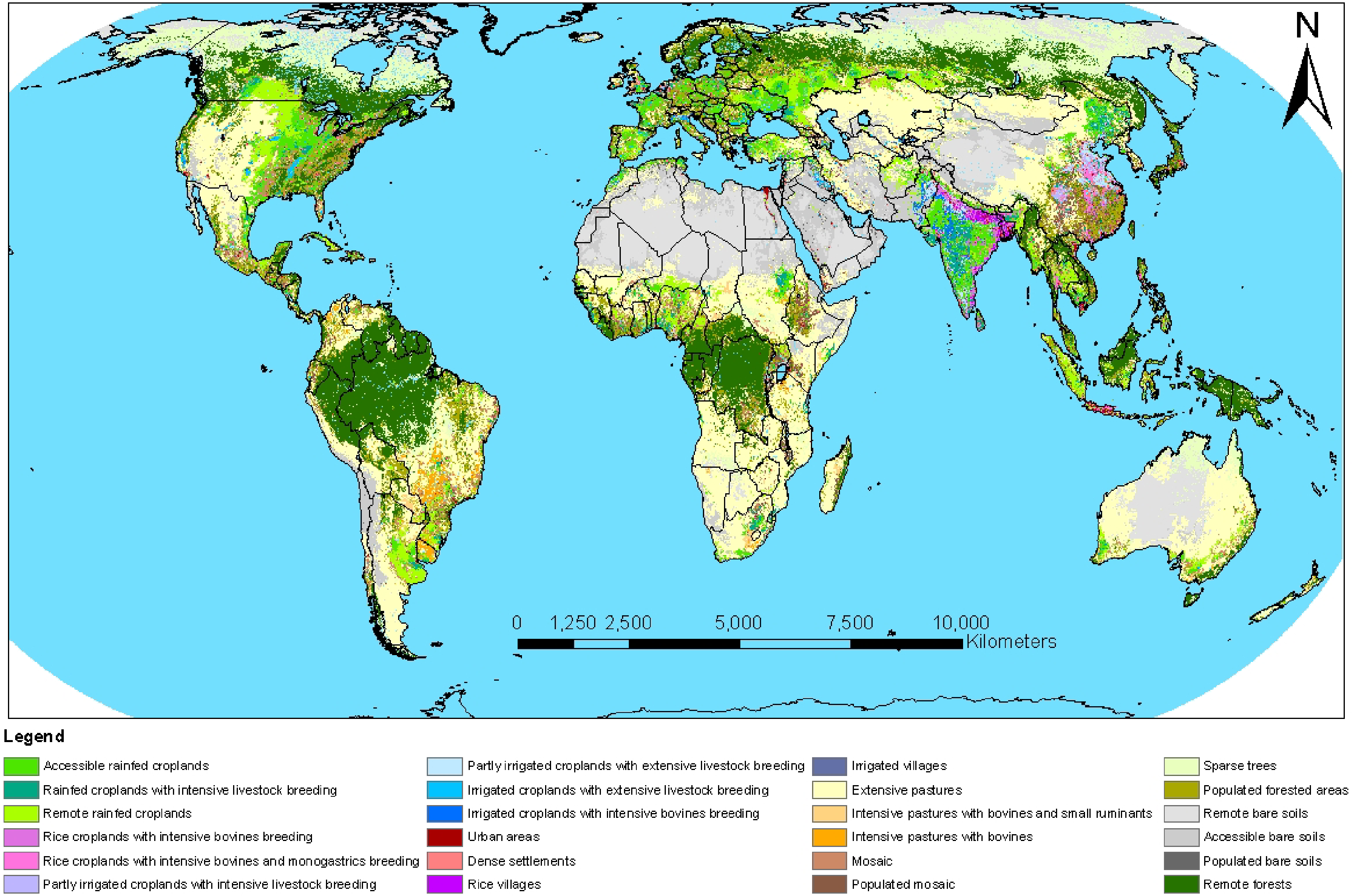
Land use systems - Year 2005



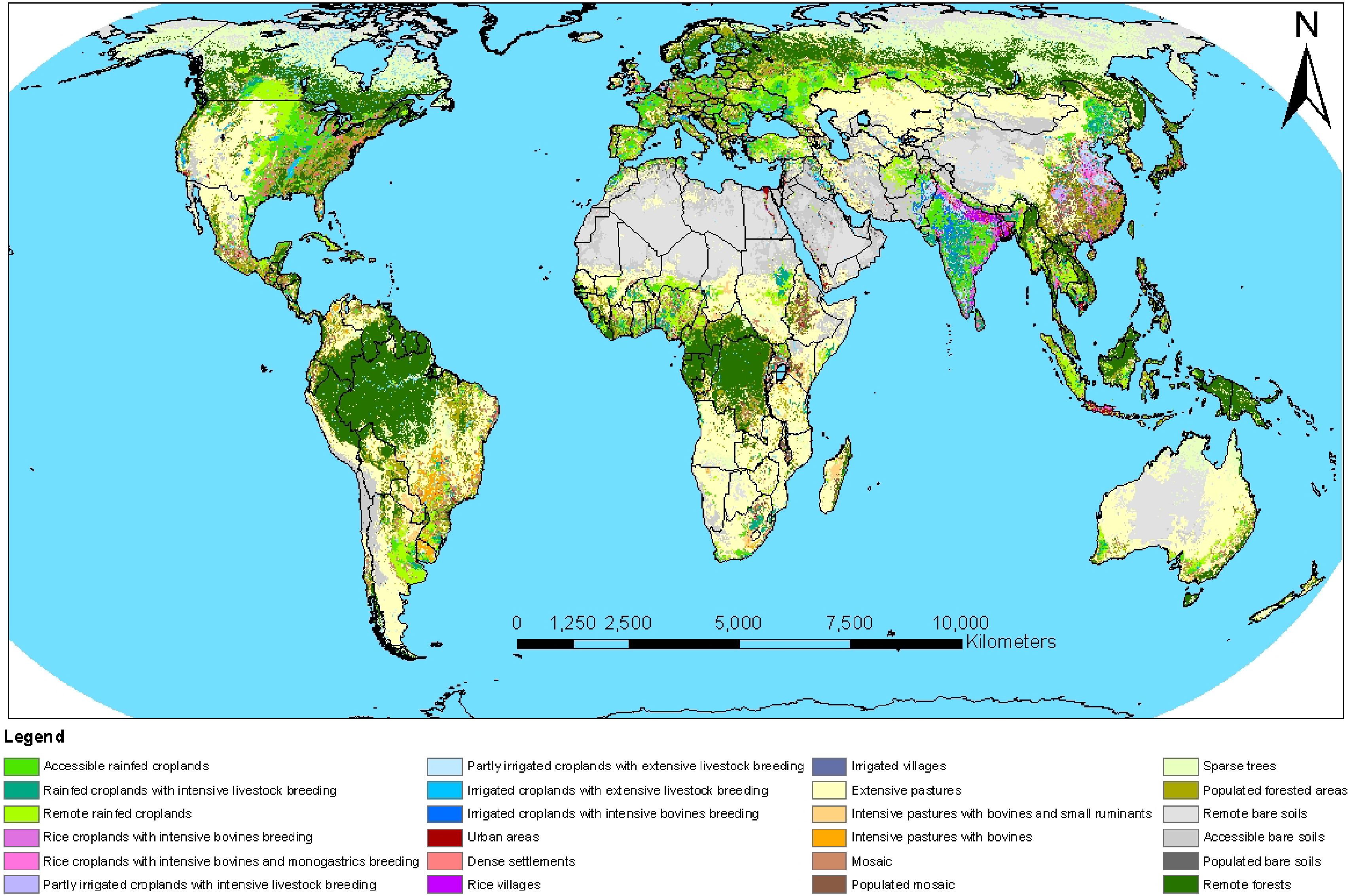
Land use systems - Year 2010



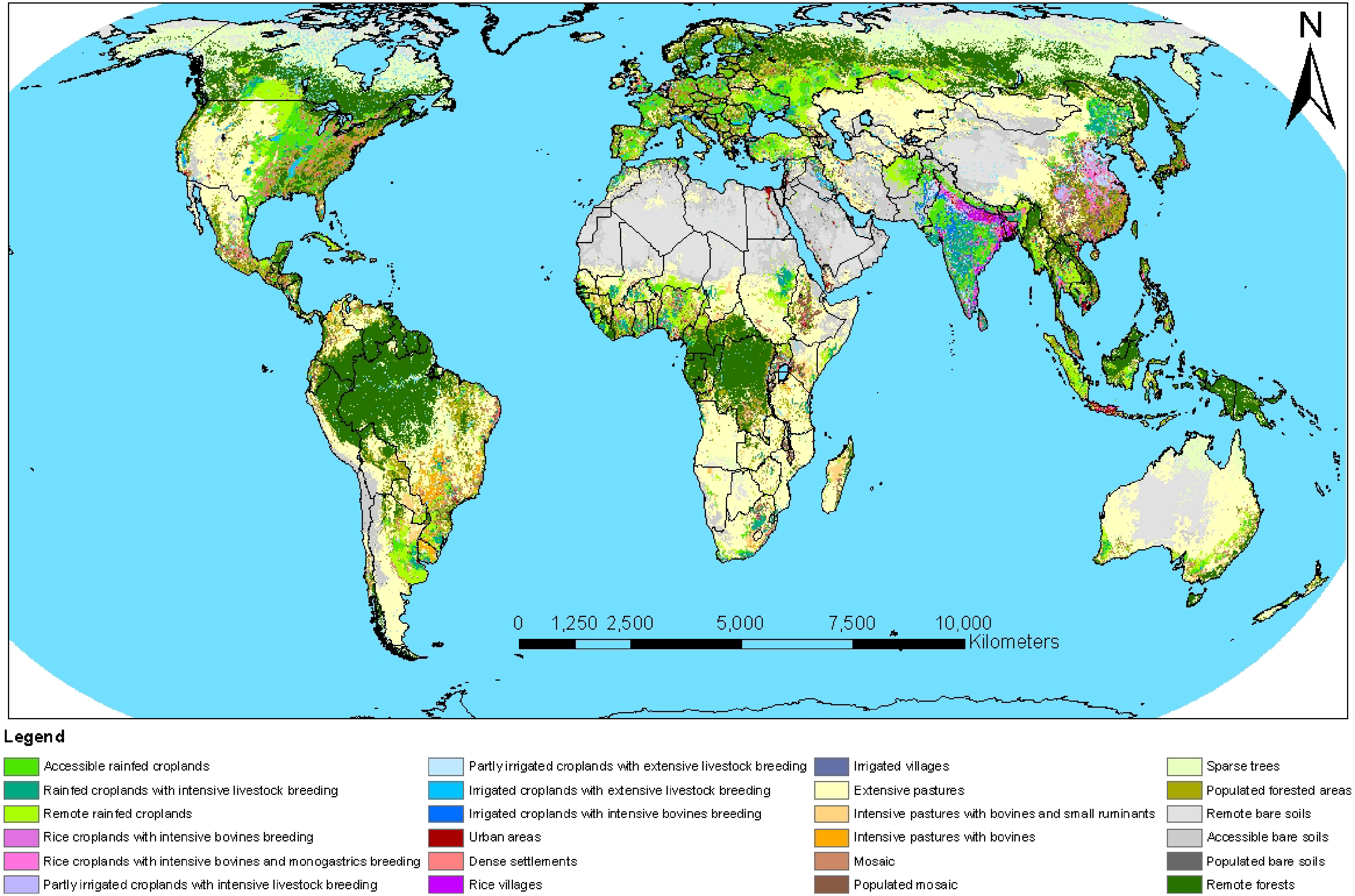
Land use systems - Year 2015



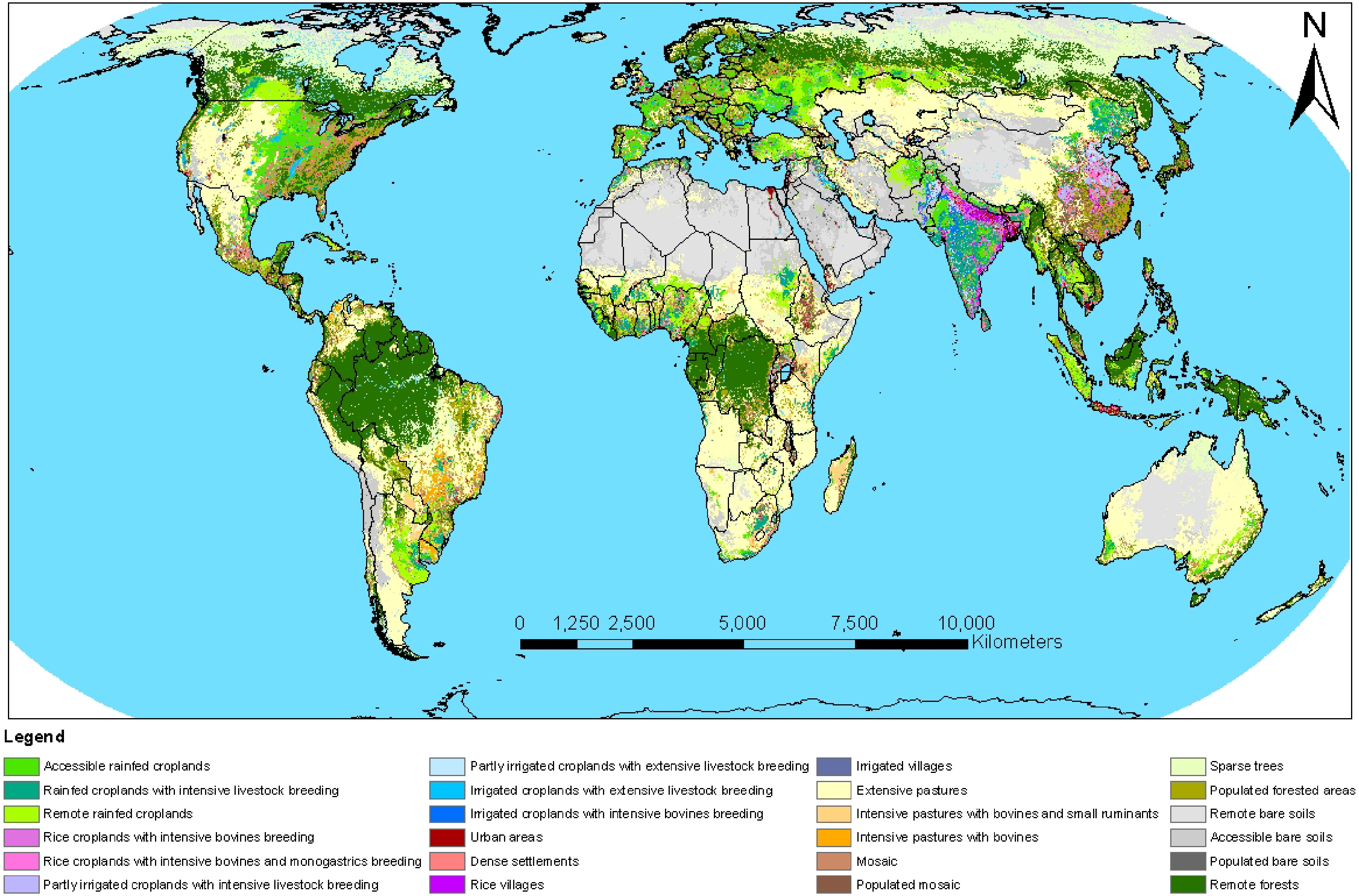
Land use systems - Year 2020



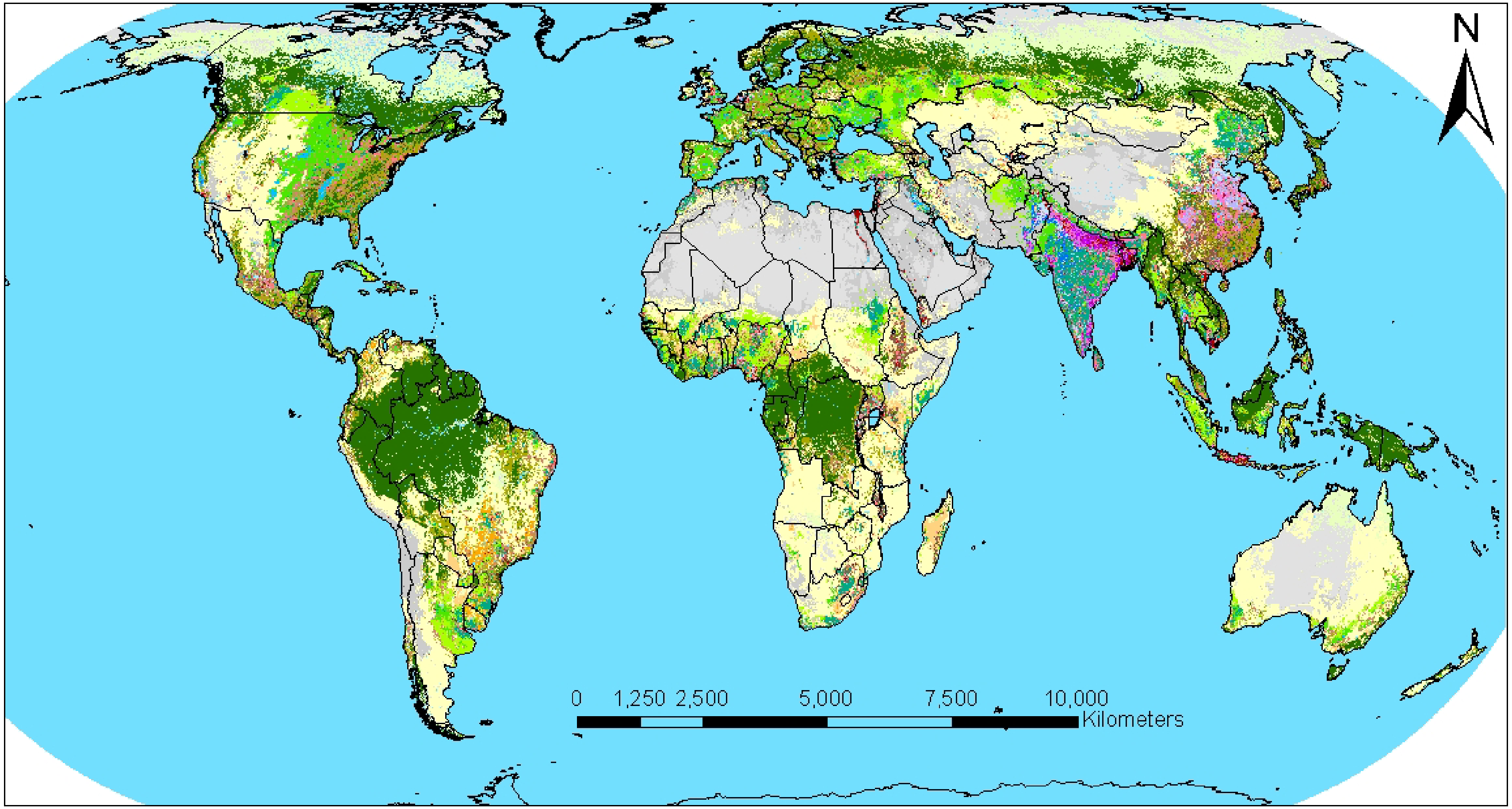
Land use systems - Year 2025



Land use systems - Year 2030



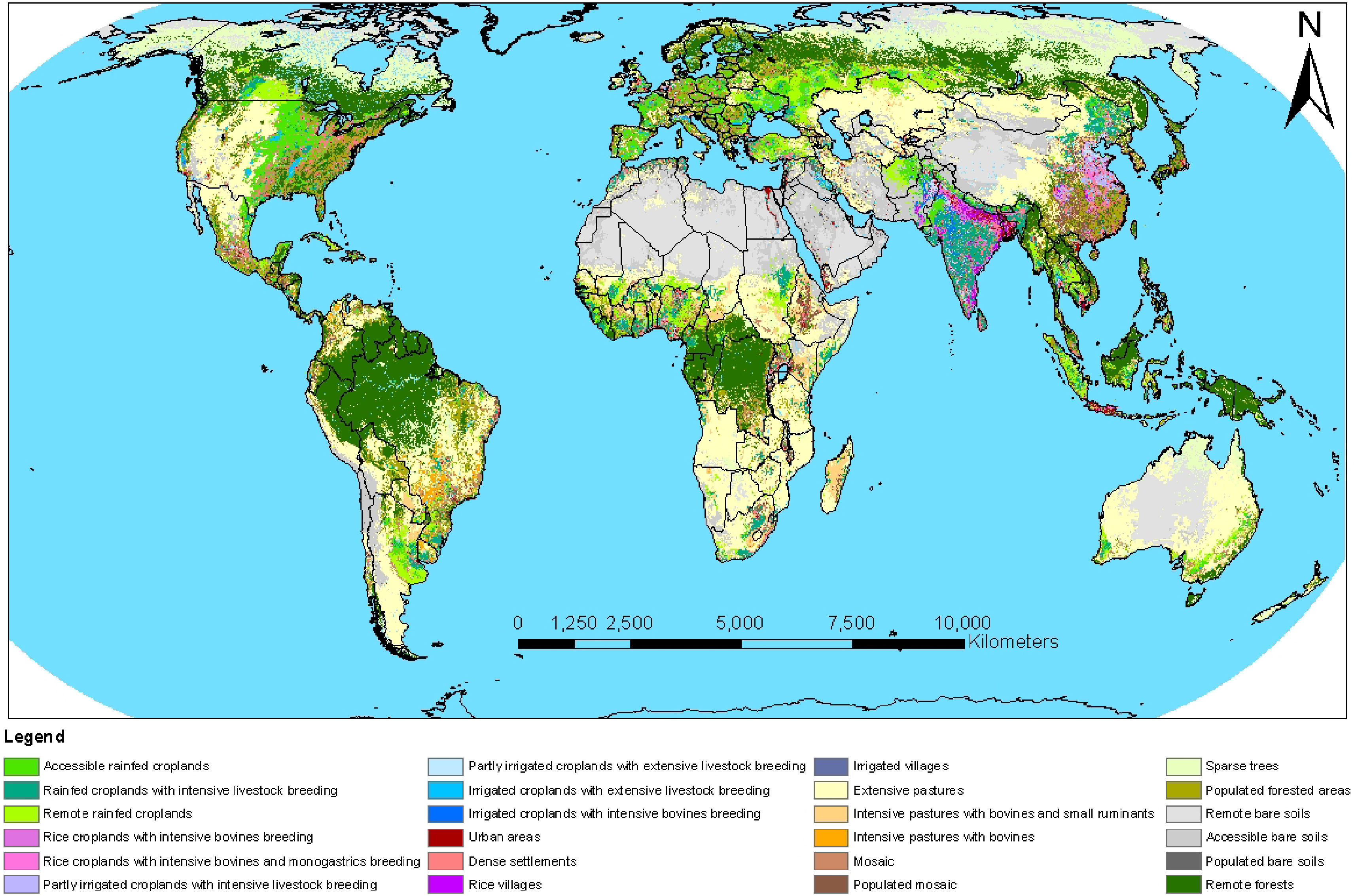
Land use systems - Year 2035



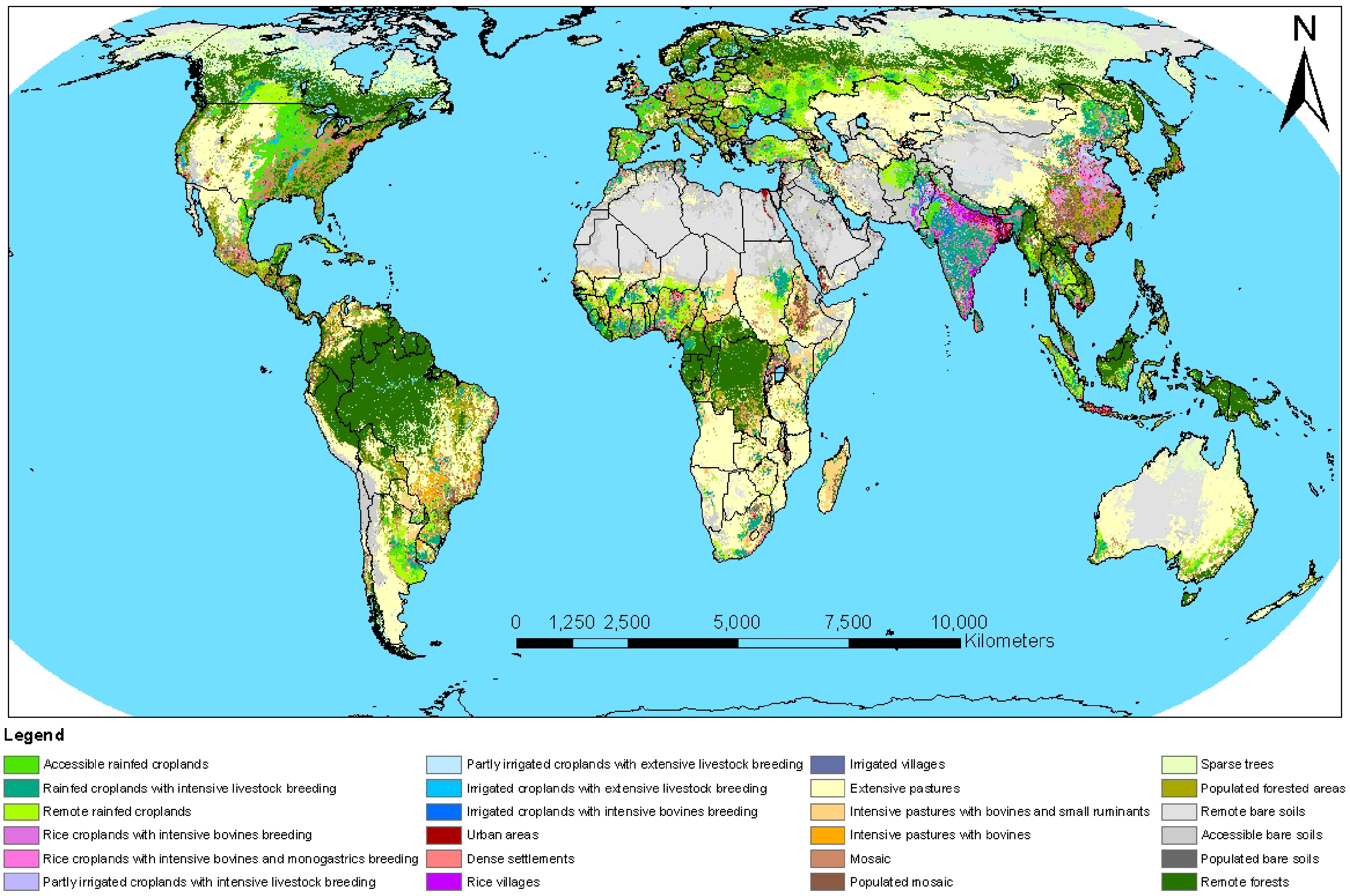
Legend

- Accessible rainfed croplands
- Rainfed croplands with intensive livestock breeding
- Remote rainfed croplands
- Rice croplands with intensive bovines breeding
- Rice croplands with intensive bovines and monogastrics breeding
- Partly irrigated croplands with intensive livestock breeding
- Partly irrigated croplands with extensive livestock breeding
- Irrigated croplands with extensive livestock breeding
- Irrigated croplands with intensive bovines breeding
- Urban areas
- Dense settlements
- Rice villages
- Irrigated villages
- Extensive pastures
- Intensive pastures with bovines and small ruminants
- Intensive pastures with bovines
- Mosaic
- Populated mosaic
- Sparse trees
- Populated forested areas
- Remote bare soils
- Accessible bare soils
- Populated bare soils
- Remote forests

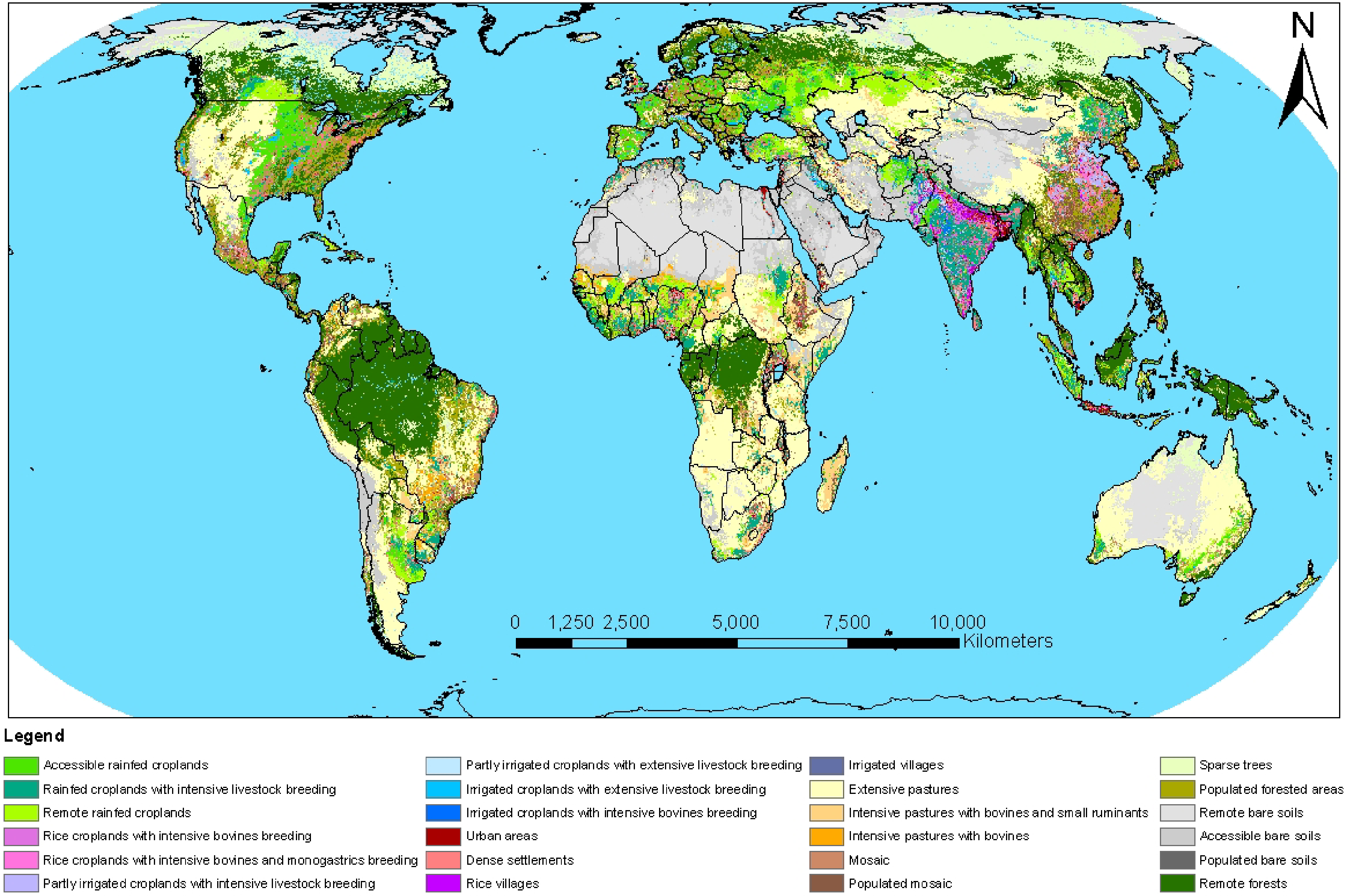
Land use systems - Year 2040



Land use systems - Year 2045



Land use systems - Year 2050



Annex 15 General remarks on the land use systems

1. Why is the accessibility the important factor in the classification given the uncertainty?
2. Is there really a difference between some LUS classes e.g. accessible rainfed croplands and remote rainfed croplands.
3. What effect would the accessibility have on the system? Farm size, technology? Should it rather be part of preference map?
4. Fixed irrigation per grid cell is problematic. Not possible/not necessary in many grid cells. That will also be visible in the range.
5. FAO livestock maps are pure statistics or also model based?
6. Add ranges to graphs.
7. Hierarchical legend for easy display.

Summary

The accessibility:
The accessibility may be too important in the classification. Questions about its influence over land use system change. Therefore it may be used as a factor for the preference map during the simulation.
Some regions are remote but rather accessible (Nantes region), sometimes it is the opposite (Namibian coast).

The irrigation:
Problem with irrigated croplands which are not (only in North America? Maybe in the Danube delta?).

Bare soils:
Pastures are overtaking bare soils in some regions (Andes and Kalahari desert). Bare soils are sometimes overtaking pastures (center of Australia).

Forests:
Forests should be sometimes mosaic or sparse trees (SE China and Rondonia).
(Populated) forests should be sparse trees or croplands (North Argentina, North Surinam).
Populated forests should be sparse trees (Iceland).

Pastures:
Refine differences between extensive pastures.

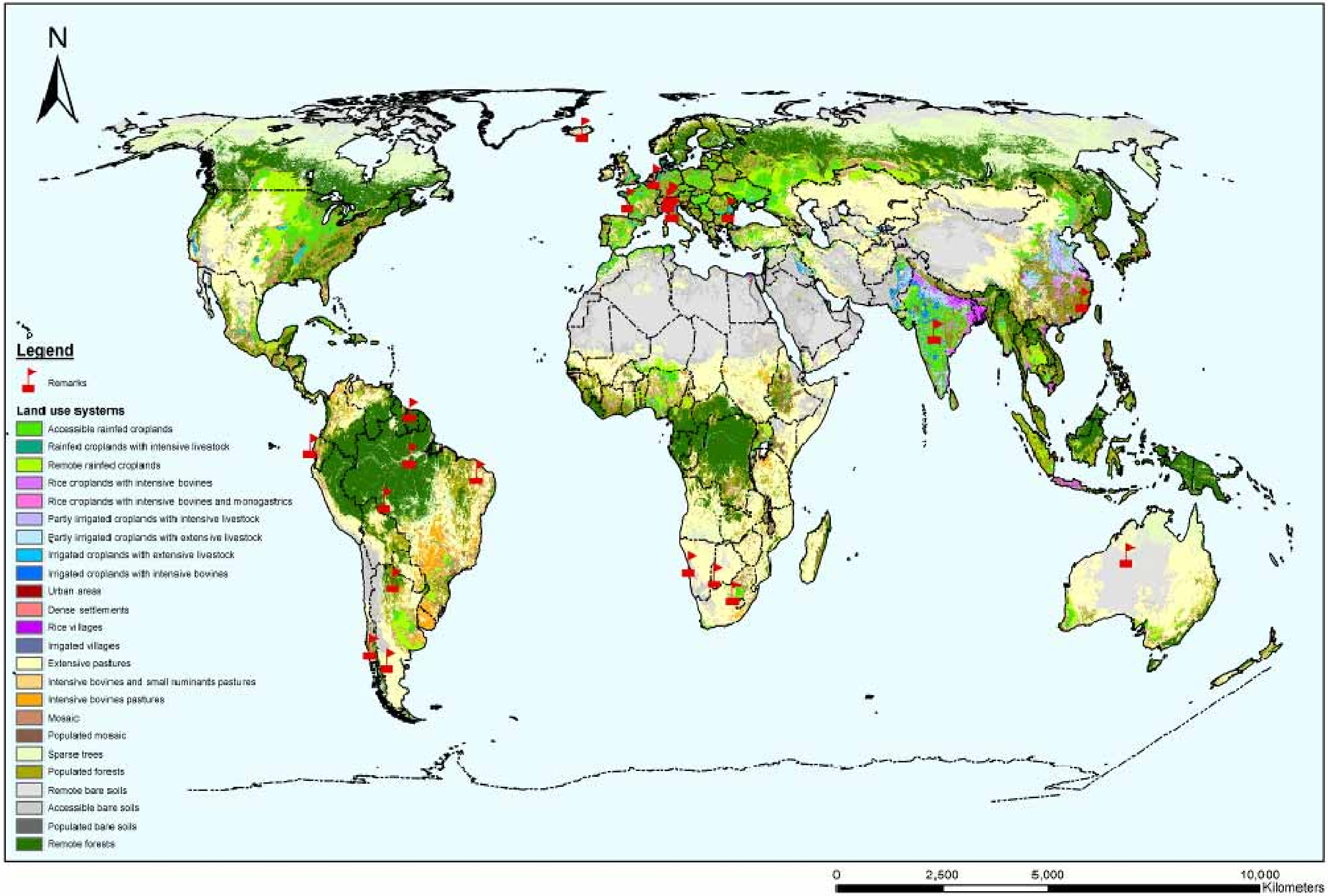
Population density:
Does not appear in Indian rural areas.

Livestock:
Extensive livestock are wrong sometimes, should intensive (Netherlands, Northern Italy).

Visualization:
Ranges need to be added to the graphs.
The legend should be hierarchical.

Possible actions:
Use the accessibility in the classification of anthropogenic cells or in the preference map only.
Review the irrigated threshold.
Review the forests / mosaic distribution. Refine mosaic classes. Forests threshold.

Land use systems of the World and general remarks



Annex 16 Model pseudo-code

```
Declare model parameters
    Starting year
    Number of iterations
    Threshold of change for adaptive land use changes
    Probability maps determinants
    Land use systems profiles
    Outputs naming
Declare starting inputs values
    Land use system map
    Initial population density
    Initial PPP
    Initial temperature
    Initial precipitation
Drivers inputs
    Population density
    PPP
    Climatic conditions
    Macro-economic demand in areas and production
Start simulation
Compute probability maps
    Likelihood of occurrence for each LUS
    Likelihood of occurrence of intensive livestock systems
    Likelihood of occurrence for each land use system
    Likelihood of occurrence of croplands
    Likelihood of occurrence of rice croplands
    Likelihood of occurrence of pastures
    Likelihood of occurrence of intensive croplands
    Likelihood of occurrence of intensive rice croplands
    Rank of likelihood of occurrence for each LUS
Determine changes in local conditions
    Determine population change.
    Determine climatic change
Prepare data to be imported in SPSS
Compute original croplands areas and production, pastoral areas and livestock densities
Compute demand in croplands areas and production, pastoral areas and livestock densities
Start allocation procedure
    Allocate local adaptive changes
    Allocate croplands changes in area
        Update demand for rice croplands areas
        Determine feasible conversions for rice croplands change in area according to
        demand
        Sort based on likelihood of occurrence of rice croplands according to demand
        Allocate required LUS conversions according to demand in rice croplands area
    Allocate croplands changes in area
        Update demand for croplands areas
        Determine potential changes in levels of croplands area
        Determine feasible conversions for croplands change in area according to demand
        Sort based on likelihood of occurrence of croplands according to demand
        Allocate required levels changes and LUS conversions according to demand
```

Allocate bovines density changes
Update demand for bovines density
Determine potential changes in levels of bovines densities
Determine feasible conversions for bovines density changes according to demand
Sort based on likelihood of occurrence of intensive bovines systems according to demand
Allocate required levels changes and LUS conversions according to demand
Allocate monogastrics density changes
Update demand for monogastrics density
Determine potential changes in levels of monogastrics densities
Determine feasible conversions for monogastrics density changes according to demand
Sort based on likelihood of occurrence of monogastrics intensive systems according to demand
Allocate required levels changes and LUS conversions according to demand
Allocate land management change of rice croplands
Update demand for rice croplands production
Determine feasible levels changes for land management change of rice croplands
Sort based on likelihood of occurrence of intensive rice croplands according to demand
Allocate required levels changes according to demand
Allocate land management change of croplands
Update demand for croplands production
Determine potential levels changes for land management change of croplands
Determine feasible conversions for land management change croplands
Sort based on likelihood of occurrence of intensive croplands according to demand
Allocate required levels changes and LUS conversions according to demand
Allocate pastures land cover changes
Update demand for pastures area
Determine potential changes in levels of pastures area
Determine feasible conversions for pastures change in area according to demand
Sort based on likelihood of occurrence of pastures according to demand
Allocate required levels changes and LUS conversions according to demand
Correct bovines density changes within pastoral systems
Update demand for bovines density
Determine potential changes in levels of bovines densities within pastoral systems
Determine feasible pastoral systems conversions for bovines density changes according to demand
Sort based on likelihood of occurrence of intensive bovines systems according to demand
Allocate required levels changes and LUS conversions according to demand
Allocate small ruminants density changes
Update demand for small ruminants density
Determine potential changes in levels of small ruminants densities
Determine feasible conversions for small ruminants density changes according to demand
Sort based on likelihood of occurrence of small ruminants according to demand
Allocate required levels changes and LUS conversions according to demand
Move to next time-step

Annex 17 Model verification procedure

Compute probability maps

- Probability maps values must be between 0 and 1.

Rank of land use systems likelihood of occurrence

- At a given grid-cell (i.e. location), each land use system should be selected only once as preferred LUS.

Allocate local adaptive changes

- At location of change, check if the allocated LUS was the most likely to occur and the result of a feasible LUS conversions according to the conversion matrix for local adaptive land use change.

Allocate rice croplands land cover changes

Update demand for rice croplands areas

- Check if the demand for rice croplands land cover change have been updated?
- Check if the potential conversions are feasible according to the conversion matrix for rice croplands land cover change and that the procedure allocates the LUS most likely to occur?
- Check if the potential levels changes and LUS conversions are resulting in rice croplands land cover increase or decrease as requested by demand?
- Check if the demand in rice croplands land cover changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in rice croplands land cover, location of change should have a low likelihood of occurrence of rice croplands. If required increase in rice croplands land cover, location of change should have a high likelihood of occurrence of rice croplands.

Allocate croplands land cover changes

Update demand for croplands and pastures areas

- Check if the demand for croplands land cover change have been updated?
- Check if levels changes are allocated prior to LUS conversions
- Check if the potential conversions are feasible according to the conversion matrix for croplands land cover change and that the procedure allocates the LUS most likely to occur?
- Check if the potential levels changes and LUS conversions are resulting in croplands land cover increase or decrease as requested by demand?
- Check if the demand in croplands land cover changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in croplands land cover, location of change should have a low likelihood of occurrence of croplands. If required increase in croplands land cover, location of change should have a high likelihood of occurrence of croplands.

Allocate bovines density changes

Update demand for bovines density

- Check if the demand for bovines density change has been updated?
- Check if levels changes are allocated prior to LUS conversions

- Check if the potential conversions are feasible according to the conversion matrix for livestock density change and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in bovines density increase or decrease as requested by demand?
- Check if the demand in bovines density changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in bovines density, location of change should have a low likelihood of occurrence of bovines. If required increase in bovines density, location of change should have a high likelihood of occurrence of bovines.

Allocate monogastrics density changes

Update demand for monogastrics density

- Check if the demand for monogastrics density change has been updated?
- Check if levels changes are allocated prior to LUS conversions
- Check if the potential conversions are feasible according to the conversion matrix for livestock density change and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in monogastrics density increase or decrease as requested by demand?
- Check if the demand in monogastrics density changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in monogastrics density, location of change should have a low likelihood of occurrence of monogastrics. If required increase in monogastrics density, location of change should have a high likelihood of occurrence of monogastrics.

Allocate rice croplands management changes

Update demand for rice croplands productivity

- Check if the demands for rice croplands productivity have been updated?
- Check if the potential levels changes in rice croplands productivity are resulting in land productivity increase or decrease as requested by demand?
- Check if the demand in rice croplands productivity changes has been fulfilled?
- Are the allocated LUS conversions occurring at the appropriate locations according to demand. If required decrease in rice croplands productivity, location of change should have a low likelihood of occurrence of intensive rice croplands. If required increase in rice croplands productivity, location of change should have a high likelihood of occurrence of intensive rice croplands.

Allocate land management changes

Update demand for croplands productivity

- Check if the demands for croplands productivity have been updated?
- Check if levels changes are allocated prior to LUS conversions
- Check if the potential conversions are feasible according to the conversion matrix for croplands productivity changes and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in land productivity increase or decrease as requested by demand?
- Check if the demand in land productivity changes has been fulfilled?
- Are the allocated LUS conversions occurring at the appropriate locations according to demand. If required decrease in croplands productivity, location of change should have a low likelihood of occurrence of intensive croplands. If required increase in

pastures land cover, location of change should have a high likelihood of occurrence of intensive croplands.

Allocate pastures land cover changes

Update demand for pastures areas

- Check if the demand for pastures land cover change has been updated?
- Check if levels changes are allocated prior to LUS conversions
- pastures land cover change and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in pastures land cover increase or decrease as requested by demand?
- Check if the demand in pastures land cover changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in pastures land cover, location of change should have a low likelihood of occurrence of pastures. If required increase in pastures land cover, location of change should have a high likelihood of occurrence of pastures.

Adjust and allocate bovines density changes

Update demand for bovines density

- Check if the demand for bovines density change has been updated?
- Check if levels changes are allocated prior to LUS conversions
- Check if the potential conversions are feasible according to the conversion matrix for livestock density change and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in bovines density increase or decrease as requested by demand?
- Check if the demand in bovines density changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in bovines density, location of change should have a low likelihood of occurrence of bovines. If required increase in bovines density, location of change should have a high likelihood of occurrence of bovines.

Allocate small ruminants density changes

Update demand for small ruminants density

- Check if the demand for small ruminants density change has been updated?
- Check if levels changes are allocated prior to LUS conversions
- Check if the potential conversions are feasible according to the conversion matrix for livestock density change and that the procedure allocates the LUS most likely to occur?
- Check if the potential conversions are resulting in small ruminants density increase or decrease as requested by demand?
- Check if the demand in small ruminants density changes has been fulfilled?
- Check if the allocated LUS conversions are occurring at the appropriate locations according to demand. If required decrease in small ruminants density, location of change should have a low likelihood of occurrence of small ruminants. If required increase in small ruminants density, location of change should have a high likelihood of occurrence of small ruminants.

Annex 18 Model code

```
# ---------------------------------------------------------------------------
# Model_v1.py
# Created on: Tuesday July 7 2010
#   (generated by Aurelien Letourneau)
# ---------------------------------------------------------------------------
```

The Model code is downloadable through
http://www.wotnatuurenmilieu.wur.nl/NL/publicaties/Werkdocumenten/Werkdocumenten_2010/ WOt-werkdocument 207

Verschenen documenten in de reeks Werkdocumenten van de Wettelijke Onderzoekstaken Natuur & Milieu vanaf 2007

Werkdocumenten zijn verkrijgbaar bij het secretariaat van Unit Wettelijke Onderzoekstaken Natuur & Milieu, te Wageningen. T 0317 – 48 54 71; F 0317 – 41 90 00; E info.wnm@wur.nl
De werkdocumenten zijn ook te downloaden via de WOt-website www.wotnatuurenmilieu.wur.nl

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