REDD-PAC

REDD+ Policy Assessment Centre

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Description of the GLOBIOM-BRAZIL database available in the REDD-PAC WFS server

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1 GLOBIOM general overview

The **GLObal BIOsphere Management** (GLOBIOM) model is a bottom-up partial equilibrium model focusing on major global land-based sectors i.e. agriculture, forestry and bioenergy (Havlik et al. 2011) which has been developed at IIASA since 2007. It has been built following the same basis as the ASM-GHG model (Schneider, McCarl, and Schmid 2007). One of the main advantages of using a partial equilibrium land use optimization model is that it allows isolating the specific effect of one policy while in the reality many parameters change simultaneously. The main characteristics of the GLOBIOM model are presented as follows.

- ***Market-equilibrium model***: Endogenous adjustments in market prices lead to the equality between supply and demand for each product and region. GLOBIOM is built on the main neoclassical theory assumptions including the fact that agents make decisions which provide them with the greatest benefits or satisfaction, the increment in satisfaction becomes lower as long as the agents buy or sell more, and there is a unique equilibrium i.e. the agents do not have interest to change their actions once equilibrium is reached.
- ***Optimization model:*** The objective of the optimization problem is to maximize the sum of the consumers and of the producers' surplus under a certain set of constraints including the market equilibrium constraint. These are discrete constraints which encompass equalities and inequalities. The model is solved using the linear programming solver Cplex in GAMS. GLOBIOM also contains some non-linear functions but they have been linearized using stepwise approximation (McCarl and Spreen 1980). In this set-up, prices are not explicit but are given by the dual of the market balance equations.
- ***Partial equilibrium model:*** GLOBIOM focuses on only few sectors of the economy: crops, livestock, forestry and bioenergy. The agricultural and forestry sectors are linked in a single model and compete for a portion of the land.
- ***Spatial price equilibrium model***: It is a specific category of partial equilibrium and linear programming model where the equilibrium solution is found by the maximization of total area under the excess demand curve in each region minus the total transportation costs of all the shipments (Samuelson 1952; Judge and Takayama 1971). They have been largely applied since the 60s to forestry and agriculture. It relies on the homogeneous good assumption where the price difference between two regions is only explained by transportation costs. If the regional prices differ by more than the interregional cost of transporting goods, then trade will occur and the price difference will be driven down to the transport cost. This allows representation of bilateral trade flows between regions but a region cannot import from and export to the same region.

- ***Recursive-dynamic***: GLOBIOM is run for several periods of 10 years each following some recursive dynamics. Contrary to fully dynamic models, the agents of the economy do not make strategic decision taking into account future value of some parameters over several periods of time. However, the optimal decision in period t depends on some decisions that the agents have taken in the previous period t-1. For instance in GLOBIOM, at the beginning of the next period, the starting conditions for land use are updated using the solutions of the simulations from the previous period. Moreover, the reference situation is updated for each time step using exogenous drivers e.g. GDP and population growth.

The originality of GLOBIOM comes from the representation of drivers of land use change at two different geographical scales*:* all land related variables i.e. land use change, crops cultivation, timber production and livestock number are related to the pixel level but final demand, processing quantities, prices, and trade are computed at the regional level. It means that in GLOBIOM, regional factors influence the allocation of land use at the local level but the local constraints also influence the outcome of the variables defined at the regional level which ensures full consistency across multiple scales within short solution time through (Figure 1).

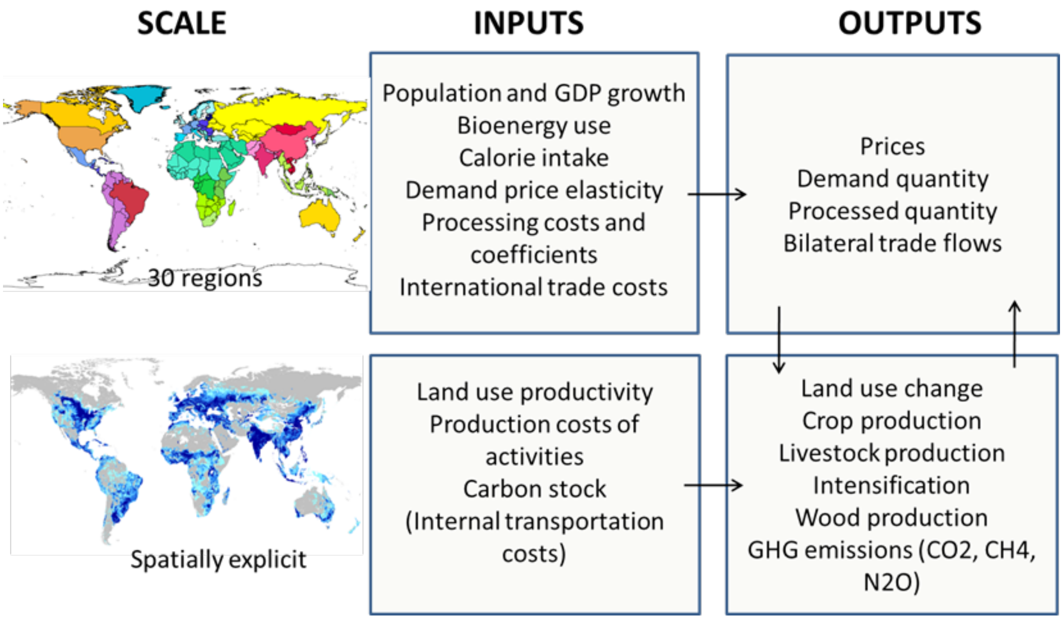


Figure 1: Main inputs and outputs of GLOBIOM at different scales

In GLOBIOM, all spatial input data are available at the simulation unit level. Simulation units are defined as combination of 5' spatial resolution grid[1] at the intersection between a 30' spatial resolution grid, Homogeneous Response Units (HRU) and country boundaries (Figure 2). The 30' spatial resolution grid is the minimum resolution level of global climate data (Skalský et al. 2008). Homogeneous Response

[1] A 5' resolution grid corresponds to ~10x10km at the equator, a 30' resolution grid corresponds to ~50x50km at the equator (the pixel size varies between 300 000 ha on equator to about 30 000 ha in high latitudes).

Units (HRU) are defined by characteristics of the landscape which are stable over time and hardly adjustable by farmers in order to simplify the biophysical computations: Five altitude classes, seven slope classes and five soil classes have been retained to represent these stable landscape characteristics. The simulation unit serves as basis for the entire GLOBIOM modeling cluster including the bio-physical Environmental Policy Integrated Model (EPIC) for estimations about agricultural productivity, the G4M forest growth model and the economic model GLOBIOM. There are 212,707 simulation units globally which are polygons with a size varying between 5' and 30' spatial resolution grid.

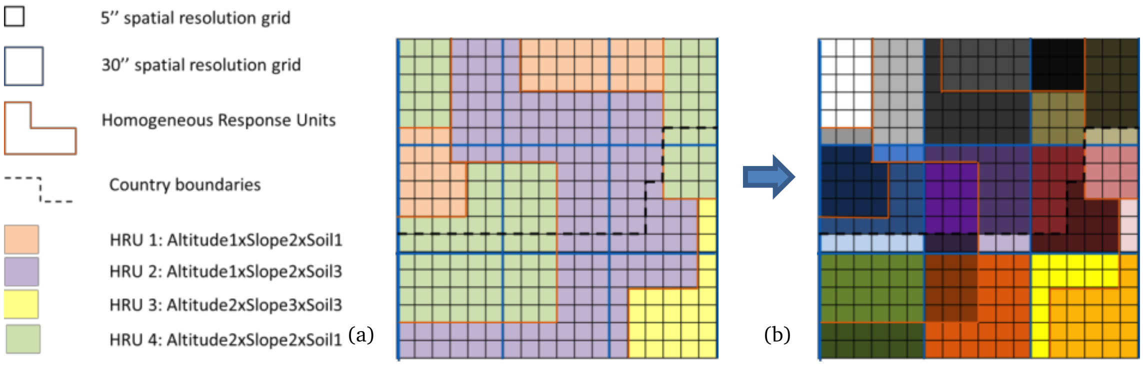


Figure 2: Spatial elements used for the delineation of homogeneous land characteristics (a) and definition of Simulation Units (b)

GLOBIOM directly represents production from four land cover types, cropland, grassland, managed forest and areas suitable for short rotation tree plantations. Different livestock production systems for five different animal species have been designed based on ILRI (International Livestock Research Institute)/FAO nomenclature and populated with data using process-based models for ruminants, and using literature review and expert knowledge for the monogastrics (Notenbaert et al. 2009; Seré and Steinfeld 1996). Production types are detailed, geographical and Leontief type (i.e. fixed input and output ratios). However, discrete changes in the technological characteristics of primary product production can occur because multiple production types (ranging from subsistence to intensive agriculture) can be specified in the model. Currently, 18 crops, five forestry products and six livestock products (four types of meat, eggs and milk) are included in the model.

2 Regional adaptation of the GLOBIOM model

GLOBIOM is a global model which can also be used for detailed regional analysis (Mosnier et al. 2014). The bottom-up approach of the database construction for GLOBIOM allows a flexible spatial resolution of the land use activities and a flexible aggregation of countries into regions. To our knowledge, GLOBIOM-Brazil is the first model to compute future land use change and the corresponding level of agricultural production for the whole Brazil at the grid level, under the influence of both internal policies and external trade.

In total, Brazil has 11,003 simulation units which size varies between ~100,000km^2 and 300,000 km^2 (Figure 3). For comparison, there are 5,565 municipalities in Brazil. All the spatially explicit input data of the model is at the simulation unit level. Since many statistics are available at the municipality level, one of the first tasks has been to compute the intersection of each simulation unit with each municipality. One simulation unit can spread over several municipalities and one municipality can spread over several simulation units. The final grid resolution level of the model (during the optimization process) is set to 30 ArcMin (ca. 300,000 hectares) i.e. the simulation units are aggregated over the HRUs. For comparison, in the other GLOBIOM regions the grid resolution level is set to 120 ArcMin. It results in 3001 spatial units in Brazil where land use and land use change are endogenously computed.

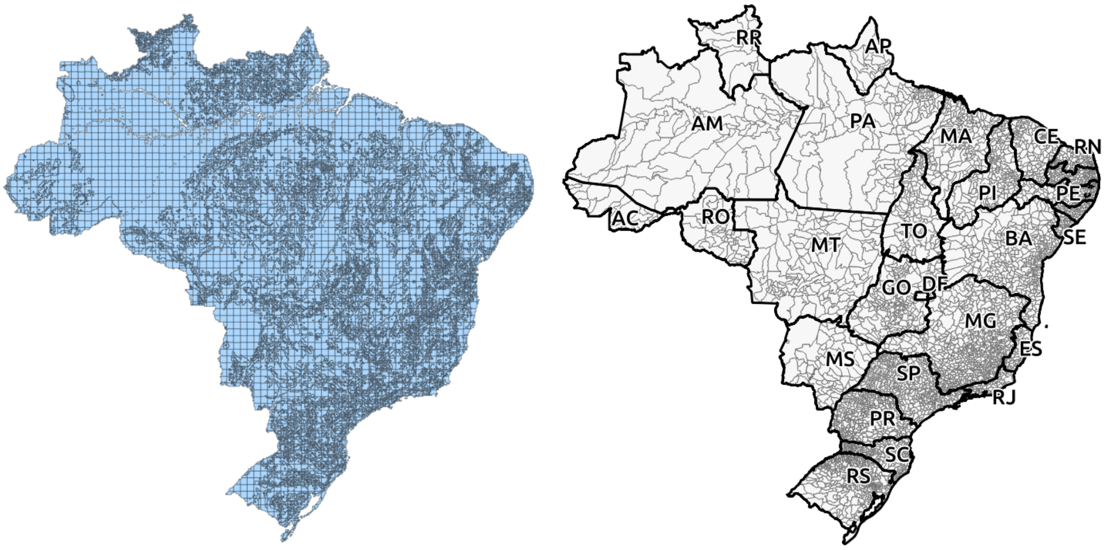


Figure 3: Simulation units in Brazil (left) and federal states and municipalities of Brazil (right)

Specific regional datasets are gathered to replace coarser information from global datasets including national land cover maps, statistics at sub-national level, and regional land use policies.

GLOBIOM is a complex model that is highly dependent on the quality of the input data. Given the size of Brazil and the extent of land use change in the recent decades, a good land use and land cover map is essential for producing adequate results. If there is a general agreement between different data sources about the extent of crop area, there is considerable disagreement for the forest and the pasture area which are crucial information for the model. The production of a consistent land cover-land use map for the whole Brazil by combining information from different sources has been a major task for the REDD-PAC team.

Brazil has six major biomes (Figure 4): *Amazonia* (tropical rain forest), *Cerrado* (tropical savanna), *Caatinga* (arid region with deciduous forest), *Mata Atlântica* (tropical and subtropical forest, largely depleted), *Pantanal* (large wetland area) and *Pampa* (low plains, mostly covered by natural grassland). Each of these ecosystems has unique inter-annual and seasonal variability, presenting unique challenges for mapping land cover and land use. The Amazonia biome has a stable natural cover, since the canopy cover is mostly stable all year round. Remote sensing images are reliable sources of information about land cover change in Amazonia, especially for measuring the reduction of forest cover with the PRODES images. In the other biomes of Brazil, remote sensing images are usually not a fully reliable guide for land use and land cover information. The problem stems from the seasonal changes in land cover associated to natural cycles (e.g. deciduous forest) or human actions (e.g., agriculture).

Figure 4: The six biomes of Brazil

The land use by activity in GLOBIOM-Brazil includes the cultivated area for the 18 crops currently included in the model, the grazed area and the timber production area. Thus, the challenge of deriving a land use and land cover map for Brazil is to be able to wisely combine maps obtained from remote sensing images with statistical information.

Heterogeneous transportation costs across simulation units for each commodity have been produced based on the information about the final destination of the commodity (e.g. local market versus port of export) as many studies have highlighted their strong influence on deforestation patterns. An important aspect of this study is the validation of the model by comparing model outputs with observations in 2010 on multiple dimensions (deforestation, cultivated area, livestock number, emissions).

3 Land cover and land use data sets for Brazil

This section presents a discussion of the land cover and land use data sets used in the simulations of the GLOBIOM model adapted for Brazil. Most of the following datasets are available for download for anyone interested as web feature service (WFS) on the REDD-PAC website (http://www.redd-pac.org/new_page.php?contents=data.csv).

3.1 IBGE vegetation map

The vegetation map produced in 2004 by the Brazilian Institute for Geography and Statistics (IBGE) provides a reliable description of the original land cover in the year 2000 and serves as a good basis to compare with the data obtained from remote sensing images (Figure 5). The vegetation map has been organized based on expert knowledge about Brazil's vegetation types and is used by the Brazilian Government as the basis for the Forest Reference Emission Level report that it has submitted to UNFCCC for REDD+ results-based payments.

The IBGE vegetation map distinguishes 52 vegetation classes. The Amazon rain forest is dominated by dense rain forests, with large and medium-sized trees. The *Mata Atlântica* is dominated by semi-deciduous forests (where 20-50% of the trees lose their leaves in the dry season). The trees in *Caatinga* dry forest lack moisture during most of the year and make up a large area of deciduous forest (where over 50% of the trees lose their leaves in the dry season).

After the forest, the second most important type of vegetation formation in Brazil is the different types of savanna that comprise the *Cerrado* biome. The *Cerrado* biome core areas are the plateaus in the center of Brazil. The main habitat types of the *Cerrado* include: *forest savanna, wooded savanna, park savanna and mixed grass and woody savanna*. The *Cerrado* accounts for a full 21% percent of the country's land area and is the second largest of Brazil's major habitat types, after the *Amazonia* rainforest. It is estimated that about 400,000 km^2, or 20% of the original vegetation, remains intact today.

The focus of the IBGE vegetation map is the description of the original (i.e., before recent human occupation) vegetation classes in Brazil. However, as the map is focused on the pristine vegetation areas, areas with human presence and land use are indicated as such in the map, but they are not classified in detail. In short, the map is a good guide for describing the native vegetation land cover types but it needs to be complemented with information about land use.

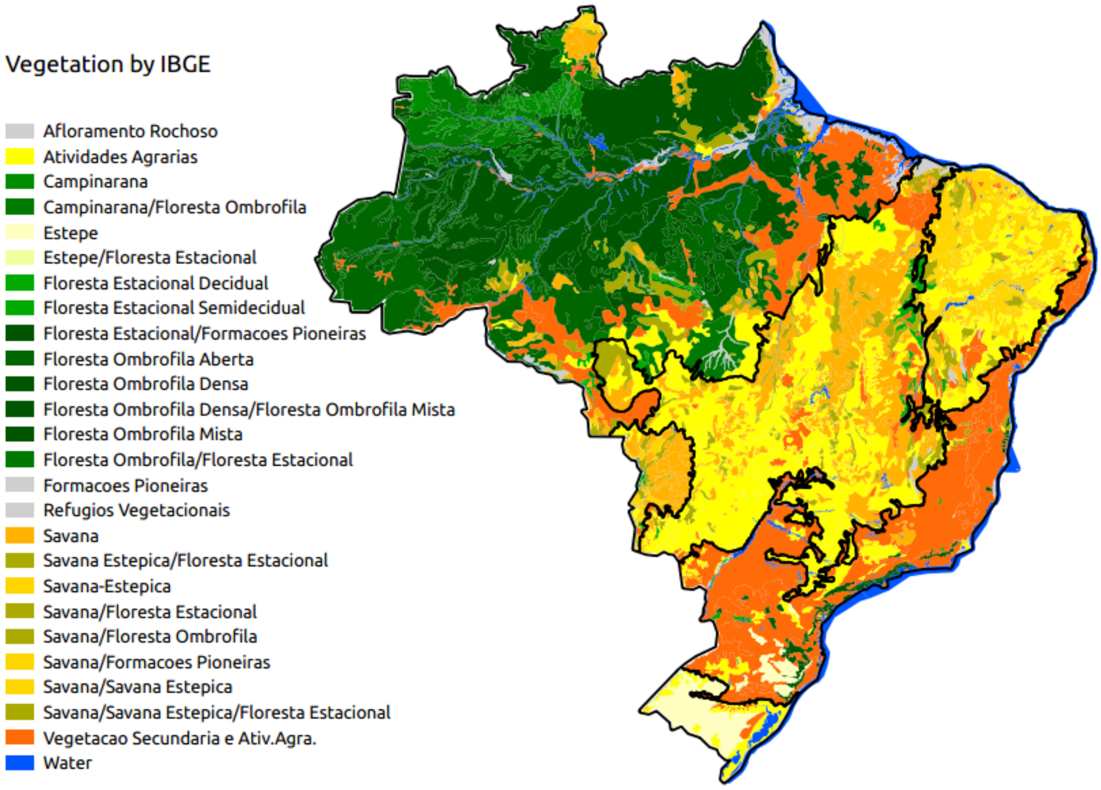


Figure 5: IBGE vegetation map

3.2 MODIS land cover map

The MODIS Land Cover Type product contains five classification schemes, which describe land cover properties derived from observations spanning a year's input of Terra- and Aqua-MODIS data (Friedl et al. 2010). The primary land cover scheme identifies 17 land cover classes defined by the International Geosphere Biosphere Programme (IGBP), which includes eleven natural vegetation classes, three developed and mosaicked land classes, and three non-vegetated land classes.

The MODIS Terra + Aqua Land Cover Type Yearly L3 Global 500 m SIN Grid product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method:

- Land Cover Type 1: IGBP global vegetation classification scheme
- Land Cover Type 2: University of Maryland (UMD) scheme
- Land Cover Type 3: MODIS-derived Leaf area /Fractional photosynthetically Active Radiation (fPAR) scheme
- Land Cover Type 4: MODIS-derived Net Primary Production scheme
- Land Cover Type 5: Plant Functional Type scheme

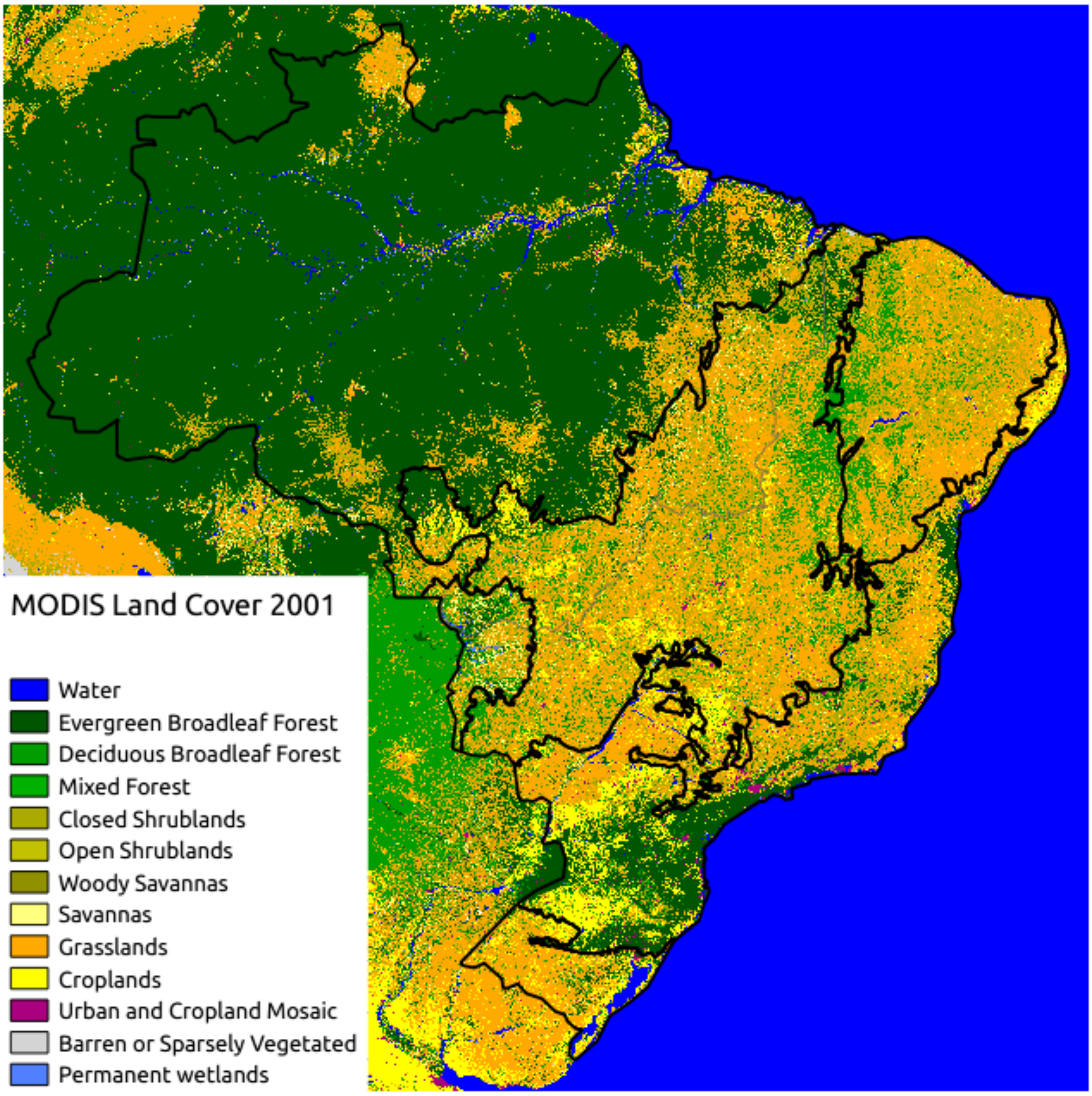


Figure 6: The MODIS land cover map type 1

The MODIS land cover product is designed to support scientific investigations that require information related to the current state and seasonal-to-decadal scale dynamics in global land cover properties. The product is derived from training set classification, based on 1860 sites distributed across the Earth's land areas. The designers of the MODIS Land Cover Type product recognize that the spectral–temporal separability of many classes is ambiguous (e.g., savanna versus woody savannas versus grasslands), a problem that is compounded by the inclusion of mixture classes (e.g., agricultural mosaic, mixed forests) [11]. The authors try to reduce these problems by post-processing methods. However, some of these ambiguity problems are inherent to remote sensing data, arising from the limitations of spatial and spectral resolution of the MODIS sensor.

3.3 IBGE Agricultural census and yearly crop and cattle surveys

To get data on land use, we used three data sets from the Brazilian Institute for Geography and Statistics (IBGE): the 2006 Agricultural Census[2], the yearly municipal agricultural survey (PAM)[3] from 2000 to 2010, and the yearly livestock survey (PPM)[4] from 2000 to 2006.

The 2006 Agricultural Census provides structural data about the agricultural sector. It includes data on the number of establishments, land use, number of tractors, implements, machinery and vehicles, characteristics of the establishment and of the producer, employed persons, livestock heads, vegetable and animal production. We consider the Census to be a reliable source of information in the South, Northeast and Southeast regions of Brazil. However, there is considerable underreporting in the Amazonia biome, mostly caused by land tenure issues. Since a lot of the land used for cattle raising in Amazonia does not have proper property rights, farmers tend to omit information about such areas.

To understand the problem, consider the case of the ten municipalities in Amazonia with the largest deforestation area in 2006, derived from remote sensing images, as reported by INPE. Table 1 shows the deforestation measured by INPE compared with the total agricultural area reported in 2006 Agricultural Census for these municipalities. The data shows that the area reported by INPE as deforested for each municipality is, in almost all cases, much greater than the area reported as crop plus pasture area by the Census.

In addition to the 2006 Agricultural Census, we have used two yearly surveys: the Municipal Agricultural Production (PAM) and the Municipal Livestock production (PPM). These statistics are based on surveys and not on a comprehensive census. They are used by GLOBIOM because they provide annual data including 2000, the base year for our simulations. The PAM survey presents the information on planted area, harvested area, amount produced, average yield and production value of products of permanent and temporary crops by municipalities. The PPM survey presents information on herd inventories, quantity and value of animal products, as well as the number of milked cows and sheared sheep by municipalities.

[2] http://www.ibge.gov.br/home/estatistica/economia/agropecuaria/censoagro/.
[3]http://www.ibge.gov.br/home/estatistica/pesquisas/pesquisa_resultados.php?id_pesquisa=44
[4] http://www.ibge.gov.br/home/estatistica/economia/ppm/2013/

Table 1: Comparison between census data for agricultural production and remote-sensing for selected municipalities in Amazonia

Municipality (State)	Area (km^2)	Deforested area PRODES 2006 (km^2)	Census 2006 crop + pasture area (km^2)	Deforest/Census agricultural area (%)
São Félix do Xingu (PA)	84249	14550	10185	175%
Paragominas (PA)	19452	8256	1920	430%
Marabá (PA)	15127	7495	3062	245%
Juara (MT)	21430	7290	4816	151%
Porto Velho (RO)	34636	6909	1951	354%
Santana do Araguaia (PA)	11607	6589	5143	128%
Cumaru do Norte (PA)	17106	6475	3335	194%
Santa Luzia (MA)	6193	5545	2003	277%
Altamira (PA)	159701	5517	3689	170%
Sta Maria das Barreiras (PA)	10350	5491	5496	100%

3.4 Protected areas, public forests and indigenous lands[5]

The environmental protected areas of Brazil are organized as the National System of Units of Conservation (SNUC). The SNUC divides the categories of federal units of conservation into two large groups: Full protection and sustainable use. Each of these groups contains diverse categories of units; the full protection group is formed by five different categories, which are *Ecological Station*, *Biological Reserve*, *National Park*, *Natural Monument*, and *Wildlife Refuge*. In the sustainable use group the most relevant categories are: *Environmental Protection Area*, *Area of Relevant Ecological Interest*, *National Forest*, *Extractive Reserve,* and *Sustainable Development Reserve*.

An *Ecological Station* aims for the preservation of nature and the undertaking of scientific research. Public visitation is prohibited, except for educational purposes. A *Biological Reserve* has as its objective the full protection of the biota inside its boundaries, without direct human interference or environmental modifications. A *National Park* is an area of great ecological relevance and scenic beauty, scientific research and ecological tourism. A *Natural Monument* preserving rare natural sites, both singular or of great scenic beauty. A *Wildlife Refuge* protecting natural environments where conditions are assured for the existence and reproduction of species or communities of the local flora and the resident or migratory fauna.

[5] The description of protected areas in Brazil is based on the documentation available on the site of the Instituto Socioambiental (http://uc.socioambiental.org/en).

An *Environmental Protection Area (APA)* is an extensive area, with a certain degree of human occupation that is relevant for environmental protection. Declaring an APA protects biological diversity, controls the process of occupation, ensuring the sustainability of the use of natural resources. An *Area of Relevant Ecological Interest* is an area of small extension, with little or no human occupation, that shelters rare examples of the regional biota. A *National Forest* is an area with forest cover of predominantly native species and has as its basic objective the multiple sustainable use of the forest resources and scientific research. An *Extractive Reserve* is an area used by traditional extractive populations, whose subsistence is based on extraction and, additionally, in subsistence agriculture. A *Sustainable Development Reserve* is a natural area that shelters traditional populations, whose existence is based on sustainable systems of exploitation of natural resources.

Brazil also has a significant area of Indigenous Lands (*Terras Indígenas*), which are areas inhabited and exclusively possessed by indigenous people. There are 698 Indigenous Lands in Brazil, with a total extension of 1,135,975 km^2 covering about 13% of the country's land area.

Recent studies (Soares-Filho et al. 2010) have shown that in the Brazilian Amazon all protection regimes helped reduce deforestation. Conservation Units in Amazonia total 1,223,882 km^2, which is 23.45% of the area of the Legal Amazonia. The total accumulated deforestation in the forest areas of these units until 2009 is 13,249 km^2 that is 1.47% of their extent .

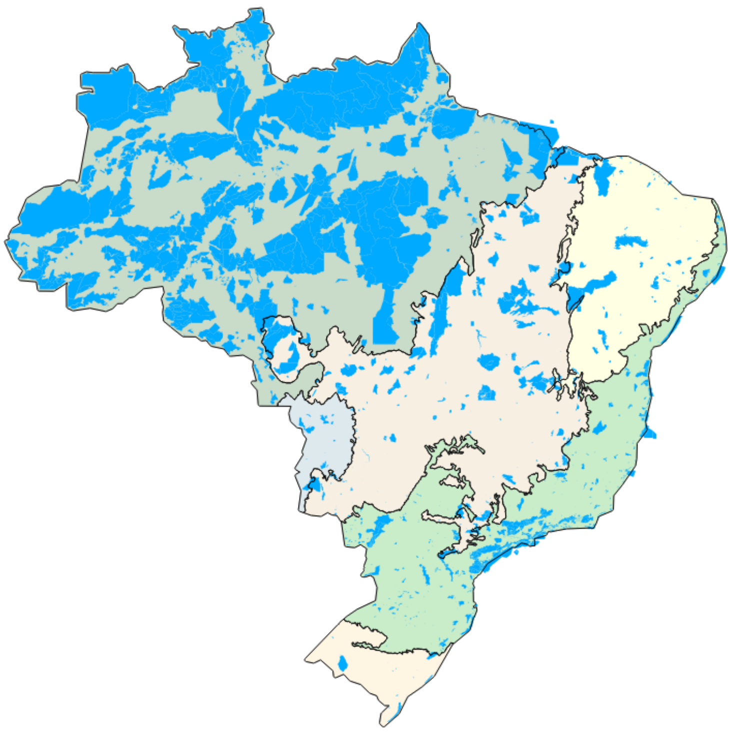


Figure 7: Protected areas in Brazil including Federal, State and Municipal conservation units and Indigenous Lands

3.5 Mata Atlântica forest remnants

The Brazilian *Mata Atlântica* had an original extension of about 1,481,946 km², which made up 17.4% of Brazil. This tropical forest is distributed over various topographic and climatic zones and regions, ranging from sea level to 2,700 m above sea height Since *Mata Atlântica* is in most densely populated areas in Brazil, it has been highly devastated. Currently, only 8% (102,000 km²) of the original forest remains. The NGO "SOS Mata Atlântica" and INPE carry out regular mapping surveys (Ribeiro et al. 2009) and produce the Atlas of Atlantic Forest Remnants (Figure 8)[6]. This data is available on the internet and was included in the GLOBIOM-Brazil database.

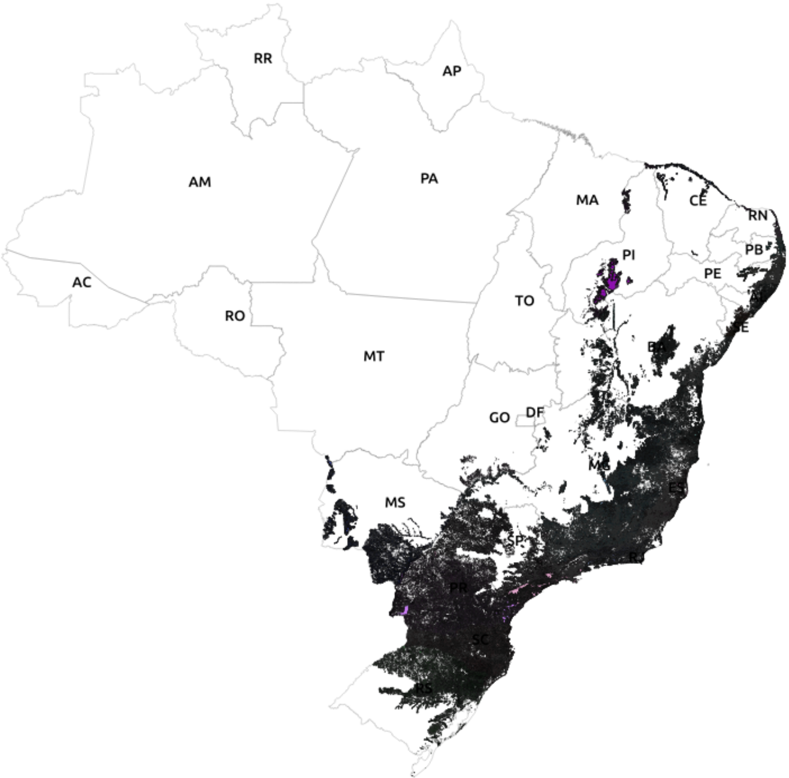


Figure 8: SOS Mata Atlântica forest cover

3.6 PRODES forest non-forest cover map for Amazonia biome

Since 1988, INPE monitors the deforestation in Brazilian Amazonia with the PRODES system. PRODES uses wall-to-wall mapping to get yearly data on the location and extent of the deforestation by clear cuts in the Brazilian Legal Amazon, an area of five million km². For a map of the Legal Amazon, see Figure 9. The input is remote sensing data with 20 to 30 meters resolution and the results are deforestation maps in the 1:250.000 scale and the annual rates of deforestation inside the Amazonia rain forest. PRODES methodology uses a fixed deforestation year from August 1st –July 31st, centered in the dry season in Amazonia. The scientific community takes PRODES to be the standard reference for ground truth in Amazonia deforestation (Kintisch 2007). All PRODES data,

[6] http://www.sosma.org.br/projeto/atlas-da-mata-atlantica/.

methods, maps and statistics are available on the web[7]. The PRODES data set is used in the GLOBIOM-Brazil model for validating the GLOBIOM estimates for deforestation in the Amazonia biome for the period 2000-2010.

3.7 TerraClass land use map for Amazonia biome

The TerraClass project is an operational project carried out by INPE (Brazilian National Institute for Space Research) and EMBRAPA (Brazilian Agricultural Research Corporation) to map the land use in the deforested areas indicated by PRODES. These areas correspond to 719,000 km^2, or about 18% of the Amazon. The methodology applied for the TerraClass mapping includes the following land cover classes: *Croplands*, *Occupations Mosaic*, *Clean Pasture*, *Dirty Pasture*, *Regeneration with Pasture*, *Pasture with Bare Soil*, *Secondary Vegetation*, *Forestry*, *Urban*, *Mining* and *Non Observed* area.

TerraClass has been elaborated for three reference years: 2008, 2010, and 2012. The results point out that from the areas deforested in Amazonia by 2008 - corresponding to 719,000 km^2 – the largest area was converted into pasture. It is a total of 447,000 km^2, divided in 335,000 km^2 of *Clean Pasture* (areas with production process and grass species predominance), 63,000 km^2 of *Dirty Pasture* (pasture areas with production process and predominance of grass and hedge species associated with shrub-grass), 48,000 km^2 of *Regeneration with Pasture* (areas with some native forest vegetation regeneration, characterized by wide diversity of vegetal species) and 594 km^2 of pasture with exposed soil (areas that have at least 50% of exposed soil). The areas with *Secondary Vegetation* correspond to 151,000 km^2, which are in an advanced process of shrub and/or trees regeneration.

In the North of the Amazon River, secondary vegetation areas are prevalent in deforested landscape, due to shifting cultivation in the region, where the areas naturally regenerate after agricultural cycles. Terra Class also shows 35,000 km^2 of annual agricultural practice in deforested areas of eastern Amazonia. In these areas, annual crops are usual, using high technology, such as certified seeds, inputs, and mechanization among others. The activity is important in the State of Mato Grosso, where 15% of deforested areas were replaced by annual crops, whereas in the whole Amazonia this percentage is only 5%.

[7] www.obt.inpe.br/prodes

Figure 9: The Legal Amazon area in Brazil (blue). The areas shaded in grey are the biomes of Brazil. Legal Amazon comprises the biome of *Amazonia* and parts of *Cerrado* and *Pantanal*.

4 A hybrid land cover-land use map for Brazil

As there is no unique best land cover map of Brazil that is suitable to REDD-PAC's needs, we have combined land cover and land use data from various sources to create one single composite land cover map for Brazil. The vegetation map by Brazilian Institute for Geography and Statistics (IBGE) serves as the basis for creating the GLOBIOM input land cover map outside the Legal Amazon while satellite-based MODIS land cover data was used in the Legal Amazon. These base maps are then enhanced with further datasets.

The spatial partitions used in GLOBIOM are the simulation units described above. However, the base data we have is available on different spatial partitions. In particular, the census and survey data from IBGE are only available per municipality. Thus, we have developed an algorithm to disaggregate and reconcile agricultural data at the simulation unit with the land cover map (Figure 10). In this section, we will describe the steps to create the land cover map by simulation units and the disaggregation algorithm.

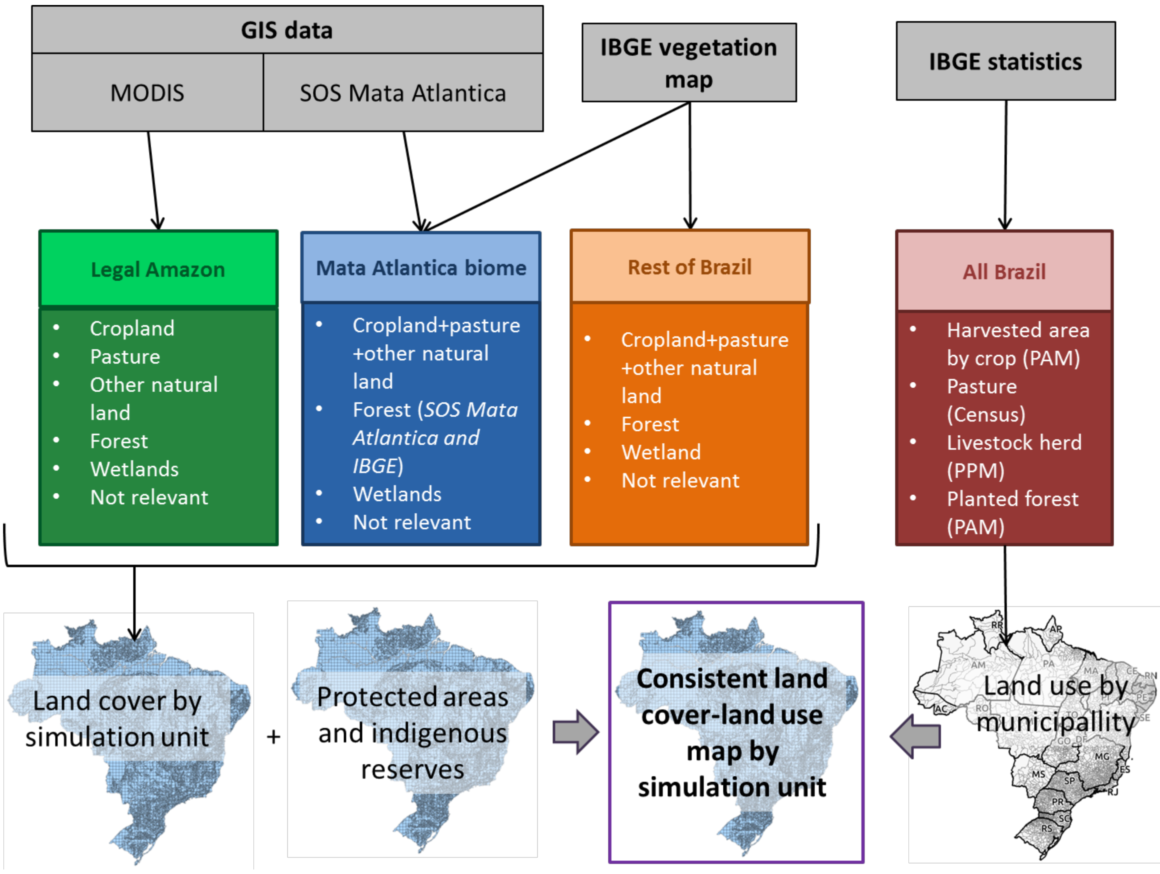


Figure 10: Creation of the consistent land cover-land use map

4.1 Mapping original vegetation classes to GLOBIOM classes

The vegetation map provided by IBGE (see Figure 5), serves as the basis for creating the GLOBIOM input land cover map outside of the Legal Amazon. It was created using a combination of experts' knowledge, field visit and remote sensing. This is especially relevant in areas where seasonal variability makes it harder for vegetation types to be distinguished using pure remote sensing, e.g. the *Caatinga* biome. The information for the IBGE vegetation map corresponds to the situation in 2001 and 2002, which is close enough to GLOBIOM base year 2000. It distinguishes 52 vegetation classes. We have aggregated these vegetation classes into land cover classes that are more directly related to GLOBIOM (see Table 2 and Figure 11).

Our aggregation followed the following rationale:

- All classes that had been named as "Forest" in the Brazilian submission of Forest Reference Level to the UNFCCC were labeled as "Forest" for use in GLOBIOM.
- Classes labeled with steppe types ("Estepe") were labeled as "GrsLnd pasture" for use in GLOBIOM.
- Classes associated to shrublands ("arbustiva", "gramíneo-lenhosa") and to non-forested savannas were labeled as "Other Natural Land" in GLOBIOM.
- Classes associated with barren land and closed water areas were labeled as "not relevant" in GLOBIOM.
- IBGE vegetation classes associated with wetlands were labeled as "Wetlands".
- All areas that have a significant land use are classified by IBGE as "anthropic areas". Furthermore, IBGE does not distinguish between croplands and area used for cattle pasture. These areas were labeled as "*Cropland, pasture or other agricultural land*".

Table 2: Correspondence between GLOBIOM land cover classes, IGBP land cover classes and IBGE land cover classes

GLOBIOM land cover class	**IGBP land cover class**	**Current vegetation (IBGE) (in Portuguese)**
CROP PASTURE OR OTHER NATURAL LAND	Cropland/Natural Vegetation mosaic	Vegetação Secundária e Atividades Agrárias
	Croplands OR Grasslands	Atividades Agrárias
	Grasslands	Estepe Arborizada
		Estepe Gramíneo-Lenhosa
		Estepe Parque
		Estepe/Floresta Estacional
FOREST	Deciduous Broadleaf Forest	Floresta Estacional Decidual Montana
		Floresta Estacional Decidual Submontana
		Floresta Estacional Decidual Terras Baixas
		Floresta Estacional Semidecidual Aluvial
		Floresta Estacional Semidecidual Montana
		Floresta Estacional Semidecidual Submontana
		Floresta Estacional Semidecidual Terras Baixas
		Floresta Estacional/Formações Pioneiras
		Savana Estépica/Floresta Estacional
		Savana-Estépica Arborizada
		Savana-Estépica Florestada
	Evergreen Broadleaf Forest	Campinarana Arborizada
		Campinarana Florestada
		Campinarana/Floresta Ombrofila
		Floresta Ombrófila Aberta Aluvial
		Floresta Ombrófila Aberta Submontana
		Floresta Ombrófila Aberta Terras Baixas
		Floresta Ombrófila Densa Aluvial
		Floresta Ombrófila Densa Montana
		Floresta Ombrófila Densa Submontana
		Floresta Ombrófila Densa Terras Baixas
		Floresta Ombrófila Densa/Floresta Ombrófila Mista
		Floresta Ombrófila Mista Alto-Montana
		Floresta Ombrófila Mista Montana
		Floresta Ombrófila/Floresta Estacional

	Woody savannas	Savana Arborizada
		Savana Florestada
		Savana/Floresta Estacional
		Savana/Floresta Ombrófila
NOT RELEVANT	Barren or sparsely vegetated	Afloramento Rochoso
		Refúgios Vegetacionais Alto-Montano
		Refúgios Vegetacionais Montano
	Water	Coastal water mass
		Continental water mass
OTHER NATURAL LAND	Closed Shrublands	Campinarana Arbustiva
	Open Shrublands	Campinarana Gramíneo-Lenhosa
		Savana-Estépica Gramíneo-Lenhosa
		Savana-Estépica Parque
	Savannas	Savana Gramíneo-Lenhosa
		Savana Parque
		Savana/Formações Pioneiras
		Savana/Savana Estépica
		Savana/Savana Estépica/Floresta Estacional
WETLANDS	Permanent wetlands	Vegetação com Influência Fluvial e/ou Lacustre
		Vegetação com Influência Fluvio-marinha
		Áreas das Formações Pioneiras Vegetação com Influência Marinha

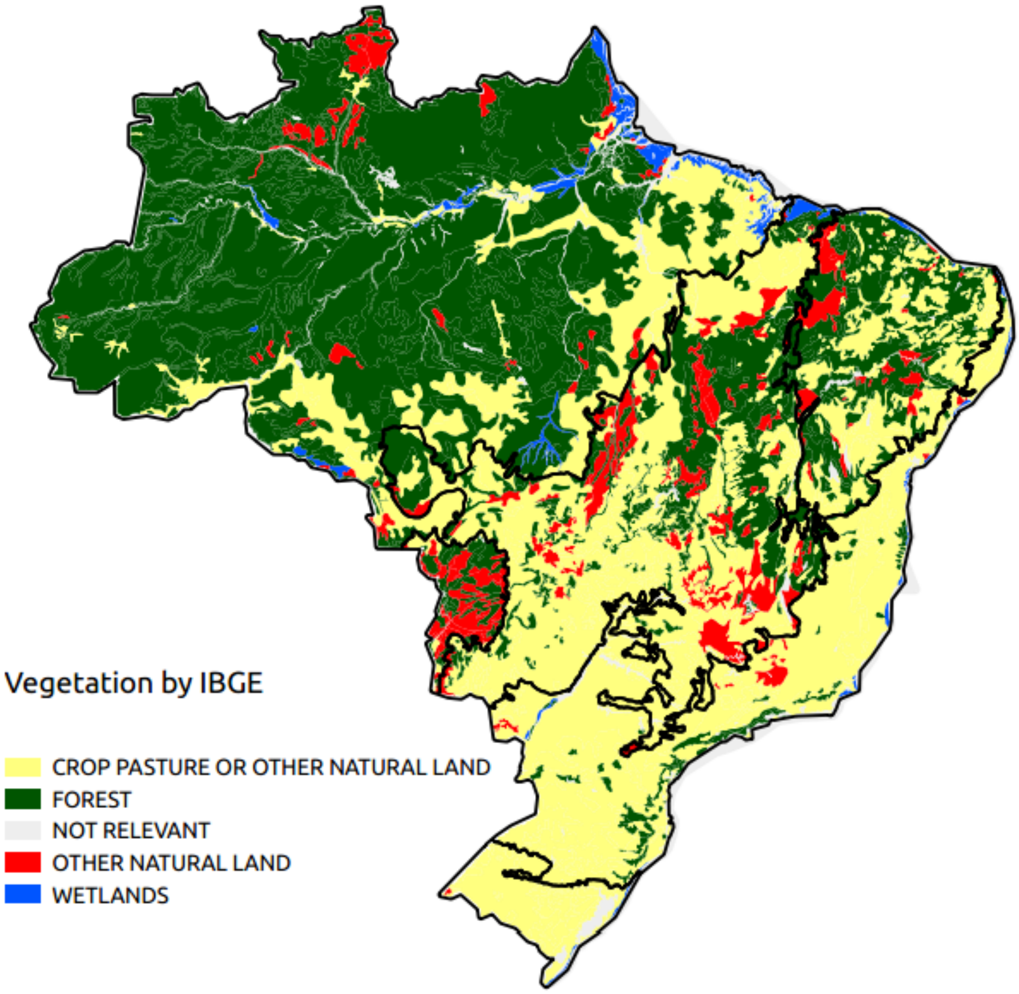


Figure 11: IBGE land cover map reclassified in GLOBIOM classes

In the Legal Amazon, satellite-borne MODIS land cover data was used instead of the IBGE vegetation map. The main reason for this is the coarse spatial scale (1:5.000.000) of the IBGE vegetation map. In the Amazon region, relatively small patches of grass or crops are not mapped. This underestimates agricultural area and leads to simulation units that allegedly have no agricultural area at all. Thus, we used the land cover information (forest areas, pasture, crops, other natural land, wetlands etc.) from MODIS as base information.

Another reason for using MODIS is that the data on the amount of pasture that was used for the rest of Brazil (see section 4.4.1) is less reliable inside the Legal Amazon, as agriculture there follows expanding frontiers and has a different dynamic. MODIS provides pasture area for every year, so no extrapolation of Census data is necessary and the imprecisions associated with the Census in the Amazon area are avoided). The mapping between the MODIS classes and the GLOBIOM classes is shown in table 3.

Table 3: Classification of the MODIS land cover data

MODIS Land Cover (IGBP classification)	Preliminary GLOBIOM class
Water	NOT RELEVANT
Evergreen Needleleaf Forest	FOREST
Evergreen Broadleaf Forest	FOREST
Deciduous Needleleaf Forest	FOREST
Deciduous Broadleaf Forest	FOREST
Mixed Forest	FOREST
Closed Shrublands	OTHER NATURAL LAND
Open Shrublands	OTHER NATURAL LAND
Woody Savannas	FOREST
Savannas	OTHER NATURAL LAND
Grasslands	CROPLAND, PASTURE or OTHER NATURAL LAND
Permanent Wetlands	WETLANDS
Croplands	CROPLAND, PASTURE or OTHER NATURAL LAND
Urban and built-up	NOT RELEVANT
Cropland/Natural vegetation mosaic	CROPLAND, PASTURE or OTHER NATURAL LAND
Snow and Ice	NOT RELEVANT
Barren or Sparsely Vegetated	NOT RELEVANT

The IBGE vegetation map underestimates the forest in the biome of the atlantic rainforest (Mata Atlântica). The Mata Atlântica area used to have a large forest cover. Nowadays, only small patches of remnants are left, which are not captured well by the IBGE vegetation map. Thus, the land cover data from SOS Mata Atlântica, which is spatially very detailed, is used to improve the land cover map in this area. It contains small patches of land in 17 states (*AL, BA, CE, ES, GO, MG, MS, PB, PE, PI, PR, RJ, RN, RS, SC, SE, SP*) in the southern and eastern part of Brazil. The mapped areas are assigned the categories forest (*Mata*), deforested areas (*Decremento de mata 2008-2010, 2010-2011, 2011-2012, Desmatamentos identificados em 2012*), *Restinga* (a type of coastal shrublands), *Mangue* (a type of Mangrove), urban area (*Área urbana*), non-forest natural areas (*Área natural não florestal*) and *Vegetação de várzea* (a type of seasonal floodplain forest).

A map of the forest cover in the year 2000 is created from the SOSMA land cover map. It includes all areas of the class forest ("*Mata*") and all deforested areas. The deforested areas were included because if they were deforested between 2008 and 2012, they must have been forest in the year 2000, for which the GLOBIOM input map was created. The geometry of the SOSMA land cover map was slightly simplified to reduce processing time. A reasonable level of simplification was found by analyzing the trade-off between file size / processing time and geometry correctness / area loss using various levels of simplification.

The SOSMA forest patches are mainly located in areas that were agrarian areas according to the IBGE vegetation map. Thus, compared to the IBGE map, we increase the amount of forest and decrease the amount of area which is available for the GLOBIOM land cover classes "*Cropland*", "*Other agricultural land*", "*Other natural land*" and "*Pasture*".

4.2 Protected areas

Protected areas in a wide sense (including indigenous lands, sustainable use areas, and public forests) cover large parts of the Brazilian territory. It is important to include them in the analysis, as they affect the scenario analysis in two ways: protected areas are considered as restrictions in some of the simulated scenarios, so crops and pasture cannot be allocated in those areas. Furthermore, the protected areas are used in the creation of the input land cover map. As the vegetation map does not include detailed agricultural data, this is added later from other sources. As mentioned before, this data is not available on simulation unit level, but per municipality. We use an algorithm for allocating survey data on crops and animal production into the vegetation base map. During this, we have to be careful not to allocate declared crop area, for example, into protected areas.

The layer of protected areas is a combination of three input layers. First, the Conservation Units dataset from the Brazilian Ministry of the Environment (MMA) provides information about 1158 conservation areas. Their categories are *"Reserva Particular do Patrimonio Natural", "Parque, Floresta", "Estacao Ecologica", "Area de Protecao Ambiental", "Reserva Extrativista", "Reserva Biologica", "Monumento Natural", "Area de Relevante Interesse Ecologico", "Reserva de Desenvolvimento Sustentavel", "Refugio de Vida Silvestre"* and *"Outros"*.

Second, the Indigenous Areas dataset shows all the indigenous areas as mapped by the FUNAI (Brazilian National Indigenous Foundation). We assume that they are also excluded from productive use.

As a third layer, the map of "Public forests by the Brazilian Ministry of the Environment (MMA) includes many indigenous areas and conservation units of various types, thus is largely overlaps with the previous two maps. In GLOBIOM, only fully protected areas and areas of sustainable use were used. These areas include areas of type Environmental Protection Area (*Área de Proteção Ambiental, APA), National/federal forest (Floresta Nacional/Estadual, FLONA, FLOTA), National Park (Parque Nacional, PARNA), Biological Reserve (Reserva Biológica, REBIO), Ecological Station (Estação Ecológica, ESEC), Extractive Reserve (Reserva extrativista, RESEX), Area of Relevant Ecological Interest (Área de Relevante Interesse Ecológico, ARIE), Sustainable Development Reserve (Reserva de Desenvolvimento Sustentável, RDS)* and *Wildlife Refuge* (*Refúgio de Vida Silvestre, RVS)*. Not fully protected / sustainable areas include areas of type *Sustainable Development*

Project (Projeto de Desenvolvimento Sustentável, PDS), Area without parceling (Gleba), Agroextractive Project (Projeto Agroextrativista, PAE) and *Agro-Forest Project (Projeto Agro-Florestal, PAF)*. Some areas have more than one category.

The maps for protected areas, indigenous lands, public forests, and sustainable use areas correspond to year 2013, which is 13 years ahead of the GLOBIOM base year 2000.

Analysts from the Ministry of Environment, responsible for suggestion areas for new protected areas, informed us that one of the criteria to choose these new locations is to consider areas where there is no consolidated crop or animal production. According to this premise, if a protected area was created in 2013, for example, it is highly that there was no crop or pasture production in that area before. Therefore, it makes sense to consider the protected areas created after 2000 when allocating crop or pasture into simulation units.

4.3 Land cover by simulation unit

The MODIS vegetation map (inside Legal Amazon), the combined IBGE-SOS MA vegetation map (outside Legal Amazon) and the combined protected areas are merged into the preliminary land cover map. It includes the classes

- Forest (protected / unprotected)
- Wetlands (protected / unprotected)
- Other Natural land (protected / unprotected)
- Cropland, grassland, other agricultural land or other natural land (protected / unprotected)
- Not relevant (protected / unprotected)

The class “Cropland, grassland, other agricultural land or other natural land” covers all area that is influenced by human use.

The parts of that class that are in protected areas are assumed to be without human influence, thus they are transferred to the class “Other natural land (protected)”. Some areas, which clearly contain pasture, had been classified as “other natural land” following the vegetation classes provided by the IBGE vegetation map. This occurred especially in pasture areas located in the Pantanal area. IBGE classifies it entirely as Forest and Other Natural Land (see Figure 5), while it has substantial animal production. For this reason, we combined the initial areas for “other natural land” and for “crop, pasture and other natural” into a modified augmented class “crop, pasture and other natural land” (for which the overall area is presented on Table 4). The area for crops, pasture and secondary vegetation class sums up to 336.049 thousand hectares.

The amount of grassland and of the individual crops is obtained from a different data source and will be included into the map in the following sections. Before this, the land cover is aggregated in simulation units. For each simulation unit, the percentage of each land cover class is computed. This is done by computing a geometrical intersection between the simulation units and the land cover map.

Table 4 presents the total areas for each GLOBIOM-compatible class. These areas result from the combination of the IBGE vegetation map (outside Legal Amazon), MODIS (for Legal Amazon) and the SOS Mata Atlântica (for the Mata Atlântica Biome). We also present estimates for the areas inside and outside protected. For these restricted locations, we have a total area estimated to be 244.617 thousand hectares. Outside these restricted areas, we have total estimated area of 594.717 thousand hectares. The total country area on the table (839.335 thousand hectares) corresponds to the sum of simulation units areas in GLOBIOM.

Table 4: Areas According to GLOBIOM Compatible Classes

Aggregated Classes	Total Area (Thousand hectares)
CROP PASTURE OR OTHER NATURAL LAND	**362.083**
Inside Protected Areas[8]	26.034
Outside Protected Areas	336.049
FOREST[9]	**464.436**
Inside Protected Areas	215.872
Outside Protected Areas	248.564
NOT RELEVANT	**8.929**
Inside Protected Areas	1.403
Outside Protected Areas	7.527
WETLANDS	**3.886**
Inside Protected Areas	1.308
Outside Protected Areas	2.578
Total	**839.335**

4.4 Area for productive use

The next step is to allocate specific activities among the above aggregated land cover classes. Filling the gaps on which activities were present in each simulation unit on the new land cover map is essential for GLOBIOM. In order to do that, we have to harmonize the land cover map at the simulation unit level that has been presented above with survey information for agriculture and animal production from IBGE which is available at the municipality level.

We have special interest on the class corresponding to crops, pasture and secondary vegetation (see table 3 in the previous section). The IBGE vegetation map does not differentiate between these three categories. When we exclude the protected areas, indigenous lands, public forests, and areas for sustainable use, the area for crops, pasture and secondary vegetation class sums up to 336.049 thousand hectares. This is the amount of land available in the simulation units for allocating crops and pasture area.

[8] "Protected areas" include all mapped areas for public forests, indigenous lands and areas for sustainable use, in addition to protected areas.
[9] Includes forest according to the SOS Mata Atlântica.

4.4.1 Pasture area (by municipalities)

GLOBIOM needs data on the amount of grassland (pasture) area per simulation unit. Estimates of pasture area from property survey information are provided by IBGE every 10 years, based on the decennial agricultural census. The most recent information available corresponds to the 2006 agricultural census. IBGE also provides estimates on the number of animals, for different classes, based on the PPM (Municipality Animal Production Survey), which collects data annually from a large sample of animal producers. From these two sources of information, Gasques et al. (2013) estimated total pasture areas for Brazil for several years. We used these numbers to extrapolate the municipality pasture area from the Census 2006 to 2000. This extrapolation was done linearly: We simply multiplied the municipality pasture area in 2006 with the entire country's pasture area in 2000 divided by the country pasture area in 2006. We use these two last numbers according to Gasques et al. (2013) annual estimates.

For Legal Amazon, we decided not use directly the numbers from Gasques et al. (2013). Instead of using pasture area estimates based on IBGE Census information, we used pasture area estimates from MODIS. The Legal Amazon encompasses several pasture and agriculture frontiers, and we imagined that using municipality area information from 2006 could not be a good proxy for the area in 2000, for the frontier regions. A second reason for using MODIS pasture area instead of IBGE Census 2006 area is the possible extra uncertainty due to the greater difficulties in collecting accurate survey information from remote areas. For example, Costa (2012) reported some possible underestimation of pasture area in the municipalities of São Felix do Xingu, Tucumã e Ourilândia do Norte, in the state of Pará, from agricultural Census data. Because of these potential inconsistencies, we decided to use MODIS pasture area estimates for the Legal Amazon.

Figure 12 shows a scatter plot comparing pasture area according to MODIS and according to IBGE Census 2006, inside the Legal Amazon. The numbers do not match exactly, with some clear differences, especially for big municipalities, where some studies report difference in figures. The coefficient of correlation between these two variables, for municipalities within the Legal Amazon, is equal to 66%.

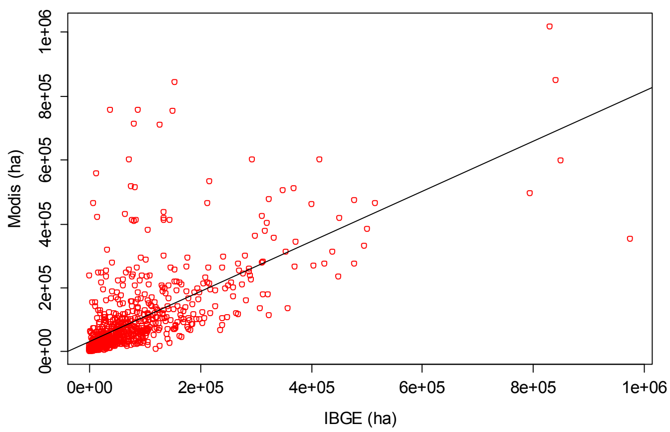


Figure 12: Pasture area from IBGE and from MODIS within Legal Amazon. Source: IBGE Census 2006, Gasques et al. (2013), MODIS.

In Figure 13, we present a scatter plot between pasture area estimates according to MODIS and IBGE, this time showing only municipalities outside the Legal Amazon. The correlation coefficient is equal to 83 %, higher than the coefficient found for municipalities inside the Legal Amazon. There are some clear differences between both sources of information, which are more pronounced for larger areas. These differences may also be due to survey uncertainties concerning large properties location. The algorithm proposed in the next section, based on a minimization problem, tries to create consistent maps, with a strategy to allocate extra areas of crops and pasture into neighboring geographic units.

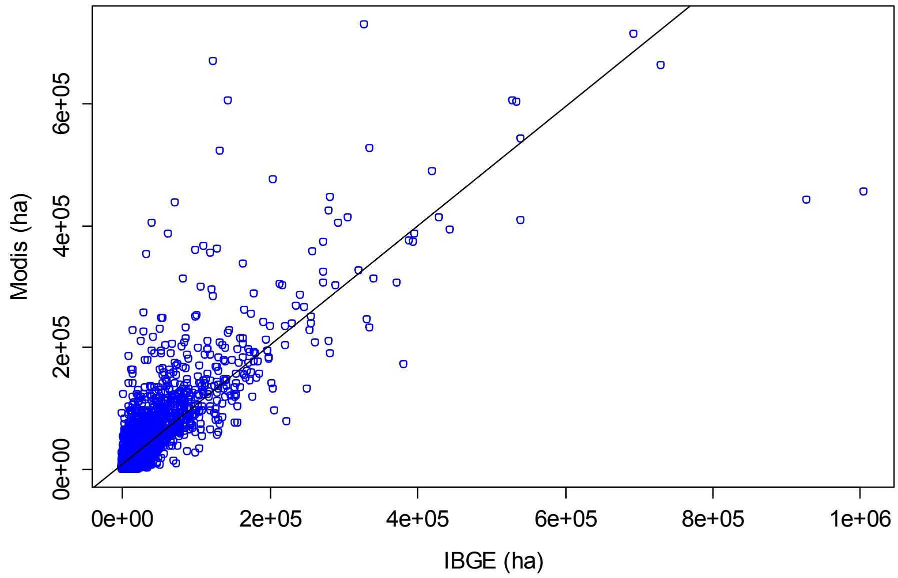


Figure 13: Pasture area from IBGE and from MODIS outside Legal Amazon. Source: IBGE Census 2006, Gasques et al. (2013), Modis.

We checked the consistency between the extrapolated area for pasture in the municipalities in 2000, based on the agricultural Census 2006 (outside Legal Amazon) and based on MODIS data (for inside Legal Amazon) and the animal production according to PPM. Inside the Legal Amazon, all municipalities that had animal production according to PPM also had grassland according to MODIS.

Out of the 4794 Brazilian municipalities outside Legal Amazon, there were only 28 municipalities that had animal production according to PPM, but where the 2006 Census did not report any pasture area (see Figure 14). Also, there were only 39 municipalities outside the Legal Amazon (out of the 4794 existing ones) that had animal production according to PPM, but did not have grass according to MODIS (see Figure 15). We consider these mismatches as inevitable, given that the PPM is a survey. These data reinforce our decision of using information from IBGE (vegetation map and pasture extrapolated from Census 2006) for outside Legal Amazon and from MODIS for inside Legal Amazon.

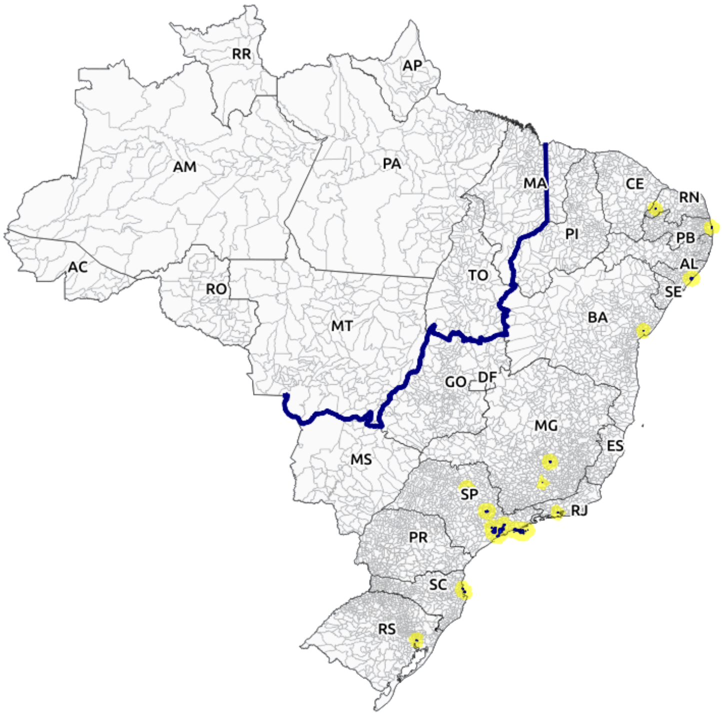


Figure 14: The 28 municipalities outside the Legal Amazon that have animal production according to PPM, while the 2006 Agricultural Census reported to pasture area.

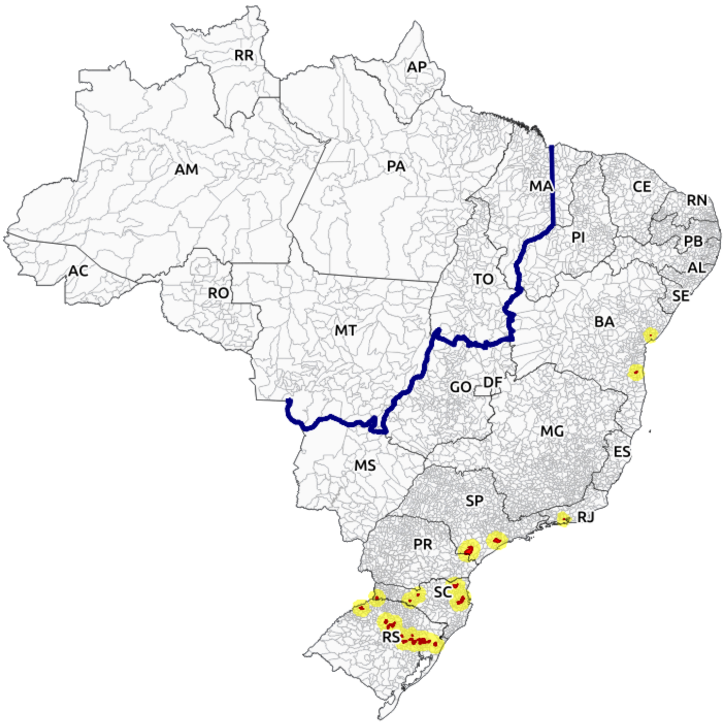


Figure 15: The 39 municipalities that have animal production according to PPM, but MODIS does not report any grasslands.

To avoid inconsistencies when running GLOBIOM, we assigned pasture areas to the 28 municipalities outside Legal Amazon which had cattle according to PPM but no pasture according to IBGE, based on an average estimate of Tropical Livestock Units (TLU) per hectare. Therefore, the additional pasture area allocated to municipality k is simply the total TLU for municipality k, according to PPM, divided by the average TLU/ha for the state where municipality k is located. TLU in this case correspond to a measure of livestock production, which tries to harmonize production from different types of livestock. For example, 100 heads of cattle correspond to 70 TLUs.

4.4.2 Cropland and planted forests (by municipalities)

The data for crops is taken from the PAM (Municipality Agriculture Survey) by IBGE. 18 crops are distinguished individually in GLOBIOM (GLOBIOM land cover class "Croplands"). They make up 86% of the total cultivated area in Brazil in 2000. The other crops that are not yet individually included in GLOBIOM cover 7 million hectares in 2000 and are assigned to the "Other Agricultural Land" class (Figure 16). For planted forests, we used the numbers per municipality from the IBGE Agriculture Census 2006. Planted forests are not distinguished by species.

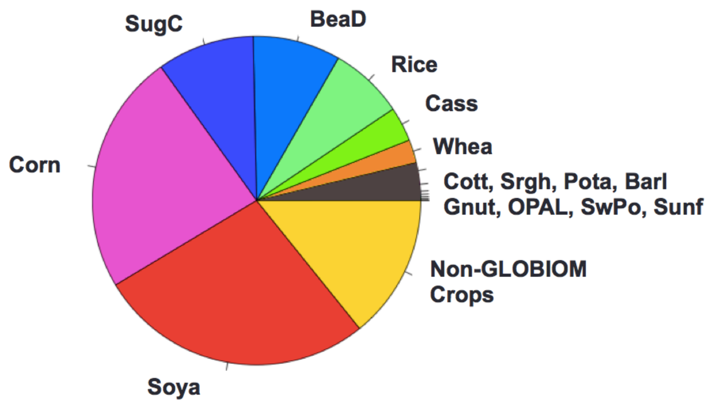


Figure 16: Division by crop of total cultivated area in Brazil in 2000 according to PAM data

4.5 Allocating land use area into the GLOBIOM simulation units

The total crop, pasture and planted forest from IBGE municipality data and from MODIS (for clarity's sake, subsequently called "production area") sums up to 236.557 thousand hectares. The next step is to disaggregate the production data into the simulation units, so that the almost 237 million hectares of production area are distributed into the 336 million hectares of available land from the land cover map (crop, pasture and other natural land, excluding protected areas and indigenous land, subsequently called "available land". Several difficulties apply in this context:

- There are errors due to survey data from IBGE Census (for some municipalities, the total agricultural production area is bigger than the municipality area itself);
- The data from different sources is not available for the same years.

Figure 17 shows the 187 municipalities where the agricultural production is larger than the total area of the municipality. In most of these municipalities, the reported production area is up to 1.7 times larger than the total area, but in extreme cases, it is twice or even 23 times as large. A possible reason for this is that a large farm has area in various adjacent municipalities but is registered in one municipality. So the municipality reported in the Agricultural Census or in one of the annual surveys (PPM, PAM) is probably the municipality where the main house is located. Therefore, the declared productive area is assigned to a single municipality, whereas in reality it may correspond to more than one municipality. Other reasons may be intentional or unintentional misreporting.

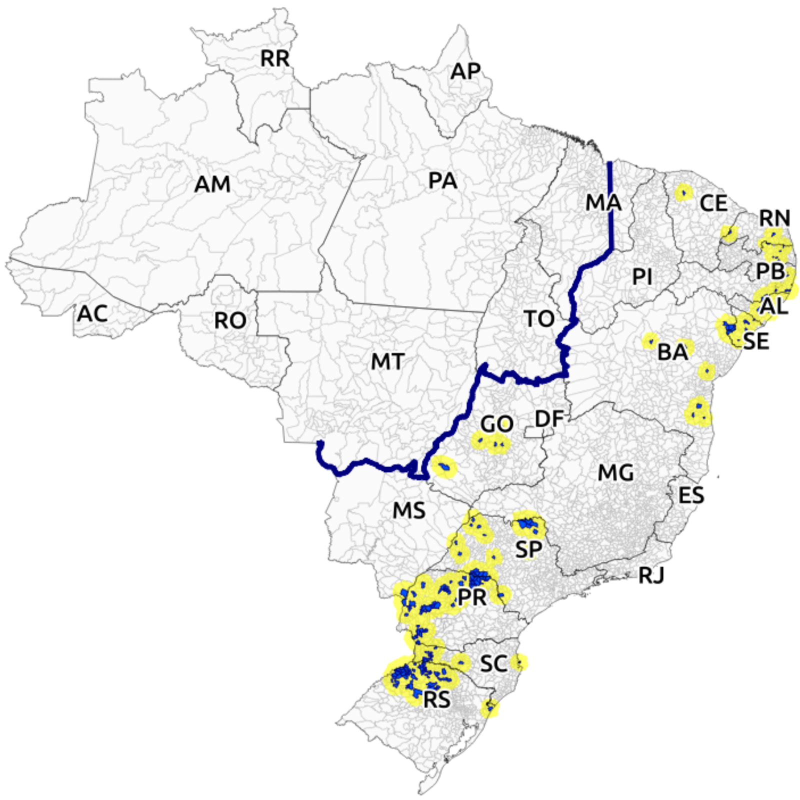


Figure 17: The 187 municipalities that have more agricultural production area than available area.

We developed a procedure to solve these inconsistencies between different sources. This section presents our approach in detail. The algorithm allocates the production area of a municipality to all simulation units that geographically overlap with it, taking into account the size of the overlap. A simulation unit that makes up 10% of a municipality receives 10% of its production area – unless it does not have enough available land. In this case, the excess production area is allocated to neighboring simulation units, with preference given to simulation units that also overlap with the same municipality, and with preference given to nearby simulation units.

Let $m(i)$ be the production area for municipality i. Our goal is to distribute $m(i)$ into simulation units. Therefore, we have to find values $x(i,j)$ corresponding to the production area in municipality i, allocated into simulation unit j. We then have $\sum_j x(i,j) = m(i)$, for all municipalities $i = 1, \dots, N$.

Let $\delta_{i,j}$ be the share of municipality i within simulation unit j, and $\gamma_{i,j}$ corresponds to the share of simulation unit j within municipality i. If municipality i and simulation unit j coincide exactly, then $\gamma_{i,j} = \delta_{i,j} = 1$. In the general case, we have $0 \leq \gamma_{i,j}, \delta_{i,j} \leq 1$, and $\sum_i \delta_{i,j} = \sum_j \gamma_{i,j} = 1$.

A simple allocation method to assign areas from municipality i to simulation unit j would be to specify the allocation function $y(i,j)$ as

$$y(i,j) = \gamma_{i,j} \times m(i).$$

In this simple method, each simulation unit receives cropland and pasture according to its share in the municipality's total area. The total area allocated to simulation unit j is given by $\sum_i y(i,j)$.

However, due to the data inconsistencies, some simulation units have $\sum_i y(i,j) > s(j)$. In this case, the available area $s(j)$ for production inside simulation unit j is less than the total allocated area $\sum_i y(i,j)$. This happens because many simulation units have areas allocated to forest and protection, which cannot be assigned as productive. Thus, this simple allocation method will not work. Furthermore, in large municipalities, this method allocates the agricultural area homogeneously over the whole municipality. In reality, agricultural areas tend to be concentrated in space, especially in the Amazon area. Thus, we need to take into account the limited area available by simulation unit that we get from the land cover map.

Thus, to include these cases, we propose the following adjustment:

$$s^*(j) = min\left(\sum_i y(i,j), s(j)\right),$$

and let:

$$y^*(i,j) = y(i,j) \times \left[\frac{s^*(j)}{s(j)}\right].$$

where s^* is the production area allocated to the simulation unit by the simple method, unless there is not enough available area, when s^* is the available area for allocating production.

By construction, we always have $\sum_i y^*(i,j) \leq s(j)$, so as we never allocate more area into a simulation unit than the available free area $s(j)$. Besides, if the simulation unit j has enough available area $s(j)$, we will have $\sum_i y^*(i,j) = s(j)$, $y^*(i,j) = y(i,j)$. We added the following restriction to the original optimization problem: $x(i,j) \geq y^*(i,j)$.

When there is not enough area in the simulation unit to allocate the expected production area, we have to allocate the surplus area in other locations where there is a land surplus. To do that, we define $d(i,j)$ to be the distance between municipality *i* and simulation unit *j*. We consider two cases: (a) there is a spatial intersection between simulation unit *j* and municipality *i*; (b) there is no spatial intersection simulation unit *j* and municipality *i*. For the second case, for pairs of *i* and *j* with intersecting area, we considered the function $d(i,j) = k\ +$ [the Euclidian distance between the centroids of simulation unit *j* and municipality *i*]. When there is an intersection between municipality *i* and simulation union *j*, we considered the distance function $d(i,j)$ as specified below:

$$d(i,j)^2 = M \times [1 - \delta_{i,j}] + M \times [1 - \gamma_{i,j}],$$

where $\delta_{i,j}$ corresponds to the share of municipality *i* within simulation unit *j*, and $\gamma_{i,j}$ corresponds to the share of simulation unit *j* within municipality *i*. The distance between *i* and *j* is only zero when the municipality corresponds exactly to the simulation unit. The coefficient *M* is the weight to increase or increase the importance of the intersections on the allocation; we chose *M* to be 1.

We use a positive value for the constant k to prioritize allocation from municipality i to spatially intersecting simulation units. Because of the value of k, the square distances $d(i,j)^2$ are much higher in situations where i and j do not intersect than in situations in which they intersect. The idea is that when there is an area to be allocated from municipality i, the algorithm first tries to allocate this area into intersecting simulation units. If there is no sufficient available area within the intersecting units, the method then tries to allocate into units nearby, with lower values for the Euclidian distances. In the results presented below, we used $k = 10$.

In our minimization problem, the effective number of considered municipalities *N* can be smaller than the number of municipalities in Brazil, because we do not need to consider municipalities which have no agricultural land to be allocated ($m(i) = 0$). The same way, it is not necessary to consider simulation units without available land ($s(j) = 0$, these are simulation units with only forests or forests and protected areas, for example). Even though, the resulting minimization problem still had more than 61 million decision variables $x(i,j)$. To further reduce the number of decision variables, we considered only movements $x(i,j)$, for pairs of *i* and *j*, with distance $d(i,j) \le c$, where *c* is a threshold chosen so as to allow for a solution under our computer resources constraints. For our choice of threshold, we ended up with around 6 million possible decision variables $x(i,j)$. Increasing the threshold, and allowing for more decision variables, did not change the solution.

The resulting final optimization problem for production areas (crops, pasture and planted forests) into simulations units corresponds to the following set of equations, which give us a smooth version of the minimum distance allocation algorithm:

$$\min \sum_{i,j} x(i,j) \times d(i,j)^2,$$

subject to

$$\sum_{i} x(i,j) \le s(j), j = 1, \dots, J$$

$$\sum_j x(i,j) = m(i), i = 1, \dots, N$$

$$x(i,j) \geq y^*(i,j), i = 1, \dots N, j = 1, \dots, J.$$

If we had enough area in all simulation units, so as $\sum_i y(i,j) \leq s(j)$, the solution for the optimization problem would be exactly $x(i,j) = y(i,j)$, because of the restriction $x(i,j) \geq y^*(i,j)$. This means that when there is enough land available per simulation unit, the production area of the municipality is distributed homogeneously among the simulation units (depending on the size of the intersection between simulation unit and municipality). For simulations units for which $\sum_i y(i,j) > s(j)$, the algorithm allocates the extra municipality production into surrounding simulation units (based on the weights for $d(i,j)$ for the cost function to be minimized).

In both versions (smooth and non-smooth) of the minimum distance allocation algorithm, there is an explicit neighboring sprawl effect. We always find a location to allocate the declared production area. If there is no sufficient free area within the simulation units intersecting the municipality, the production area is transferred to simulation units intersecting surrounding municipalities.

The main result from the previous algorithm is the sequence of variables $x(i,j)$, corresponding to the total production area allocated from municipality i into simulation unit j. We then use this information to transform information at the municipality level into information at the simulation unit level. The idea is quite straightforward. Let $r(i,j)$ be the variable indicating the share of productive area from municipality i allocated into simulation unit j, calculated as

$$r(i,j) = \frac{x(i,j)}{\sum_j x(i,j)}.$$

Let $v(i)$ be any variable, at the municipality level. The variable $v(i)$ can be, for example, the area for corn production (in hectares), the total area for planted forest, the area for pasture, or the number of heads of cattle. To find the value for the specific variable $v^*(j)$ at the simulation unit j, we can use the expression:

$$v^*(j) = \sum_i r(i,j) \times v(i).$$

By employing the previous expression, we can easily find the value any variable at the simulation unit level, based on information at the municipality level. Therefore, our algorithm works by first assigning municipality productive areas into simulation units, and then using the area optimized allocation as the driver for other variables assignment.

4.6 Result of the spatial allocation procedure

The final land cover map comprises the land cover classes *Forest*, *Wetlands* and *Not Relevant*, resulting from the GIS analysis described above, and the classes *Cropland* (incl. all 18 GLOBIOM crops), *Planted forest*, *Pasture*, *Other Agricultural Land* and *Other Natural Land*, that were added by the allocation algorithm presented in section 4.5. The area of each of these classes is available in hectares per simulation unit. Please see Table 4 (on page 24) for an overview of the total amounts of these classes. Furthermore, we obtain animal productivity and number of animals for different animal species. Figure 18 and Figure 19 show maps of these results. Figure 18 shows the estimates for *Grassland* and *Forest* area per simulation unit, together with data from other sources to facilitate comparison. The forest areas according to PRODES are quite consistent with the estimates from our method. Some care must be taken when comparing with information from PRODES because it only shows forest for the Legal Amazon and was created specifically for mapping deforestation.

Table 5 presents an overview over the amounts of land in the different land use classes, aggregated by biomes. For computing the total area in each biome and in each class we used a mapping between simulation units and biomes, where each simulation unit is assigned in its entirety to one biome. This explains why the summed areas may be slightly different from the official biomes' areas. Also, the total area of all land use classes is smaller than Brazil's official area. The reason for this is that the simulation units do not cover the entire territory. For example, they leave out water bodies such as the Amazon river (see Figure 17).

The total forest area in Table 5 is the same as the total forest area presented in Table 4; the allocation algorithm did not change it. The total pasture area is a combination of total pasture area according to the IBGE Census 2006, for outside Legal Amazon, and total pasture area inside Legal Amazon, according to MODIS. Our results show that almost 43 % of the total Legal Amazon area are protected (including different types of protection and including indigenous lands). This rate is very close to the 42 % estimated by Barreto et al. (2009).

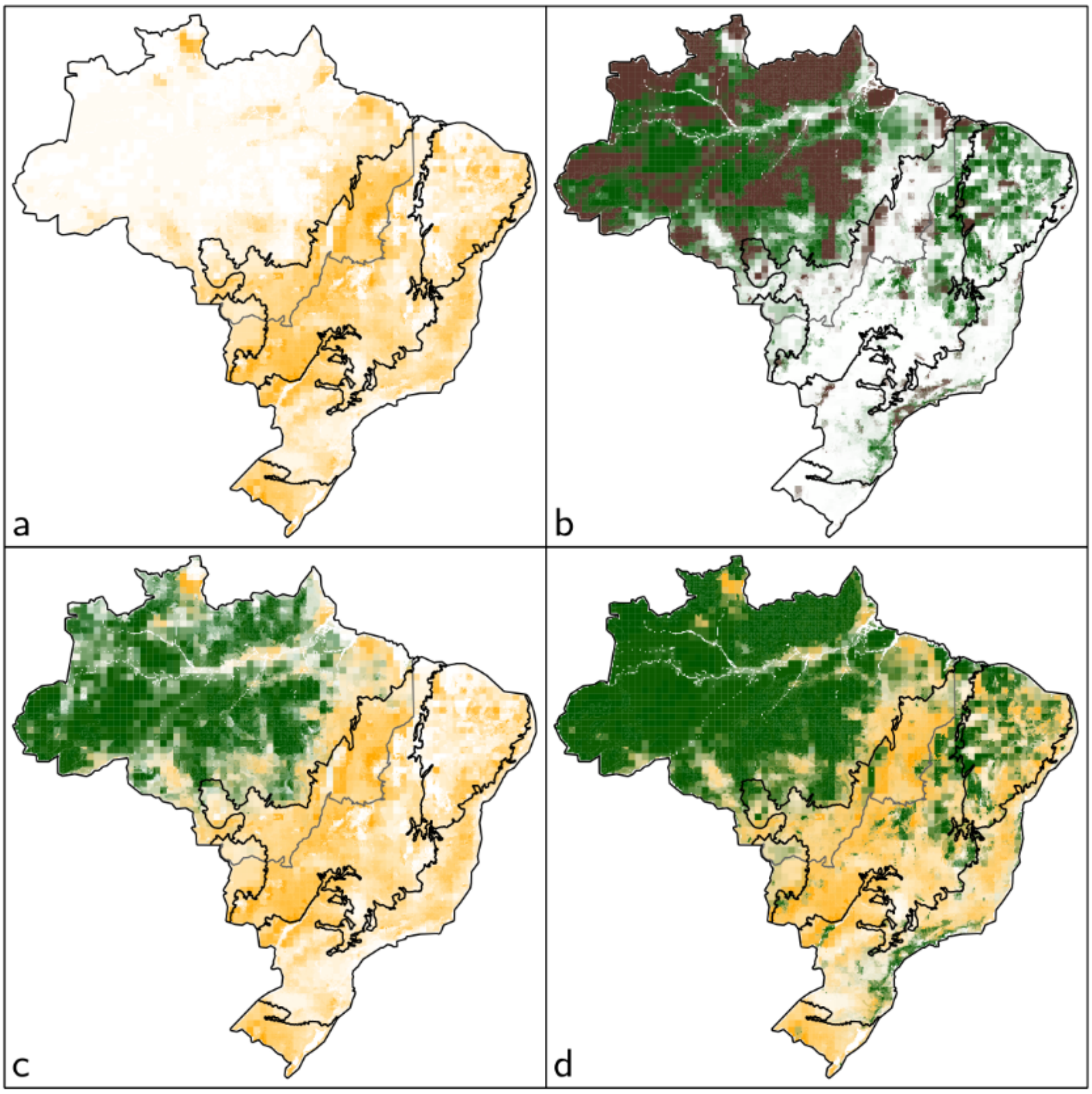


Figure 18: Final land cover map: *Grassland* and *Forest* per simulation unit. (a): yellow = *Grassland* (0 to 100%), (b): green = *Forest* (0-100%), brown = *Forest* in protected areas (0-100%), (c): yellow = *Grassland* (0 to 100%), green = PRODES forest area for comparison (Legal Amazon only), (d): green = *Forest* (0-100%), yellow = *Grassland* (0-100%).

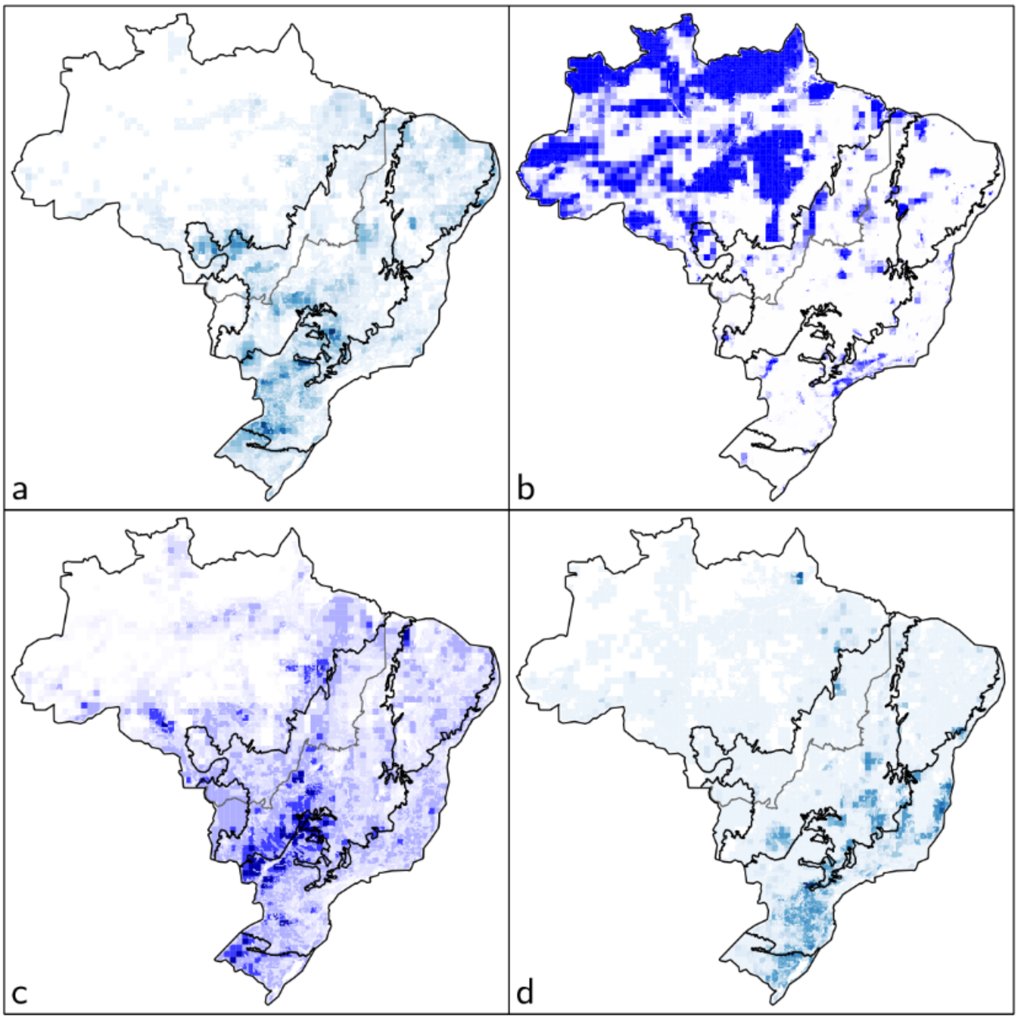


Figure 19: Maps of Cropland, Animal Production and Planted Forest. (a): Cropland area (0 to 232 Mha) (b) Protected Areas (0 to 100%), (c) total animal production (tropical livestock units, bovines and other animal species, 0 to 300000 TLUs), (d): Planted Forests (0 to 85 Mha).

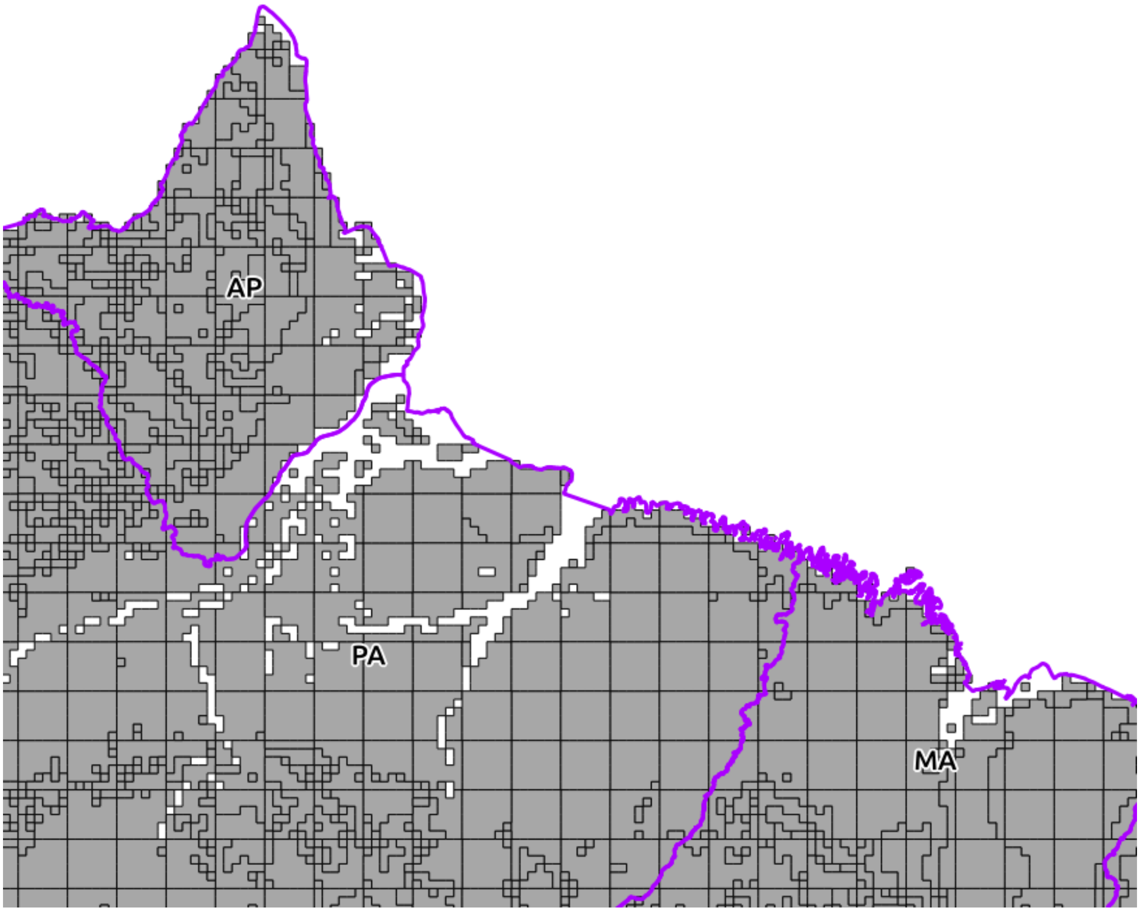


Figure 20: Area covered by simulation units (detail)

Table 5: Total Area for Land Use Classes per Brazilian Biomes

Biome	Total SIMU area (Mha)	Total Crop Area (Mha)	Total Pasture Area (Mha)	Total Forest Area (Mha)	Total Protected Areas (Mha)
Amazon	412,493.9	3,723.9	31,881.3	350,181.2	204,631.9
Caatinga	82,638.3	6,252.5	20,360.4	41,996.6	6,252.0
Cerrado	202,487.8	15,258.7	82,820.6	50,792.5	23,371.2
Mata Atlântica	113,731.2	22,820.3	35,613.1	17,322.5	9,375.2
Pampa	15,771.9	2,114.7	7,484. 7	145.7	485.1
Pantanal	12,211.3	27.3	3,758.0	3,997.3	501.7
Legal Amazônia	511.143.1	9,392.6	75,342.5	374,391.2	219,558.0
Brazil	839,334.5	50,197.4	181,918. 1	464,435.9	244,617.1

4.7 Discussion

This section describes how the land cover and land use map for GLOBIOM Brazil was built by combining various datasets. We argue that no single dataset has the information we need. Remote-sensing data provides systematic data on land cover classes, such as forest cover. However, it is not possible to get a direct matching between land cover classes such as "grasslands" and land use data on cattle production. Census data is better for providing land use in distinguishing individual crops or livestock amounts, but is prone to misreporting, for example in case a farmer is taxed or receives subsidies based on production area. Also, different datasets have different spatial scales. The IBGE vegetation map is arguably the best current description of native vegetation types in Brazil. However, it is available in a coarse scale (1:5,000,000) and does not provide information on anthropic areas. The SOS Mata Atlântica dataset is more detailed and captures well the fragmented forest remnants. However, it is only available in one of Brazil's six biomes.

The Brazilian territory is so vast and heterogeneous in its biophysical conditions (ecosystems, seasonality), but also in its socioeconomical conditions (incentive for reporting in Census, average size of farms and of municipalities), that the same dataset does not provide the same quality throughout the country. This is well illustrated by the necessity of choosing two different base maps inside and outside the Legal Amazon.

All datasets have flaws, so the more datasets we combine in a single map, the more likely we will find inconsistencies between the maps, for example productive areas exceeding the total area of a municipality. In this section, we explained where such inconsistencies occurred and how we handled them to come up with a consistent map.

The algorithm helped to solve inconsistencies in the agricultural census and survey datasets. The method is general and can be applied to cases where data available for aggregated spatial units (in this case: municipalities) needs to be disaggregated to smaller spatial units, considering restrictions in available area. The method also helps in reconciling land cover and land use information For example, the Pantanal area is known as one of the world's largest wetland areas, and many maps based only in land cover information classify it as wetlands. GLOBIOM, however, considers wetland areas as areas where no agricultural expansion takes place, while Pantanal has a substantial animal production. Thus, we have allocated productive areas for cattle in Pantanal.

In some municipalities, the total area for crop, pasture and planted forest according to IBGE is bigger than the amount of available area within the simulation units covering the municipality. In these cases, the algorithm allocates the exceeding area to surrounding simulation units. This shows the advantages of the algorithm. This situation occurs in 187 municipalities. For these municipalities, in average, the sum of crop, pasture and planted forest area exceeds the total municipality area by approximately 28%.

An important issue to be addressed in future research is the location and total area for pasture. Pasture corresponds to the economic activity with highest use of land in Brazil, and has been reported as the main driver for deforestation in the Amazon forest. In terms of available information, pasture area is reported, at the municipality level, in the Agricultural Census, which happens each ten years. On the other hand, one could explore in more details how satellite information can be combined with the data on numbers of animals (PPM) to obtain better estimates of pasture area in Brazil.

5 Computation of internal transport costs

GLOBIOM needs information on how much it costs to transport produced goods to the consumer. The cost of transport differs by merchandise and by destination. Some goods are consumed inside the country, so the cost to be considered is the cost to the interior markets, e.g. from the southern plains to the population agglomerations in the Southeast. Other goods are exported, usually by ship freight, so we need to consider the cost of shipping to the nearest seaports.

We compute the cost of transportation in USD per ton for agricultural commodities and in USD per m3 for wood products, depending on its location and connectivity to the road network, its produced goods and the goods' consumption locations. The internal transportation costs are computed at the 0.5 degree grid level which is the spatial grid resolution of GLOBIOM-Brazil (also referred as "ColRow level").

Transportation maps were computed using an algorithm implemented as a variation of the Generalized Proximity Matrix (GPM) (Aguiar et al 2003). This algorithm deals with transportation costs when the distances outside official roads matter. We use the centroid of each spatial unit ColRow as the starting point to compute the costs. When there is no road touching the starting or the ending points, we need to estimate an additional cost to enter or to leave the roads. This cost is computed as twice the Euclidean distance times the highest cost per kilometer amongst the available roads.

In this algorithm, the path from the starting to the ending point enters the road network only once. It means that it will leave the road only on the location closest to the ending point. Due to this restriction, the algorithm requires that all roads must be connected. The shortest paths inside the network are computed using Dijkstra algorithm (Dijkstra, 1959).

The original data comes from the 2012 National Plan for Logistics and Transportation. This plan includes the federal roads and a transportation cost within them, which varies from R$ 0.1791 to R$ 0.597 per ton transported per km. Some roads inside Amazonia were manually edited to keep them connected to the rest of the country. The cost of such roads is twice the highest cost of the roads in the database, making it similar to the cost outside roads. Figure 21 shows the edited data used as input for the algorithm to build the transportation maps. The roads with cost R$ 1.194 are the ones added manually. State roads were not added to the input data because they would require a significant increase in the computational cost, but would not produce better outcomes due to the resolution of the CRs in GLOBIOM.

The GPM was computed for capitals and for exportation ports. Figure 22 shows the cost to the nearest capital (left) and nearest exportation port (right). Yellow dots indicate the possible destinations. Costs range from R$ 2.11 per ton to R$ 512.02 for capitals and from R$ 5.08 to R$ 1145.44 for ports.

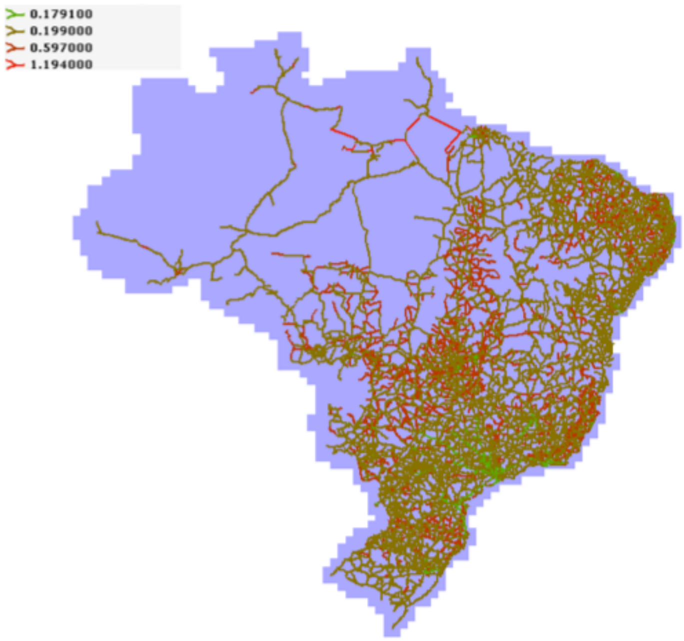


Figure 21: Roads in Brazil. The red ones were edited manually to guarantee that the network is fully connected.

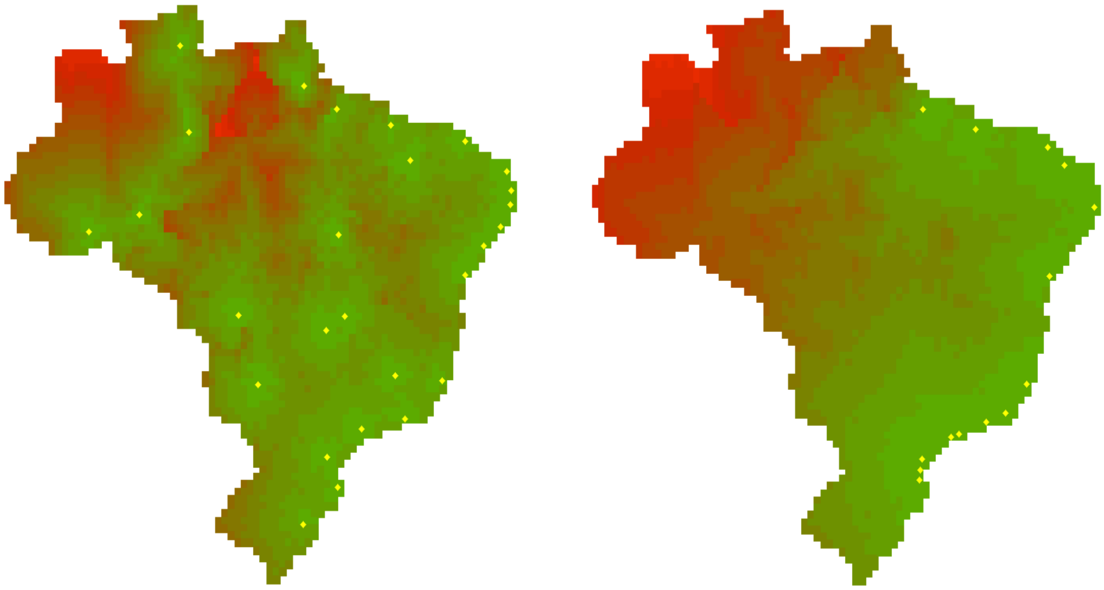


Figure 22: Transportation costs to the nearest state capital (left) and ports (right). Green means lower costs and red means higher costs.

The final transportation costs used by GLOBIOM were derived from these two maps, using the proportions of internal consumption and exportation per product. For example, Brazil exports 44% of the produced soybeans. Therefore, the transportation cost for soybeans for each CR is 0.44 times the cost to the nearest port plus 0.56 times the cost to the nearest capital. The final maps converts from Brazilian Reais to Dollars using the proportion US$1,00 = R$1,954. The transportation maps were computed for each product from agriculture, livestock and forestry sectors of GLOBIOM. Figure 22 shows the final transportation maps for soybeans and cattle, in Dollars per ton.

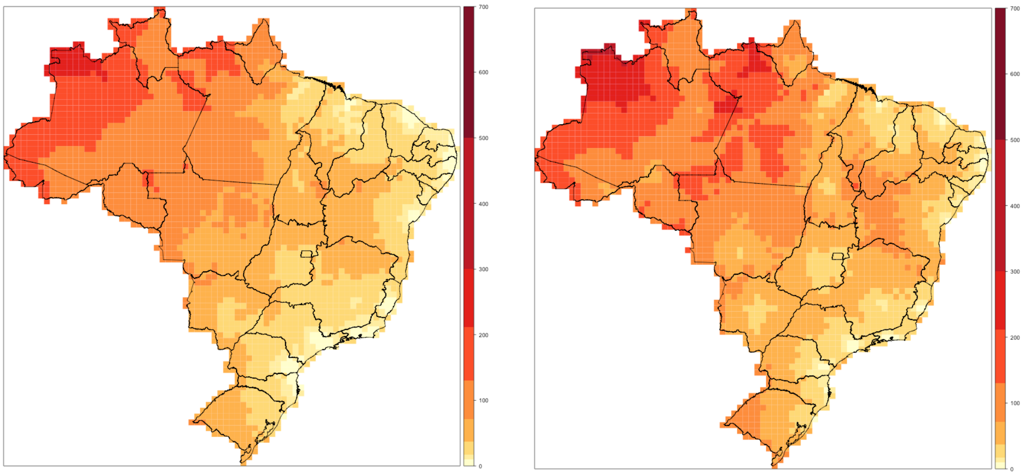


Figure 22: Final transportation costs for soybeans (left) and cattle (right).

6 Detailed WFS description

This section includes a detailed description of the attributes of the layers available on the REDD-PAC WFS and REDD-PAC website and of the adaptations performed on the datasets. On the REDD-PAC website, we provide maps versions of the datasets. To reduce loading time and increase clearness, very complex and detailed maps were simplified. Thus, they contain a subset of the attributes available on the WFS.

6.1 Vegetation map of Brazil

Name of the layer: `wfs_vegetation_ibge`

The vegetation map by IBGE is the base map for the GLOBIOM land cover map. The version available on the REDD-PAC WFS and on the website is a slightly adapted version of the original data available publicly at IBGE. We cleaned the original data, by removing open seas polygons and eemoved Portuguese diacritics from text attributes. We also corrected "*Vegetação Ombrófila*" to "*Floresta Ombrófila*", as on the official IBGE document, only "*Floresta Ombrófila*" exists. We created the name, code and label attributes from the existing information of codes and names of current and previous vegetation. Finally, we added the classification to IGBP and GLOBIOM classes and the forest flag.

Name	Meaning
`detail_nam`	Name of vegetation, including previous vegetation in case of human influenced areas, e.g. "*Atividades Agrarias (previous: Estepe)*"
`detail_cod`	Detailed vegetation code. It contains the code for current vegetation and, in case of human influenced areas, the code for previous vegetation as well.
`detail_lab`	Code and name of current and previous vegetation, for labelling purposes.
`curr_nam`	Name of nowadays vegetation, e.g. "*Estepe arborizada*".
`curr_cod`	Code of nowadays vegetation, e.g. "*Ea*".
`curr_lab`	Code and name of current vegetation, for labelling purposes, e.g. "*Ea = Estepe arborizada*".
`prev_nam`	Name of previous vegetation.
`prev_cod`	Code of previous vegetation.
`prev_lab`	Code and name of previous vegetation, for labelling purposes.
`coarse_nam`	Name of the aggregated vegetation group, e.g. "*Estepe*" instead of "*Estepe arborizada*".
`coarse_cod`	Code of the aggregated vegetation group, e.g. "*E*" instead of "*Ea*", "*Ep*", "*Eg*".
`coarse_lab`	Name and code of aggregated vegetation group.
`forestflag`	This indicated whether the vegetation is considered as forest in GLOBIOM (=1) or not (=0).
`class_igbp`	The original vegetation classes were mapped by the REDD-PAC team to

	vegetation classes according to IGBP.
`class_glob`	The original vegetation classes were mapped by the REDD-PAC team to GLOBIOM land cover classes. Please note that this does not show the final GLOBIOM classes, as these will be complemented by other data sources.

6.2 Forest cover data from 'SOS Mata Atlântica'

Name of the layer: `wfs_sosma`

The forest cover data available on the WFS and website is a subset of the SOS Mata Atlântica land cover dataset. It includes only the areas that were covered by forest in the year 2000, excluding non-forest areas, urban areas and other vegetation types such as *Restinga* (a type of coastal shrublands), *Mangue* (a type of Mangrove) and *Vegetação de várzea* (a type of seasonal floodplain forest). Areas that SOSMA marked as deforested from 2008-2012 are included in this map, as they were forest in the year 2000.

We merged all land cover polygons from all 17 states. For this, the geometry was slightly simplified; otherwise, processing would have taken too much time. A reasonable level of simplification was found by analyzing the trade-off between file size / processing time and geometry correctness / area loss using various levels of simplification.Some polygons in the merged map overlap and some of them have contradictory land cover classes, being mapped as "Non-forest area" and "Forest" at the same time. These were considered "Forest". This only concerns 170 hectares in Brazil.We removed all patches that are not forest. 426,275 patches remain.

Name	Meaning
Legenda	Land cover. This map includes the classes: *Mata* *Decremento de mata 2000-2005* *Decremento de mata 2005-2008* *Decremento de mata 2010-2011* *Decremento de mata 2011-2012* *Decremento de mata 2008-2010* *Desmatamentos identificados em 2012* Other classes present in the original SOSMA dataset have been excluded.
State	Federal state where the patch is located.
class_glob	GLOBIOM Land Cover class. This has only one value: "*FOREST*".

6.3 Conservation Units

Name of the layer: `wfs_conservationunits_mma`

The conservation units' map by MMA is one of the parts of the protected areas in GLOBIOM. The version available on the REDD-PAC WFS is a slightly adapted version of the original data available publicly at MMA.

The original conservation units' map contains about 3.7 millions of hectares of overlapping areas. If such a map is used without removing the overlaps, areas can be counted twice, so we removed them. In the overlapping area, the part belonging to the smaller protected area is removed, but its ID is stored in the attribute 'overlaps', so no information is lost.

The adaptations that were carried out include removal of geometry errors, and removal of overlaps. The version shown on the website was further simplified to reduce loading time (simplification using the QGIS simplification algorithm, deletion of sliver polygons below 2 hectares).

Name	Meaning
`id_uc0`	This is an attribute provided by MMA. It is the areas' ID.
`overlaps`	This map does not contain any overlaps. When two areas overlap, the part that belongs to the smaller area is deleted. Its ID is recorded in this attribute.
`area_pa`	This is the area of the entire protected area, before deletion of overlaps and including all parts of a conservation unit (in case it consists of spatially disconnected parts). In meters.
`area_ha`	This is the area of the areas after deletion of overlaps, in hectares. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part.
`area_geo`	This is the area of the areas after deletion of overlaps, in meters. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part. (On the website, this attribute is called 'area_ha' and is in meters).
`loc_code`	This is an id for the areas. Spatially disconnected parts have different Ids. Parts that overlap with other conservation units also get a different ID.
`Others`	All other attributes are the original attributes from MMA. Please refer to MMA for documentation: NOME_UC1, ID_WCMC2, NOME_ORG12, CATEGORI3, GRUPO4, ESFERA5, ANO_CRIA6, GID7, QUALIDAD8, ATO_LEGA9, DT_ULTIM10, CODIGO_U11.

6.4 Indigenous Areas

Name of the layer: `wfs_indigenousareas_funai`

The indigenous areas' map by FUNAI is one of the parts of the protected areas in GLOBIOM. The version available on the REDD-PAC WFS is a slightly adapted version of the original data available publicly at FUNAI.

The original map of the indigenous areas contains about one million of hectares of overlapping areas. If such a map is used without removing the overlaps, areas can be counted twice, so we removed them. In the overlapping area, the part belonging to the smaller protected area is removed, but its ID is stored in the attribute 'overlaps', so no information is lost.

The adaptations that were carried out include:

- Geometry errors, as found by QGIS, were removed manually (QGIS)
- Removal of overlaps, using GRASS GIS and R.

The version shown on the website was simplified to reduce loading time (geometrical simplification using the QGIS simplification algorithm, deletion of sliver polygons with area less than 1000 square meters).

Name	Meaning
`terrai_cod`	This is an ID of the areas, provided by FUNAI.
`loc_code`	This is an id for the areas. Spatially disconnected parts have different Ids. Parts that overlap with other conservation units also get a different ID.
`area_pa`	This is the area of the entire indigenous area, before deletion of overlaps and including all parts of a indigenous area (in case it consists of spatially disconnected parts). In meters.
`area_geo`	This is the area of the areas after deletion of overlaps, in meters. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part.
`area_ha`	This is the area of the areas after deletion of overlaps, in hectares. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part.
`overlaps`	This map does not contain any overlaps. When two areas overlap, the part that belongs to the smaller area is deleted. Its ID is recorded in this attribute.
`Others`	All other attributes are the original attributes from FUNAI. Please refer to FUNAI for documentation: TERRAI_COD, TERRAI_NOM, ETNIA_NOME, MUNICIPIO_, UF_SIGLA, SUPERFICIE, FASE_TI, MODALIDADE, REESTUDO_T, SUPERFIC_1

6.5 Public Forests

Title of the layer in wfs: `wfs_publicforests_mma`

The public forests map by MMA is one of the parts of the protected areas in GLOBIOM. The version available on the REDD-PAC WFS and on the website is a slightly adapted version of the original data available publicly at MMA. The original map of public forests contains about 0.1 millions of hectares (95,000 ha) of overlapping areas. If such a map is used without removing the overlaps, areas can be counted twice, so we removed them. In the overlapping area, the part belonging to the smaller protected area is removed. Its ID is stored in the attribute 'overlaps', so no information is lost.

Name	Meaning
`FPCODIGO1`	This is an ID of the areas, provided by MMA.
`catmix`	This indicates whether the area has several categories assigned ("*yes*") or not ("*no*"). If an area has several categories, both are given in the FUNAI attribute "CATEGORI6", separated by semicolon, e.g. "ARIE; Terra Indigena".
`protected`	This indicates whether the category (or one of them) is in the list of fully protected categories (APA, FLOTA, FLONA, PARNA, REBIO, ESEC, RESEX, ARIE, RDS and RVS) ("*yes*") or not ("*no*").
`year`	This is the year of creation as a numeric attribute, derived from the text attribute "DATA_CRI8" from MMA. Areas that are "*em levantamento*" (being surveyed) have no value.
`loc_code`	This is an id for the areas. Spatially disconnected parts have different Ids. Parts that overlap with other public forests also get a different ID.
`area_pa`	This is the area of the entire public forest area, before deletion of overlaps and including all parts of a public forest area (in case it consists of spatially disconnected parts). In meters.
`area_ha`	This is the area of the areas after deletion of overlaps, in meters. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part.
`area_geo`	This is the area of the areas after deletion of overlaps, in meters. In case an area consists of spatially disconnected parts, this attribute contains the area of every single part.
`overlaps`	This map does not contain any overlaps. When two areas overlap, the part that belongs to the smaller area is deleted. Its ID is recorded in this attribute.
`All others`	All other attributes are the original attributes from MMA. Please refer to MMA for documentation: GID0, FPCODIGO1, NOME2, ORG_GEST3, TIPO_FLO4, ESTAGIO5, CATEGORI6, GRP_DEST7, DATA_CRI8, DOC_LEGA9, MUNI_UF10, BIOMA11, CLAS_VEG12, IMP_PROB13, PRI_PROB14, HECTARES15

6.6 Protected Areas

Title of the layer in wfs: `wfs_protectedareas`

This layer is the union of all areas that should be considered as 'protected' in GLOBIOM, i.e. not be available for agricultural expansion. It includes the conservation units, indigenous areas and a subset of public forests.

Spatially overlaying layers that have overlapping areas often results in so-called 'sliver polygons'. These are small polygons that occur where the same boundary is present in both layers, but not precisely equal. These small polygons are not meaningful and increase computing time and file size. For removing them, we carefully analysed the union in a GIS to find out beneath which area size the polygons mostly are sliver polygons. All areas beneath 50 hectares were either merged to the adjacent polygon with the longest common boundary or deleted (if the longest part of the boundary not adjacent to any area). In this process, 323838 hectares of protected area is lost, which is about 0.13 % of the total protected areas.

This layer is a union of three input layers, each of which has a set of attributes. If all attributes are kept, this results in a huge table with NULL values for most attributes (table of 1.5 GB). Thus, the attributes from the various individual layers were deleted, while keeping the Ids which allow to reconstruct which areas were included in the first place.

The version on the website, for further reducing loading time, was spatially dissolved. This means that borders between neighbouring areas were removed. The Ids of the individual areas can not be kept in this case. The website version is thus only an visual illustration of the protected areas, without any attributes.

The steps that were carried out to create this layer were:

- A spatial union of conservation units and indigenous areas is computed.
- A spatial union of the previous union with the public forests is computed (resulting layer in GRASS: *union_prot_indig_florpub*).
- Most attributes are removed (resulting layer in GRASS: *union_prot_indig_florpub_ lessattrib*). This reduces the size of the attribute table from 1.5 GB to 60 MB. Note: A csv file with all the attributes is available.
- Small areas under a threshold of 50 hectares are removed or merged to adjacent areas (using the GRASS tool “rmarea”; resulting layer in GRASS: *union_prot_indig_florpub_ smallremoved*). The shapefile size is reduced from 170 MB to 50 MB.
- Dissolve version for the website (resulting layer in GRASS: *union_prot_indig_florpub_ smallremoved_dissolved*). This further reduces the file size to 20 MB.

Attributes:

Name	Meaning
jointid	The id of the area, i.e. protected-area ID ('ID_UC0') or indigenous-area ID ('terrai_cod') or public forest ID ('FPCODIGO1'), or a concatenation of the Ids in case of overlapping areas. This only joins one ID per area type, If there is overlaps inside those types, check the 'overlaps' attributes of the maps with the whole set of attributes. Example: ID_UC0_70,FPCODIGO1_FPA-5240901W-3259762S means that in this location, a conservation unit with the ID '70' is overlapping with a public forest area with the ID 'FPA-5240901W-3259762S'.

Attributes inside the csv file:

Name	Meaning
jointid	(see above)
area_prot,area_indig	Area of the original conservation unit or indigenous area at this location (whose ID is given in the jointid).
over_flpb, over_prot, over_indi	Overlapping areas of the various categories. Note: Only overlaps inside one type of area (public forests 'flpb' OR conservation units 'prot' OR indigenous areas 'indi') are recorded here.
ID_UC0, NOME_UC1, ID_WCMC2, NOME_ORG12, CATEGORI3, GRUPO4, ESFERA5, ANO_CRIA6, GID7, QUALIDAD8, ATO_LEGA9, DT_ULTIM10, CODIGO_U11	Attributes from the "Conservation Units" layer from MMA.
terrai_cod, terrai_nom, etnia_nome, municipio_, uf_sigla, superficie, fase_ti, modalidade, reestudo_t, superfic_1	Attributes from the "Indigenous Areas" layer from FUNAI.
fpGID0, fpCATEGOR	Two attributes from the Public Forests layer (GID0, CATEGOR), please refer to MMA for further documentation.
cat	A unique ID of all polygons which share the same attribute values.

6.7 Simulation Units

Name of the layer: `wfs_simus_basis`

The simulation units are the fundamental geographical unit for GLOBIOM simulations. All the input data as well as the results are given on this spatial level.

Name	Meaning
SIMUID	The unique ID of the units.
area_ha	Area of the simulation unit in ha.
protected	Overall percentage of protected areas (all land cover classes)
prot_for	Percentage of forest inside the protected areas.
prot_nonf	Percentage of nonforest inside the protected areas.
GRD30	Reference number in a 30" wide latitude/longitude grid
country	The country code, which is 76 (for Brazil).
hru	Homogenous response unit (see GLOBIOM description above)

6.8 Simulation Units with algorithm input

Name of the layer: `wfs_simus_algorithminput`

This layer shows fractions of the land cover per simulation unit, before the disaggregation algorithm was used for distributing crops and pasture area. This is an input to the disaggregation algorithm. All fractions sum up to one. For some simulation units, there was not enough information available to cover the entire unit. In these cases, the fractions were expanded to sum up to one, i.e. we assume the land cover to be representative for the entire unit.

Name	Meaning
SIMUID	The unique ID of the units.
fr_FOR_UN	Forest cover outside protected areas.
fr_FOR_PR	Forest cover inside protected areas.
Fr_CPO_UN	Land cover class "Cropland, pasture or other natural land".
fr_WET_UN	Wetland outside protected areas.
fr_WET_PR	Wetland inside protected areas.
fr_NOT_UN	Not relevant to GLOBIOM outside protected areas ("*Not relevant*").
fr_NOT_PR	Not relevant to GLOBIOM inside protected areas ("*Not relevant*").
fr_OTH_UN	Land cover class "*Other Natural Land*" inside protected areas. Later, this will be added to "*Crops, pasture or other natural land*".
fr_OTH_PR	Fraction of the land cover class "*Other Natural Land*" outside protected areas.

6.9 Simulation Units with Planted Forest Area

Name of the layer: `wfs_simus_plantedforest`

This layer shows the amount of planted per simulation unit. This is an output of the disaggregation algorithm.

Name	Meaning
`SIMUID`	The unique ID of the units.
`PLF`	Area of planted forest, according to the 2006 Agricultural Census.

6.10 Simulation Units with crop data

Name of the layer: `wfs_simus_individual_crops`

This layer shows the amount of cropland per crop and per simulation unit. This is an output of the disaggregation algorithm.

Name	Meaning
`SIMUID`	The unique ID of the units.
`Barl, BeaD, Cass, Corn, Cott, Gnut, OPAL, Pota, Rice, Soya, Srgh, SugC, SwPo, Whea`	The area (in thousands of hectares) covered by each crop, respectively, barley, dry beans, cassava, corn, cotton, ground nut, palm oil, potato, rice, soya, sorghum, sugarcane, sweet potato, wheat.
`total`	Sum of the area of all crops, ranging from 0 to approximately 232 Mha, summing up to 43968 Mha (43.06 Mio. ha).

6.11 Simulation Units layer with livestock data

Name of the layer: wfs_simus_livestock

This layer shows the amount of tropical livestock units per animal species. This is an output of the disaggregation algorithm.

Name	Meaning
SIMUID	The unique ID of the units.
t_BOVI00, t_BOVI10	Bovines / cattle (Tropical Livestock Units) in the years 2000 and 2010.
t_GOAT00, t_GOAT10	Goats (Tropical Livestock Units).
t_PTRY00, t_PTRY10	Poultry (Tropical Livestock Units).
t_SHEP00, t_SHEP10	Sheep (Tropical Livestock Units).
t_PIGS00, t_PIGS10	Pigs (Tropical Livestock Units)
fr_BOVI00, fr_BOVI10, …	Bovines / cattle (fraction of bovines in the total Tropical Livestock Units) in the years 2000 and 2010. The same pattern applies for other animal species.
total2000, total2010	Sum of tropical livestock units in the year 2000 (total = 137.6 Mio TLU) and 2010 (total = 171.5 Mio TLU).

6.12 Simulation Units with PRODES data

Name of the layer: `wfs_simus_prodes`
This layer shows the fractions of the data of each simulation unit that is covered by a specific land cover class in the PRODES dataset. Please note that the PRODES dataset only covers the Legal Amazon area.

Name	Meaning
SIMUID	The unique ID of the units.
FLORESTA	Forested area in 2012.
DESFLOREST	Deforested area found in 2012.
NAO_FLORES	Non-forest area (has never been forest). The non-forest mask used by PRODES is the same every year.
NUVEM	Cloud-cover in 2012.
HIDROGRAFI	Water area.
RESIDUO	Pixels that could not be classified.
defor_all	Sum of all deforestation area (incl. “DSF_ANT” and “DESFLORESTAMENTO”)
DSF_ANT	Anterior deforestation.
area_ha	Area of the simulation unit, provided from GLOBIOM.
No_data	Area covered by pixels with value zero (area covered by the raster, but outside Legal Amazon).
d2002_4 (etc.)	Deforested area identified in a specific year. The number under the underscore indicated for how many years that pixel had not been seen before, so the deforestation could have taken place earlier.

6.13 Simulation Units with GLOBIOM land cover

Name of the layer: `wfs_simus_algorithmresults`

Name	Meaning
`SIMUID`	The unique ID of the units.
`CrpLnd, fr_CrpLnd`	Area and fraction of cropland in the simulation unit.
`CrpLnd_H`	Area of cropland in the production system “High Yield”.
`CrpLnd_L`	Area of cropland in the production system “Low Yield”.
`CrpLnd_I`	Area of cropland in the production system “Irrigated System”.
`CrpLnd_S`	Area of cropland in the production system “Subsistence Agriculture”.
`OthAgri, fr_OthAgri`	Area and fraction of class “Other Agricultural Land” (cropland of all crops that are not individually listed in GLOBIOM) in the simulation unit.
`Grass, fr_Grass`	Area and fraction of class “Grassland”.
`Forest, fr_Forest`	Area and fraction of class “Forest”.
`OthNatLnd, fr_OthNatL`	Area and fraction of class “Other Natural Land”.
`NotRel, fr_NotRel`	Area and fraction of class “Not relevant”.
`Pas, fr_Pas`	Area and fraction of class “Protected Areas”.
`WetLnd, fr_WetLnd`	Area and fraction of class “Wetland”.

6.14 Simulation Units with TerraClass 2008 data

Name of the layer: `wfs_simus_terraclass2008`

All attributes express the share of a simulation unit's area that is covered with that specific land cover / land use. Thus, the attribute values range from 0 to 1 and all attributes add up to 1.

Note: The original description of the dataset which was provided along with the raster contains the class "*FLORESTA_SOB_NUVEM*" (forest under cloud cover), but no pixel was assigned this class. The same goes for "DV" (dummy value).

Name	Meaning
`SIMUID`	The unique ID of the units.
`Forest`	Forest („*Floresta*")
`Nonforest`	Non-forest („*Nao_Floresta*")
`PastLimp`	Clean pasture area ("*Pasto limpo*").
`PastSujo`	Unclean pasture area ("*Pasto sujo*").
`PastSolEx`	Pasture area with exposed soil („*Pasto com solo exposto*").
`MosaOcu`	Area with a mosaic of occupations („*Mosaico de ocupacoes*").
`Urban`	Urban area („*Area_urbana*").
`Water`	Water („*Hidrografia*")
`Other`	Other land cover („*Outros*")
`Mining`	Mining area („*Mineracao*").
`Defor08`	Accumulated deforested area in 2008 ("*Desflorestamento_2008*").
`SecoVeg`	Secondary vegetation („*Vegetacao_secundaria*").
`RegPast`	Regenerated area with pasture ("*Regeneracao_com_pasto*").
`AnnuAgri`	Annual agriculture („*Agricultura_Anual*").
`AgroPec`	Mixed crop-livestock farming ("*Agropecuaria*").
`NotObs`	Not observed area ("*Area_nao_observada*").

6.15 Simulation Units with TerraClass 2010 data

Name of the layer: `wfs_simus_terraclass2010`

All attributes express the share of a simulation unit's area that is covered with that specific land cover / land use. Thus, the attribute values range from 0 to 1 and all attributes add up to 1.
In various cases, the state of Acre uses different class names than the other states. The classes with different names are kept separate in this dataset for the user to make his/her own choice of adding classes up.

Note: The original description of the dataset which was provided along with the raster contains the class "*VS2008_SOB_NUVEM*" (secondary vegetation of 2008 under cloud cover), but no pixel was assigned this class. The same goes for "VEGETACAO_SECUNDARIA" (secondary vegetation), "PASTAGEM_MUITO_DEGRADADA_SE" (very degraded pasture, secondary vegetation), "NAO_FLORESTA_2" (a 2nd non-forest class), "DV" (dummy value), "FLORESTA_SOB_NUVEM" (forest under cloud-cover) and "HIDROGRAFIA_2" (a 2nd water class).

Name	Meaning
SIMUID	The unique ID of the units.
noclass	Area outside TerraClass2010' study area, i.e. outside the Legal Amazon. No TerraClass 2010 pixels are available in this area.
FLORESTA	Forest („*Floresta*").
NAO_FLOR	Non-forest („*Nao Floresta*"). This is all area that is naturally not forest, so its current land-use is not being mapped by the TerraClass project.
DESFL2010	Accumulated deforested area in 2010 ("*Desflorestamento_2010*"). This class includes area in all states of the Legal Amazon except for Acre.
DESMAT2010	Accumulated deforested area in 2010 ("*Desmate_2010*"). This class includes area in the state of Acre.
REFLOREST	Reforested area ("*Reflorestamento*").
URBANO	Urban area ("*Urbano*"). This class includes area in the state of Acre.
URBANA	Urban area ("*Area urbana*"). This class includes area in all states of the Legal Amazon except for Acre.
REG_PASTO	Regenerated area with pasture ("*Regeneracao_com_pasto*"). This class includes area in all states of the Legal Amazon except for Acre.
PAS_LIM	Clean pasture area ("*Pasto limpo*"). This class includes area in all states of the Legal Amazon except for Acre.
PAS_LIM2	Clean pasture area ("*Pastagem limpa*"). This class includes area in the state of Acre.
PAS_SUJ	Unclean pasture area ("*Pasto_sujo*"). This class includes area in all states of the Legal Amazon except for Acre.
PAS_SOLEX	Pasture with exposed soil („*Pasto_com_solo_exposto*").

PASDEG_VE	Very degraded pasture area with vegetation (“*Pastagem_muito_degradada_veg*”). This class includes area in the state of Acre.
PASDEG	Degraded pasture area (“*Pastagem_degradada*”). This class includes area in the state of Acre.
AGRI	Agricultural area („*Agricultura*“).
AGRIANUA	Annual agriculture („*Agricultura_Anual*”).
AGRIPECU	Mixed crop-livestock farming (“*Agropecuaria*”). This class includes area in the state of Acre.
PALMOIL	Oil palm culture („*Oleo_de_palma*“).
NOT_OBS	Not observed area (“*Area_nao_observada*”).
MOSAIC	Area with a mosaic of occupations („*Mosaico de ocupacoes*“).This class includes area in all states of the Legal Amazon except for Acre.
QUEIMADO	Burnt area („*Area_queimada*“).
HIDRO	Water („*Hidrografia*“)
OUTROS	Others („*Outros*“)
NUVEM	Cloud-covered area („*Nuvem*“).
MINERACAO	Mining area („*Mineracao*“).
VS_2010	Secondary vegetation identifed in the year 2010 (“*VS2010*”).

6.16 Simulation Units layer with MODIS

Name of the layer: `wfs_simus_modis2001, wfs_simus_modis2002, …`

These layers show the fractions of MODIS land cover (in the IGBP classification). For further documentation, please refer to the MODIS project.

Name	Meaning
SIMUID	The unique ID of the units.
EvBroaFor	Fraction of pixels classified as evergreen broadleaf forest.
DeBroaFor	Deciduous broadleaf forest.
EvNeeFor	Evergreen needleleaf forest.
DeNeeFor	Deciduous needleleaf forest.
MixFor	Mixed forest.
forest_all	Sum of all five forest classes.
ClShru	Closed shrublands.
OpShru	Open shrublands.
WoSav	Woody savannas.
Sav	Savannas.
Urba_up	Urban and built-up area.
Grass	Grassland.
Crops	Cropland.
Water	Water.
PerWet	Permanent wetlands.
CNMosaic	Cropland/Natural vegetation mosaic.
Barren	Barren/sparsely vegetated.
Snow	Snow and ice.
FillValue	Fill value.

6.17 Biomes

Title of the layer in wfs: `wfs_biomes`

The biome map by IBGE was not used as input to create the GLOBIOM land cover map. It was used for aggregation statistics and for visual orientation while interpreting maps. The version available on the REDD-PAC WFS and on the website is a slightly adapted version of the original data available publicly at IBGE. We did a geometrical cleaning, when overlaps, rings, holes were removed. We also merged the the inland water bodies (rivers, lakes) to the surrounding biomes. We extende the biomes to cover islands close to the mainland, such as Ilha Bela and Ilha Grande. Islands that are far away (e.g. Fernando de Noronha) are not included. We corrected the boundaries of the biome map to match the municipality map.

Attributes:

Name	Meaning
`COD_BIOMA`	Code of the biome
`NOM_BIOMA`	Name of the biome
`area`	The biome's area in millions of hectares (string attribute, including unit)

6.18 Municipalities

Title of the layer in wfs: `wfs_municipalities_basis`

The municipality map by IBGE shows the boundaries of the Brazilian municipalities in 2007. It was used for distributing municipality-based agricultural data on the simulation units. The layers available on the REDD-PAC WFS and on the website are slightly adapted versions of the original data available publicly at IBGE. We deleted two polygons that are not municipalities but large lakes – as they have NULL values in most attributes, they disturb analysis. We computed the percentage of each municipality that is located inside the Legal Amazon area, using the Legal Amazon’s outline. We added the attributes that were used for creating the GLOBIOM land cover map.

This layer contains the basic information about the municipalities: The regions, the area size in hectares, the amount of area that is inside the Legal Amazon.

Name	Meaning
GEOCODIG_M	Code of the municipality
name_plain	Name of the municipality without any special characters
state	Name of the federal state
State_abb	Abbreviation of the federal state
region	Name of the region
mesoreg	Name of the meso-region
microreg	Name of the micro-region
area	Area in hectares or square kilometres (depending on the municipality's size), as string, with unit included. Computed in QGIS, using an Albers Equal Area projection. It is not the official area of the municipalities.
area_ha	Area in hectares (numerical attribute), computed in QGIS, using an Albers Equal Area projection. It is not the official area of the municipalities.
perc_legal	Percent of the municipality's area that is located in the Legal Amazon area.

6.19 Municipality layer with PPM values

Title of the layer in wfs: `wfs_municipalities_ppm`

This municipality layer contains the data of the PPM study (livestock heads and Tropical Livestock Units). These are the values by municipality which were used as input to the allocation algorithm. All attributes exist for the year 2000 and for the year 2010. The unit of the attributes is number of heads, except for the overall pasture area (ha) and the overall livestock amount (tropical livestock units).

Name	Meaning
`GEOCODIG_M`	Code of the municipality
`name_plain`	Name of the municipality without any special characters
`state`	Abbreviation of the federal state
`donke_00`, `donke_10`	Number of heads of donkeys (*Efetivo_2000_Asininos*).
`chi_f_00`, `chi_f_10`	Number of heads of female chickens (*Efetivo_2000_Galinhas*).
`goats_00`, `goats_10`	Number of heads of goats (*Efetivo_2000_Caprinos*).
`horse_00`, `horse_10`	Number of heads of horses (*Efetivo_2000_Equinos*).
`cattl_00`, `cattl_10`	Number of heads of cattle (*Efetivo_2000_Bovinos*).
`rabbit_00`, `rabbit_10`	Number of heads of rabbits (*Efetivo_2000_Coelhos*).
`sheep_00`, `sheep_10`	Number of heads of sheep (*Efetivo_2000_Ovinos*).
`pigs_00`, `pigs_10`	Number of heads of pigs (*Efetivo_2000_Suinos*).
`chi_m_00`, `chi_m_10`	Number of heads of male chickens (*Efetivo_2000_Galos*).
`mules_00`, `mules_10`	Number of heads of mules (*Efetivo_2000_Muares*).
`tlu2000`, `tlu2010`	Total amount of Tropical Livestock Units (*tlu_total_2000, tlu_total_2010*).
`past2000`, `past2010`	Total amount of pasture area according in hectares to Gasques (Agricultural Census, extrapolated for the year, *2000, area_ha_2000_pasture*). On top of that, pasture area was added to municipalities that do not have any pasture area according to Gasques, but do have livestock according to PPM.

6.20 Municipality layer with PAM values

Title of the layer in wfs: `wfs_municipalities_pam`

This municipality layer contains the input values of the PAM study (crop area). These are the values by municipality which were used as input to the allocation algorithm. All attributes exist for the year 2000 and for the year 2010. Attributes exist in several units: Planted area in thousands of hectares (*are_...*), produced quantity in tons (*ton_...*), monetary value of the produced crops in thousands of Brazilian Reais (R$) (*val_...*).

Name	Meaning
`GEOCODIG_M`	Code of the municipality
`are_perm00, ton_perm00, val_perm00, are_perm10, ton_perm10, val_perm10`	Area, weight or value of permanent crops (*CultPermanentes*) in the year 2000 and 2010.
`..._temp...`	Area, weight or value of temporary crops (*CultTemporarias*).
`..._SugC...`	Area, weight or value of sugarcane (*CanaDeAcucar*).
`..._CasN...`	...Cashew nuts (*CastanhaCaju*).
`..._SwPo...`	... Sweet potateoes (*BatataDoce*).
`..._Cass...`	... Cassava (*Mandioca*).
`..._Gnut...`	... Groundnuts (*Amendoim*).
`..._Sunf...`	... Sunflower (*Girassol*).
`..._BeaD...`	... Dry beans (*Feijao*).
`..._Pota...`	... Potatoes (*Batata*).
`..._Barl...`	... Barley (*Cevada*).
`..._Corn...`	... Corn (*Milho*).
`..._Rice...`	... Rice (*Arroz*).
`..._Oats...`	...Oat (*Aveia*).
`..._Srgh...`	... Sorghum (*Sorgo*).
`..._Cott...`	... Cotton (*Algodao*).
`..._Whea...`	... Wheat (*Trigo*).
`..._Ccau...`	... Cacao (*Cacau*).
`..._Sisa...`	... Sisal (*Sisal*).
`..._Coff...`	... Coffee (*Café*).
`..._Soy...`	... Soy (*Soja*).
`..._OPAL...`	... Oil Palm (*Dende*).

6.21 Municipality layer with Planted Forest values

Title of the layer in wfs: `wfs_municipalities_plantedforest`

This municipality layer contains the input values on various types of economically used forest of the Agricultural Census 2006 per municipality. The attribute that is used as "Planted Forest" input to the allocation algorithm is "*Sistemas agroflorestais*". All attributes exist in several units: area in hectares and number of establishments.

Name	Meaning
`GEOCODIG_M`	Code of the municipality
`name_plain`	Name of the municipality without any special characters
`state_abbrev`	Abbreviation of the federal state
`area_ha`	Area in hectares (numerical attribute), computed in QGIS, using an Albers Equal Area projection.
`perc_legal`	Percent of the municipality's area that is located in the Legal Amazon area.
`area_FNLR`, `num_FNLR`	Area (ha) of native forest in Legal Reserves (the part of a private farm that has to be kept under native vegetation by law, *Matas e/ou florestas - naturais destinadas à preservação permanente ou reserva legal)*. Attribute name in GAMS computation: *area_ha_2006_ForestNativeLegalReserve*
`area_FNO`, `num_FNO`	Area (ha) of native forest in farms (*Matas e/ou florestas - naturais (exclusive área de preservação permanente e as em sistemas agroflorestais)*. Attribute name in GAMS computation: *area_ha_2006_ForestNativeOthers*
`area_AFS`, `num_AFS`	Area (ha) of agro-forest systems (*Matas e/ou florestas - florestas plantadas com essências florestais*). Attribute name in GAMS computation: *area_ha_2006_AgroForestSystems.*
`area_PLF`, `num_PLF`	Area (ha) of planted forest (*Sistemas agroflorestais - área cultivada com espécies florestais também usada para lavouras e pastoreio por animais*). Attribute name in GAMS computation: *area_ha_2006_ForestPlanted*. Note: This is the only type of forest production that is considered as "Planted Forest" in GLOBIOM. Its total is approximately 4.4 Mio. Ha.

6.22 Federal States

Title of the layer in wfs: `wfs_federalstates`

The map of the federal states was created from the map of municipalities, by spatially dissolving the map using the '*Sigla*' attribute. It was not used for the GLOBIOM land cover map, but is useful for visual analyses of land cover data.

Name	Meaning
state	Name of the federal state (without diacritics or special symbols), e.g. "*Sao Paulo*".
abbrev	Abbreviation of the federal state, e.g. "*SP*".
uf_number	Number of the federal state (federal union, união federal), e.g. 35.

7 WFS User manual

The REDD-PAC data is made available as vector datasets in a Web Feature Service (WFS). A web feature service is a service that provides access to geographical (vector) data in the format GML. You can directly load the data into Geographical Information System (GIS) and use them or store them as a shapefile.

The URL of the service is `http://terrabrasilis.info/redd-pac/wfs`

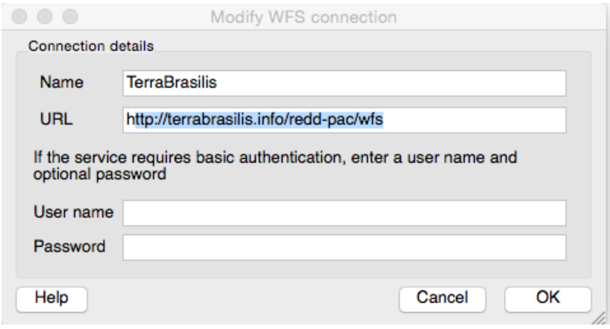
To access the data, you will need a software that allows loading the data from a WFS service. We will describe below how to access the data using QGIS.

7.1 Retrieving WFS data using QGIS

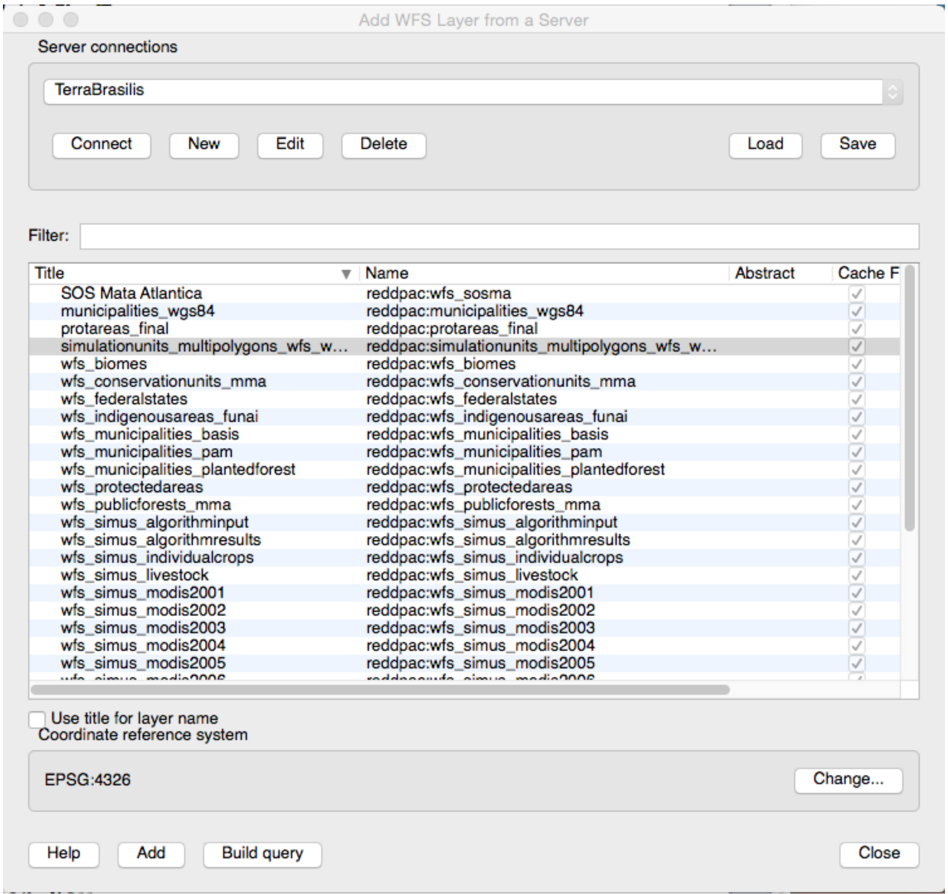
To retrieve the data in QGIS (and storing them as a shapefile, if desired), please perform the following 4 steps.

(1) Open QGIS, go to the menu "*Layers*" and choose "*Add WFS Layer*".

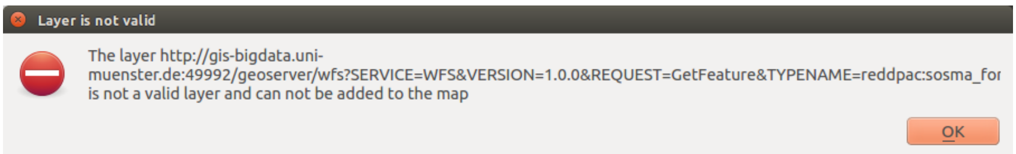
(2) In the window that has opened, click "*New*". Now choose a name, e.g. "TerraBrasilis", and copy-paste the URL given above. The WFS does not require any password and user name. Click "*Ok*".



(3) Select "TerraBrasilis" in the dropdown menu and click "*Connect*". Now you should see a number of layers in the list. Choose a layer and add it by clicking "*Add*". For example, use the layer "reddpac:wfs_biomes" as a test, as it is relatively small and will not take much time for loading. When it has finished loading, you see the layer displayed in the map window, just like any other vector layer. You can style it the way you are used to.



(4) If you want to store the data as a shapefile for later offline use or for being able to make changes and store them, select the layer in the layer list and go to the menu “*Layers*” “*Save As*”. Now, you can store it as a shapefile on your local hard disk.



(5) Some of the layers are really large, for example the layer of the SOS Mâta Atlantica forest cover data. If the layer is too large, QGIS does not finish loading it, because it takes too much time. In this case, you can adjust QGIS' settings to give it more time to load the layer. Please go to the menu “Settings” and choose “Options”. Go to the tab “Network” and set the value of “Timeout for network requests (ms)” to 180 000.

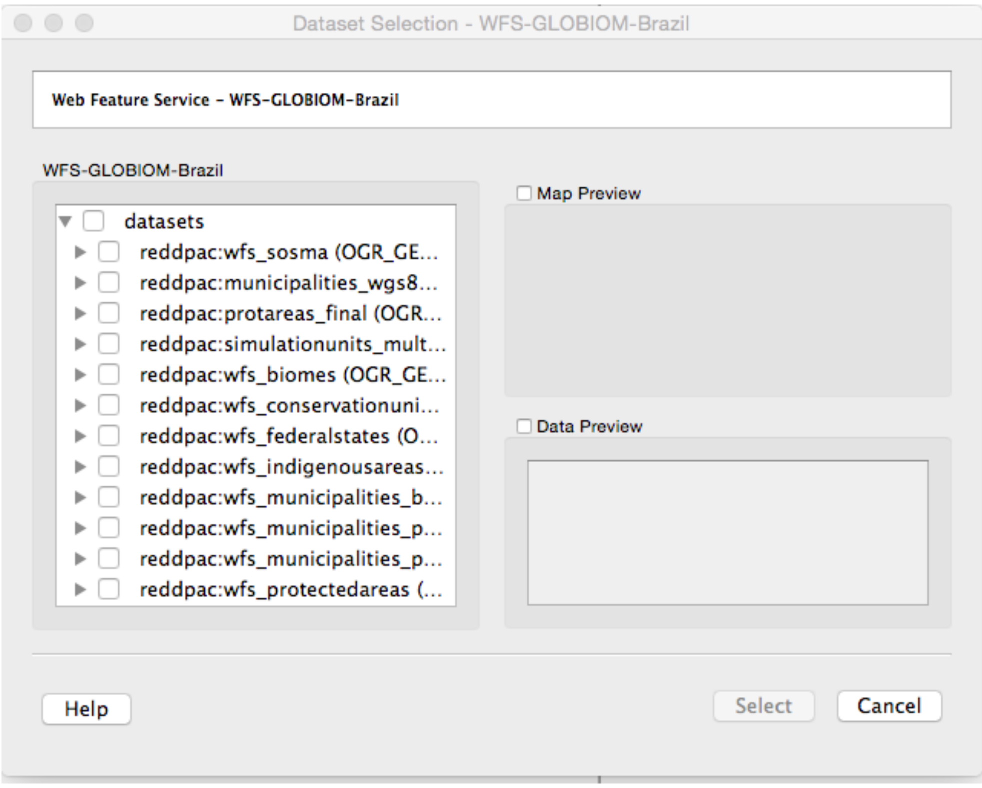
7.2 Retrieving WFS data using TerraView 5.0

To retrieve the data in TerraView 5.0 (and storing them as a shapefile, if desired), please perform the following 4 steps.

(1) Open TerraView, please click the "*Add Layer*" icon in your "*Project*" tool bar, and then select the option "*From Data Source*".

(2) In the window that has opened, select the "Web Feature Service" data source. Click on the "+" signal to add a new WFS data source. Now use "WFS:http://terrabrasilis.info/redd-pac/wfs" as the service address and choose a data source title, e.g. "TerraBrasilis". The WFS does not require any password and user name. Click "*Test*" to test the connection. If all works, then click "Close". When back to the data source menu, click "Select".

(3) You will get a dataset selection menu (see below). Now you should see a number of layers in the list. Choose a layer by clicking on the selection tab and add it by clicking "*Select*". For example, use the layer "reddpac:wfs_biomes" as a test, as it is relatively small and will not take much time for loading. When it has finished loading, you see the layer displayed in the map window, just like any other vector layer. You can style it the way you are used to.



(4) If you want to store the data as a shapefile for later offline use or for being able to make changes and store them, select the layer in the layer list and go to the menu "*Layers*" "*Save As*". Now, you can store it as a shapefile on your local hard disk.

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