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# Exploration of the spatial-temporal capabilities of the PLUC model

A CASE STUDY ON THE BRAZILIAN LAND USE  
CHANGE

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# 1 Introduction

## 1.1 Background

Rapid population growth, food shortages, deforestation; it is no new science that the world around is constantly changing. Global land change is one of the most important factors in global change in the world. Currently, roughly 32% of the land has been altered by human behaviour and this is expected to increase in the near future (Cockburn, 2021). Issues such as climate change and land change are too extensive to comprehend. Modelling can help create a better understanding of these concepts and can provide necessary predictions for the future of the global issues. The Integrated Model to Assess the Global Environment (IMAGE) is a model that simulates human induced changes on the global climate (PBL, 2021). It explores human-climate relations and analyses long term climate processes and trends. IMAGE is often used for making future scenarios. While there is great uncertainty in the direction of the future, models such as IMAGE create a better understanding of the current changes happening to the environment. It also helps identify key factors in change, which can be used for decision and policy making. Such models require lots of data to make predictions. The History Database of the global Environment (HYDE) is a database that is designed to support the IMAGE model by providing data on the global historic landuse (Klein Goldewijk, K., A. Beusen, J. Doelman and E. Stehfest, 2017). HYDE is an extensive database with global landuse data from 10 000 BC to current day. While HYDE is designed to support the IMAGE model, it can also be used for other predictive models.

## 1.2 model description

The PCraster Land Use Change model (PLUC) is a python extension build by Utrecht University. It can model land use changes using suitability maps, demand, yield, and cartographic modelling operators. This research will use the “PLUC model created for any country, edited for education” (Verstegen, 2018). The model requires a lot of data about the landuse and present land features such as roads and rivers. The model recognises 4 land use types that will change: Urban, Cropland, Pasture, and Forest. Additional land use types can be added, but these do not have a demand nor yield, and thus cannot expand. The model considers 11 parameters that will explain the changes in landuse: a demand and a yield, and 9 suitability factors. These suitability factors have weights that all add up to 1. Using this, the priority of specific suitability factors can be adjusted and suited to reality. A full list of these 11 parameters and their explanation can be found in *table 1*. These suitability factors use suitability maps to determine which land use type is most suitable for a cell when considering demand and yield. In timestep 0, the model assumes that the demand is filled. It then considers the demand increase to determine how many additional raster cells are required to fill that demand. If the total demand is not met of a landuse type, additional raster cells that are most suitable for the required landuse will be converted. Additionally, the yield increases per timestep which balances out the increase in demand.

*Table 1: The demand, yield, and suitability factors of land use change*

Name in PLUC	Full name	Explanation
demand_increase	Demand increase	The demand increase per cell per timestep
yield_increase	Yield increase	The yield increase per cell per timestep
w_neighborhood	Number of neighbouring cells	The importance of neighbouring cells having a related land use type
w_distance2roads	Distance to roads	The distance of a cell to the nearest road cell
w_distance2water	Distance to open water	The distance of a cell to the nearest water cell
w_distance2cities	Distance to cities	The distance of a cell to the nearest city cell
w_potentialyield	Potential yield	The maximum potential yield of a cell
w_populationdensity	Population density	People per cell
w_cattledensity	Cattle density	Animals per cell
w_edge	Distance to forest edge	Distance to forest edge is important for deforestation as it is assumed that there is more deforestation at the edge of a forest than in the middle
w_currentlanduse	Current land use	The current land use type that is provided in a landuse raster file. This file can support more land use types than the 4 types considered, but these will not grow over time. Some landuse types have a higher resilience than others.

To see if the PLUC model can accurately predict future land use change, it can be compared to established models such as the IMAGE model. If the two models follow the same trends, it can be concluded that the PLUC model is able to predict future land use changes.

### 1.3 Case study

To analyse the effectiveness of the PLUC model, Brazil is chosen as a case study. Brazil is an important player in global climate change since it houses the amazon rain forest, the largest forest in the world. The forest is home to about 10-15% of global land biodiversity (S. P. Hubbell, 2008), it is a major source of freshwater, it stores an estimated 150 to 200 billion tons of carbon (H. K. Gibbs, 2007) and it is a cultural hub for a plethora of cultural groups (L. J. Gorenflo, 2012). All these factors show the significance of the Amazon rainforest. Despite this however, over the last 60 years around 20% of the forest has been cut down to make way for low productivity farms and pastures (C. A. Nobre, 2016). Brazil's current president Jair Bolsonaro has suggested that Brazil may leave the United Nations Paris agreement in which countries worldwide agreed to reduce global emissions by 2030 by reducing deforestation and land degradation (Artaxo, 2019). Before Bolsonaro took office, the country had made great steps in the preservation of the rainforest. From 2003 to 2014 the country has reduced its deforestation from 27,700 to 4,500 km<sup>2</sup> per year (Artaxo, 2019). With the political and economic crisis came a reduction of preservation practices and research. From 2015 to 2019 the deforestation increased again, growing to around 8000 km<sup>2</sup> of forest disappearing each year (Artaxo, 2019). With Brazil's history with deforestation, it is interesting to analyse the land use changes in the past years it is important to model the landuse of Brazil for the future. Since PLUC models deforestation, it is interesting to analyse the future land use change of Brazil.

## 1.4 Scope

This research will focus entirely on Brazil and its land use change. For the sake of this research, 2017 will be used as a base year since most data is available for that year. The temporal scope will be 200 years; from 1900 to 2100. This will provide enough historic data to calculate the parameters and model variables (117 years) while also going as far in the future as the IMAGE model (2100) to see what the future of land use in Brazil will be. The goal of this research is to explore whether a PLUC model can accurately describe historic trends and be used for future predictions similarly to the IMAGE model. While Brazil is used as a case study, other countries or regions could also be suitable for this research.

## 1.5 Research questions and goal

This research aims to explore the PLUC model and will attempt to find whether it can accurately follow the same predictions as the IMAGE model. This research will explore and answer the following research questions:

- To what extent is the PLUC model able to describe the future land use change of Brazil?
  - o What are the future predictions of the IMAGE model on the land use change of Brazil?
  - o To what extent is the PLUC model able to follow the conclusions drawn by the IMAGE model for the land use change of Brazil?
  - o To what extent can the PLUC model describe the land use change of Brazil of the past 117 years based on data from the HYDE model?

Additionally, this research will provide a detailed methodology on building input data for the PLUC model. Currently no such methodology is present, and the PLUC model is only able to run for 5 countries provided through the course Land Change Science (GEO3-2419).

## 2. Methodology

The methodology for building and analysing the model is important to describe due to all the yet unknown mechanisms of the model. Before this research, there was no guide on how to produce new maps for the PLUC model. The only way the model could have been used, was with the input maps provided in the Land Change Science course (GEO3-2419). To analyse the capabilities of the model, a detailed methodology should be made to guide future research. Such a methodology could also prove useful for educational purposes, since it can be used in the Land Change Science course for students that want to challenge themselves to let the PLUC model run for countries other than the 5 provided.

### 2.1 Building maps in ArcGIS pro

The input files for the PLUC model are in a raster format. Rasters are grids of cells where every grid holds information on that area. The smaller the cell size, the more detailed the raster is and the better it represents reality. Rasters can be stacked on top of each other to provide different types of information for the same cell. An elevation map could be stacked on top of a roads map to provide both the presence of roads and the elevation of a cell in the raster. These rasters can be made with programs such as ArcGIS pro and ArcMap. For this project, all maps are built in ArcGIS pro. The PLUC model requires 8 maps to be able to run. The exact details on how to build these maps in ArcGIS pro can be viewed in appendix 1. The description of these maps, the data label and the sources are shown in *table 2*.

*Table 2: Description, data label, and source of the input maps for the PLUC model*

<b>File name</b>	<b>Description</b>	<b>Data label</b>	<b>sources</b>
Dem.map	Elevation map. DEM is an acronym for digital elevation model	Scalar	World elevation GMTED (Esri, 2020)
Landuse.map	Current land use	Nominal	HYDE (Klein Goldewijk et al, 2017), Biome map (Prentice, et al., 1997)
nullMask.map	A map to indicate the study area	Ordinal	Brazil country Boundary 2016 (ESRI 2021)
Pasture_area.map	Land that is available for pastures	Scalar	HYDE (Klein Goldewijk et al, 2017)
Pop_density.map	Number of inhabitants	Scalar	HYDE (Klein Goldewijk et al, 2017)
Protected_areas.map	Protected areas	Ordinal	FAO (FAO, 2006)
Roads.map	All types of roads in the study area	Nominal	(Meijer et al., 2018)
Suitability_res03_crav6190_sxhr_cer.map	Net primary productivity. This is used as a proxy for the suitability map of croplands	Scalar	NPP (FAO, 2006)
Suitability_res03_crav6190_sxhr_alf.map	Net primary productivity. This is used as a proxy for the suitability map of pastures	Scalar	NPP (FAO, 2006)

### 2.1.1 Landuse 1900 map

The landuse map built is a combination of a biome map (prentice et. al, 1997) and HYDE data maps for pasture, cropland, and urban area (Klein Goldewijk et al, 2017). Since these are all global datasets, they should be clipped to Brazil only. This is done by downloading “Brazil country boundary 2016” (ESRI, 2021) and clipping all maps to this shapefile. The pasture, cropland and urban maps indicate what area of a raster cell is comprised of that type of landuse. For example, if a raster cell for cropland has a value of 0.37, then 37% of the area in that raster cell is comprised of cropland. The PLUC model cannot use partial area, so a simplification of the raster datasets must be made. Since there was little intense agriculture, large pastures nor big cities in 1900, a raster cell will be counted as “urban” if the urban area is greater than 5%, “pasture” if the pasture area is greater than 10% and “cropland” if the cropland area is greater than 10%. If a raster cell has a higher percentage than the benchmark for 2 or 3 categories, the largest percentage will be chosen. The model also looks for the availability of water, so the “water” class should be added to the landuse map. A world surface water map (ESRI, 2014) is downloaded, resampled, and added to the landuse map. These previous steps are performed through the raster calculator and explained in appendix 1.1 and 1.2. The landuse map should now have 9 categories, where 8 are present in Brazil. The wetland category is not represented in Brazil.

### 2.1.2 Landuse 2017 map

A landuse map for 2017 is also made. This is done through the same steps as the 1900 map, but instead pasture, cropland, and urban maps from 2017 are used. Intensification of agriculture, and the increase in density for pastures and urban areas are taken in consideration. To do this, the percentages for the presence of cropland, pastures and urban area are increased. A raster cell will be counted as “urban” if the urban area is greater than 20%, “pasture” if the pasture area is greater than 35% and “cropland” if the cropland area is greater than 35%. If a raster cell has a higher percentage for more than 1 category, the category with the largest percentage will be chosen. The rest of the steps are the exact same as for the landuse 1900 map, resulting in 9 categories where 8 are present in Brazil.

### 2.1.3 DEM map

DEM is an acronym for Digital Elevation Model. A DEM map for Brazil is made from a world elevation map GMTED (ESRI, 2014). This map is also clipped to the Brazil countries boundary shapefile and resampled to the cell size and extent of the landuse map. No addition maps are required be added to this file.

### 2.1.4 Null mask map

A Null mask map is a raster that represents the shape of the country. The model uses this map to indicate the study area. To build this map, the Brazil country boundary shapefile is converted to a raster and resampled to the cell size and extent of the landuse map.

### 2.1.5 Pasture area map

Next to the pasture area category in the landuse map, an additional pasture area map should be made as input data for the model. This map is created with the pasture area 1900 file from the HYDE dataset. This raster is clipped to the Brazil country boundary shapefile and resampled to the cell size and extent of the landuse map.

### 2.1.6 Population density map

A population density map is made that represent the population density per raster cell. This map is created with the inhabitants per grid cell for 1900 (urb\_1900) raster. This raster is clipped to the Brazil country boundary file and resampled to the cell size and extent of the landuse map.

### 2.1.7 Protected area map

A map that indicates the protected areas in Brazil is also made. This map should be a Boolean datatype with values of 0 (not protected) and 1 (protected). This map is made using a global protected areas map derived from FAO (FAO, 2006). This raster is clipped to the Brazil country boundary shapefile and resampled to the cell size and extent of the landuse map.

### 2.1.8 Suitability maps

A suitability map is made to indicate which areas are most suitable for cropland and pastures. Net primary productivity (NPP) is used as a proxy for the suitability for these two land use types. To make this map, a NPP map is downloaded from FAO (FAO, 2006) and clipped to the Brazil country boundary shapefile. This raster is then resampled to the cell size and extent of the landuse map. The model requires 2 input maps to determine the suitability of cropland and pastures, one for cereals and one for alfalfa. Only one suitability map is created now and copied under a different name later since NPP is used instead of suitability of cereals and alfalfa.



## 2.2 Converting maps to the correct format

All maps have now been created and the rasters should have the same rows, columns, and cell sizes. These maps are in the wrong format however, and thus must be converted for the model to use. This is done in two steps. First the ArcGIS pro raster files are converted to an ASC file. In order to convert these ASC files into the correct .MAP format, a python prompt with a PCraster module has to be opened. This was initially done through the Myworkplace environment provided by the UU. It was later discovered that the python version used in this module has been updated as of November 2021. This means that access to many functions is restricted, and the PLUC model cannot run the python script anymore. Thus, a local version of python with the PCraster module is downloaded using miniconda. The details of this installation can be found at the PCraster documentation of the UU (PCraster owners, 2021). Python 3.6 is downloaded and installed and the PCraster environment is activated. In this environment, maps can be converted, mask maps can be created, and maps and timeseries can be viewed. The ASC files can only be converted into .map files with a corresponding clone map. These maps are blank sheets that hold map data such as cell size, extent, and data label. First, 3 clone maps must be created: A nominal, Scalar and Ordinal clone map. The cell size of these maps should be 1000, and the extent should match the created ASC files. When converting ASC files to .map files, the corresponding clone map should be used. For instance, a protected areas map has the data label ordinal since it is true or false map. So, when converting the ASC file into an .map file, the ordinal clone map should be used for protected areas. All maps should be converted into the .MAP format before the model is able to run. The suitability map created from the NPP file should be created twice with a different name since this model uses the same NPP map for both the suitability for pastures and croplands. The names of the map files should be the same as in *table 2* for the model to recognise the files.

## 2.3 Final adjustments

A few final adjustments must be done before the model can run. The legend file should be adjusted to fit the legend of the created landuse map. There should be 11 categories, 9 that correspond with the created landuse map, and 2 new categories that the model creates: abandoned and deforested. The inputs file should then be filled in to set a baseline for the model to run. This inputs file contains the parameters for the model and shows the weights of suitability maps. It also contains the demand increase and the yield increase. The model attempts to fill the demand for all the dynamic landuse types (urban, cropland, pastures, and forest). If the demand is higher than the total yield, the model will change raster cells into the desired landuse type. The baseline scenario for this project is the same as the PLUC scenario created for Mozambique (Verstegen, 2018). The base inputs for the model can be found in appendix 2. Once the input file is filled in, the model should be able to run using the PCraster python prompt. Finally, the amount of timesteps should be adjusted to 117 in the parameter file, to make sure the model runs from 1900 to 2017.

## 2.4 Parameter fitting

Once the model can run, the correct suitability factors should be found. The created landuse map for 2017 will be used as a goal for the model. The suitability factors are then adjusted in a trial-and-error method until the result of the model roughly fits the 2017 landuse map. This process is visualised in *figure 1*.

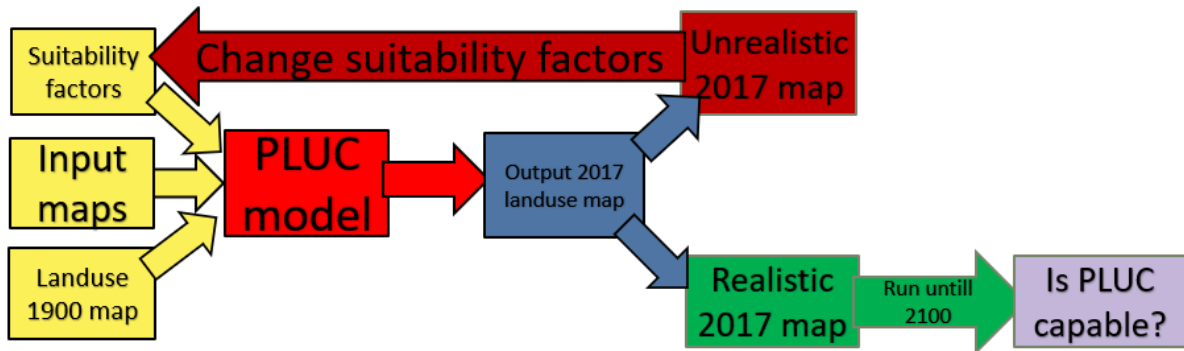


Figure 1: Diagram on parameter fitting for the PLUC model

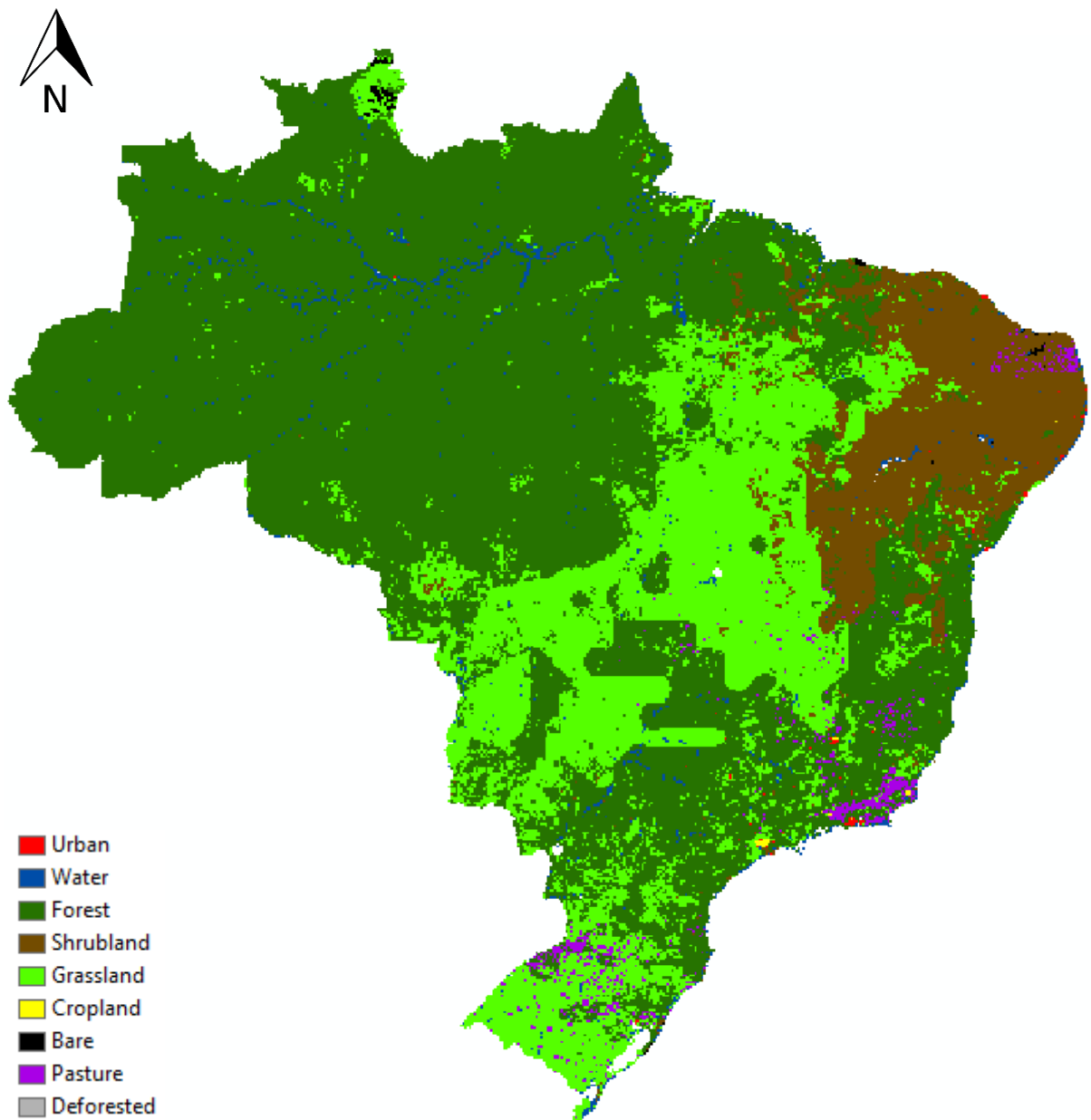
## 2.5 Future scenario runs

Once the model roughly corresponds with the present day landuse, these suitability factors will be used to determine the model's ability to predict future landuse changes. This method assumes that the landuse change trends of the past 117 years will continue at least until 2100. The found suitability factors will be applied to the created 2017 landuse map to see the capabilities of the model to predict future scenarios. In addition, another run is performed where the model runs from 1900 to 2100 with the found suitability factors. The two created maps are then analysed, and it is observed which map is the best prediction of the future. This output is then compared to landuse maps of IMAGE. If the same trends can be observed, the PLUC model has shown potential to predict future landuse processes.

## 3. Results

### 3.1 1900 and 2017 landuse maps

The landuse of 1900 show limited cropland and pasture area. Pastures and croplands are generally located along the coast and around cities, with the area of Rio de Janeiro having the densest pastures and croplands. Cities are small and uncommon, also located along the coast.



*Figure 2: Landuse map of Brazil in 1900*

The landuse of 2017 show much greater cropland and pasture expansion. While the area around the Amazon River is static, the cropland expansion around the Paraná River (south) is much greater. Pasture expansion is along existing patches of pastures, located along the coastline. There is some pasture and cropland expansion in the amazon rainforest in the south-west and north, but no extensive cropland and pasture expansion deeper in the Amazon. Cities have generally expanded, but also some new cities have formed such as Brasilia in the centre of the country

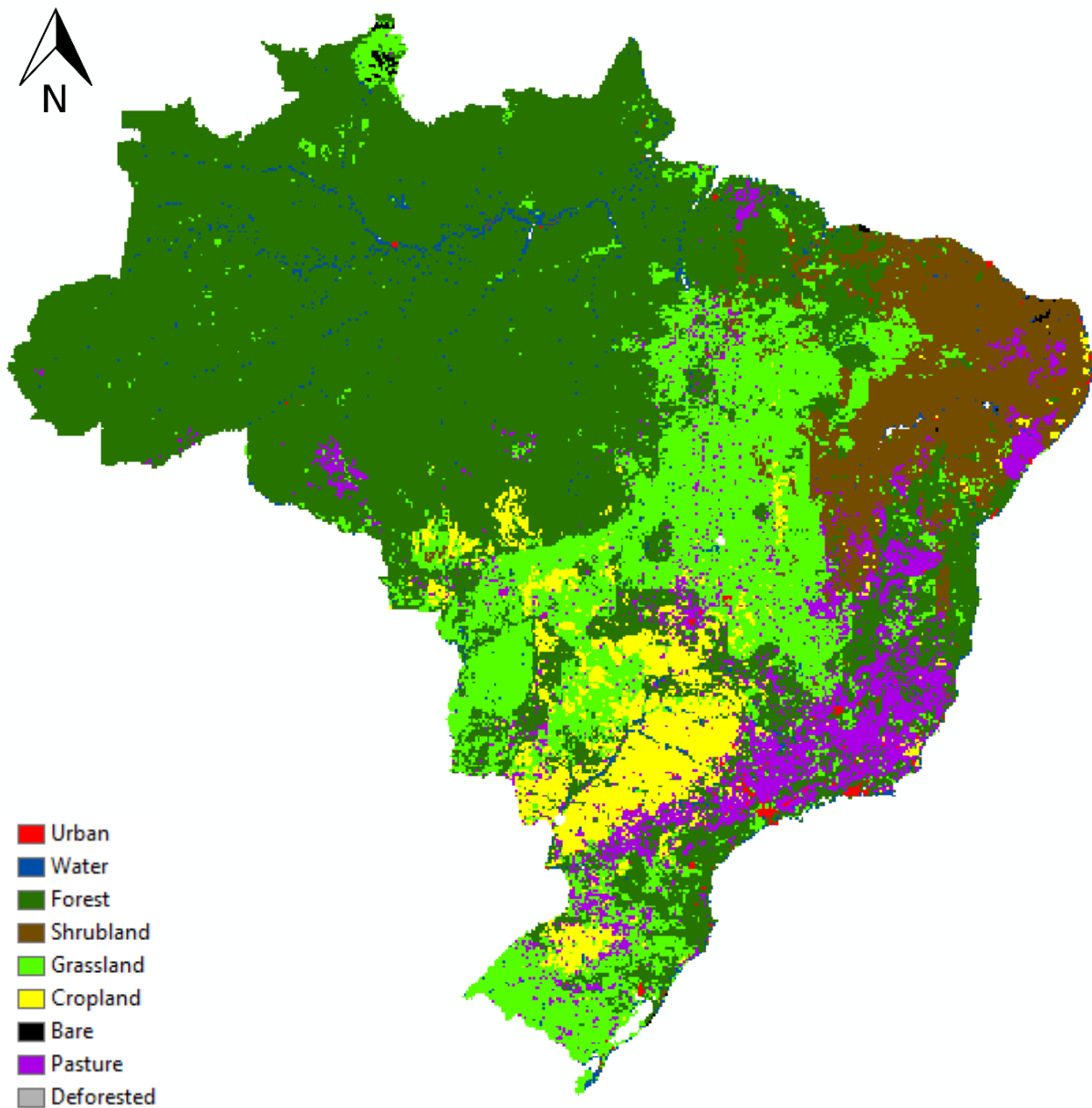


Figure 3: Landuse map of Brazil in 2017 with known data

### 3.2 Investigating the model/noteworthy trends

When running the model and adjusting the suitability factors, new insights of the model have been found. Since this model is not widely used, these observations are important to note in to be able to understand the mechanics of the model. Once new observations are found, the suitability factors can be adjusted in a controlled and focussed manner. A detailed list of the suitability factors of each of the runs can be found in appendix 2.

#### 3.2.1 Baseline

First a baseline should be established to be able to compare results. These values are derived from the PLUC model of van der Hilst et. Al that was built for assessing the land availability for energy crops in Mozambique. These will serve as a baseline for the comparison. When running this model, a few observations are made. There is limited cropland expansion. Due to the small demand for cropland and its relatively high yield, there is little cropland expansion for this run. Most cropland expansion is around existing areas of cropland, located around cities on the coast due to the high road density and city density. There is also very limited pasture expansion due to the low demand. Most pasture expansion is along existing patches of

pastures. Deforestation is generally along roads. Most deforestation appears deep in the Amazon rainforest, since this area has a high yield. Deforestation is also more prevalent near cities. New cities are not formed, but instead existing cities expand directly around them.

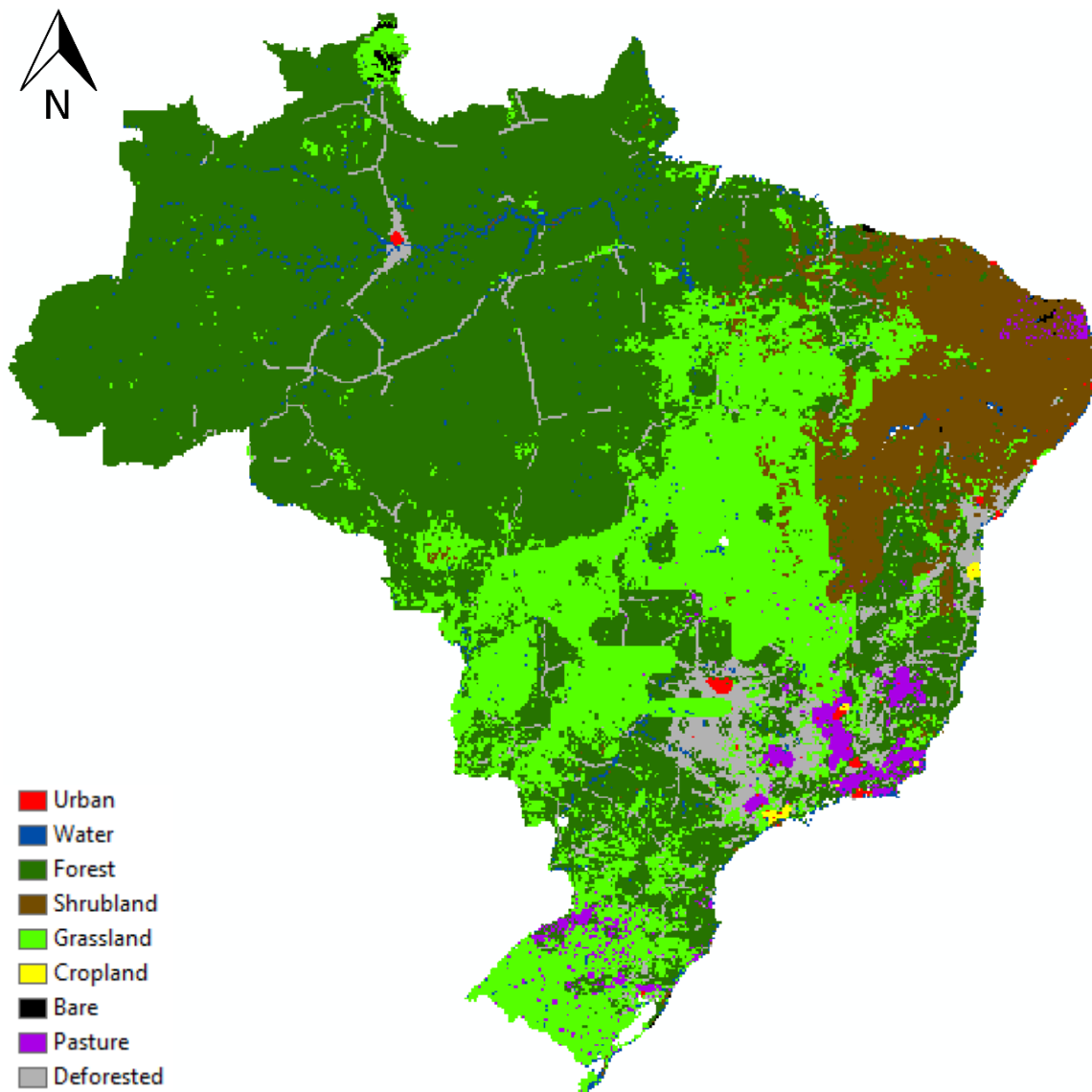
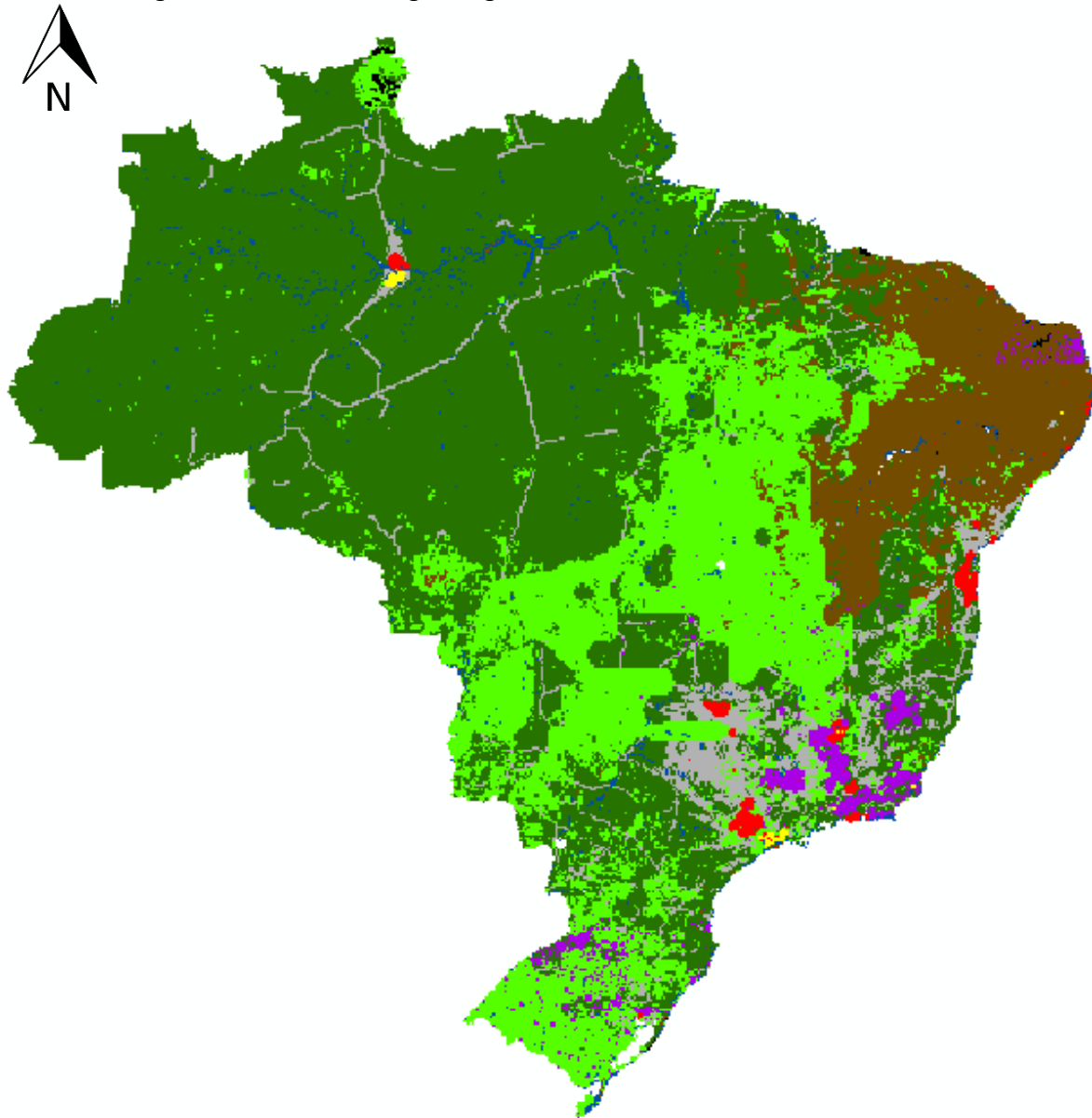


Figure 4: Landuse map of Brazil in 2017 generated by PLUC with "Baseline" suitability factors

### 3.2.2 Urban

In this run, the demand for urban area is increased greatly. The same trends as in the baseline scenario can be observed, but with an increase in city growth. Still, no new cities are being formed. Cropland, pasture, and deforestation trends stay the same. The area of North-west of Brazil has developed greatly, and cropland has appeared. This is due to the lack of space for cropland in the west. The area in the north-west has a high maximum yield and is relatively

densely covered with roads compared to surrounding areas. The presence of the Amazon River is also an important factor for cropland presence.



*Figure 5: Landuse map of Brazil in 2017 generated by PLUC with "urban" suitability factors*

### 3.2.3 Cropland

In this run, the demand for cropland is increased greatly. Most of the previous trends are present, while cropland expansion is greater. Most cropland expansion appears around the north-west. As observed in the baseline run, this was a favourable area to deforest due to high yield, proximity to rivers and the presence of roads. For the model, deforested areas are favourable to convert to other landuse types such as cropland. This explains the presence of cropland in the north-west. While there is some cropland expansion in the other regions of Brazil, this is limited to the already existing areas. Except for the area in the north-west, no additional cropland patches are formed.

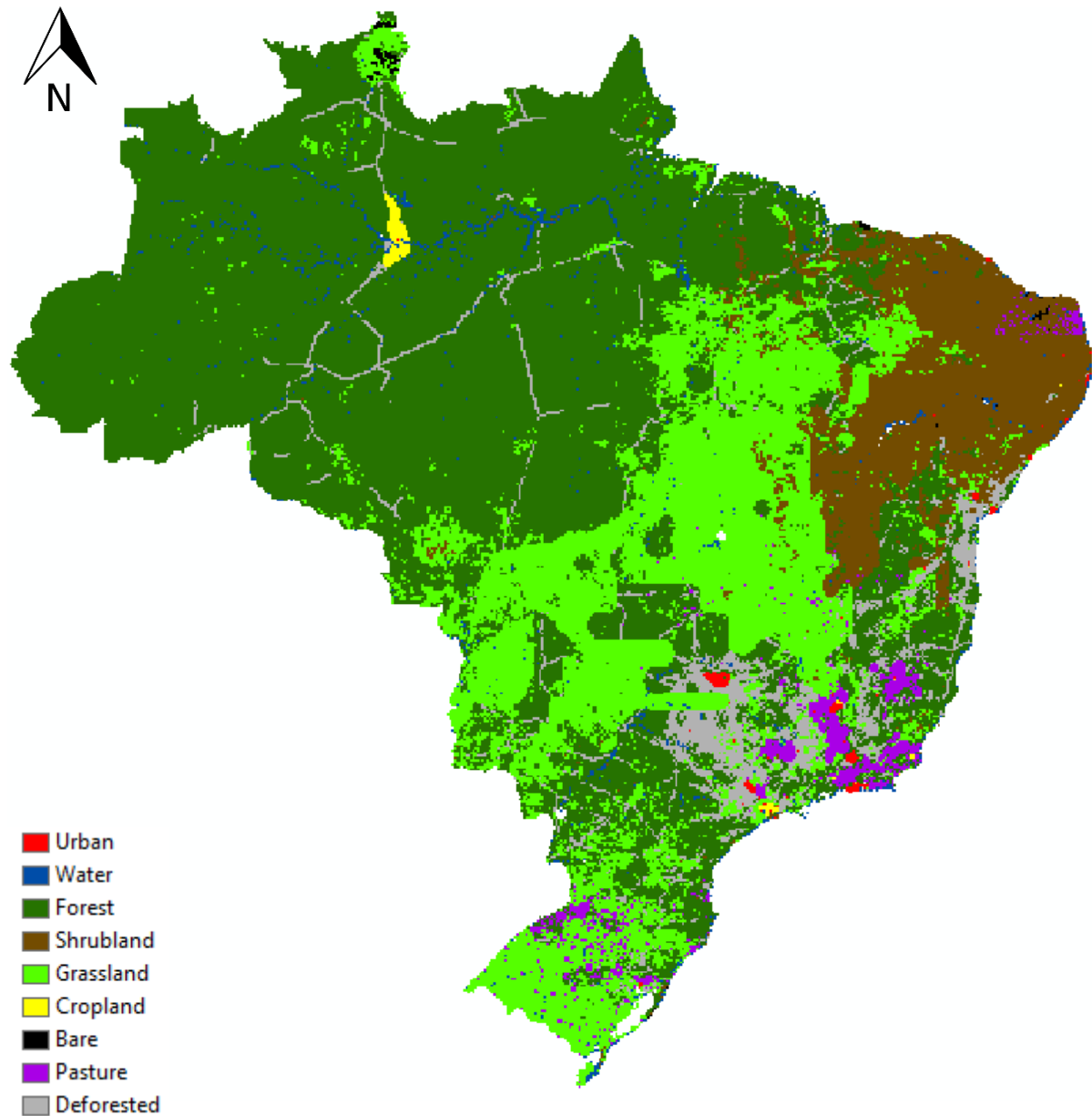


Figure 6: Landuse map of Brazil in 2017 generated by PLUC with "Cropland" suitability factors

### 3.2.4 Forest

In this run, the demand for forest is reduced greatly. While a low demand for cropland means less cropland cover, a low demand for forest results in less deforestation and more forest cover. Compared to the baseline, the deforestation in this run is less, and existing deforestation is only around roads and cities. Croplands, pastures, and cities also develop differently. Instead of growing out as one round patch, these landuse types develop much more sporadically. Due to the lack of deforestation, only areas around roads are cut down to make way for pastures, croplands, and cities. The priority of city development is different. Cities with a high forest density around them show less development compared to the baseline scenario. Cities surrounded with other landuse types such as grassland show more development due to the lack of deforestation.



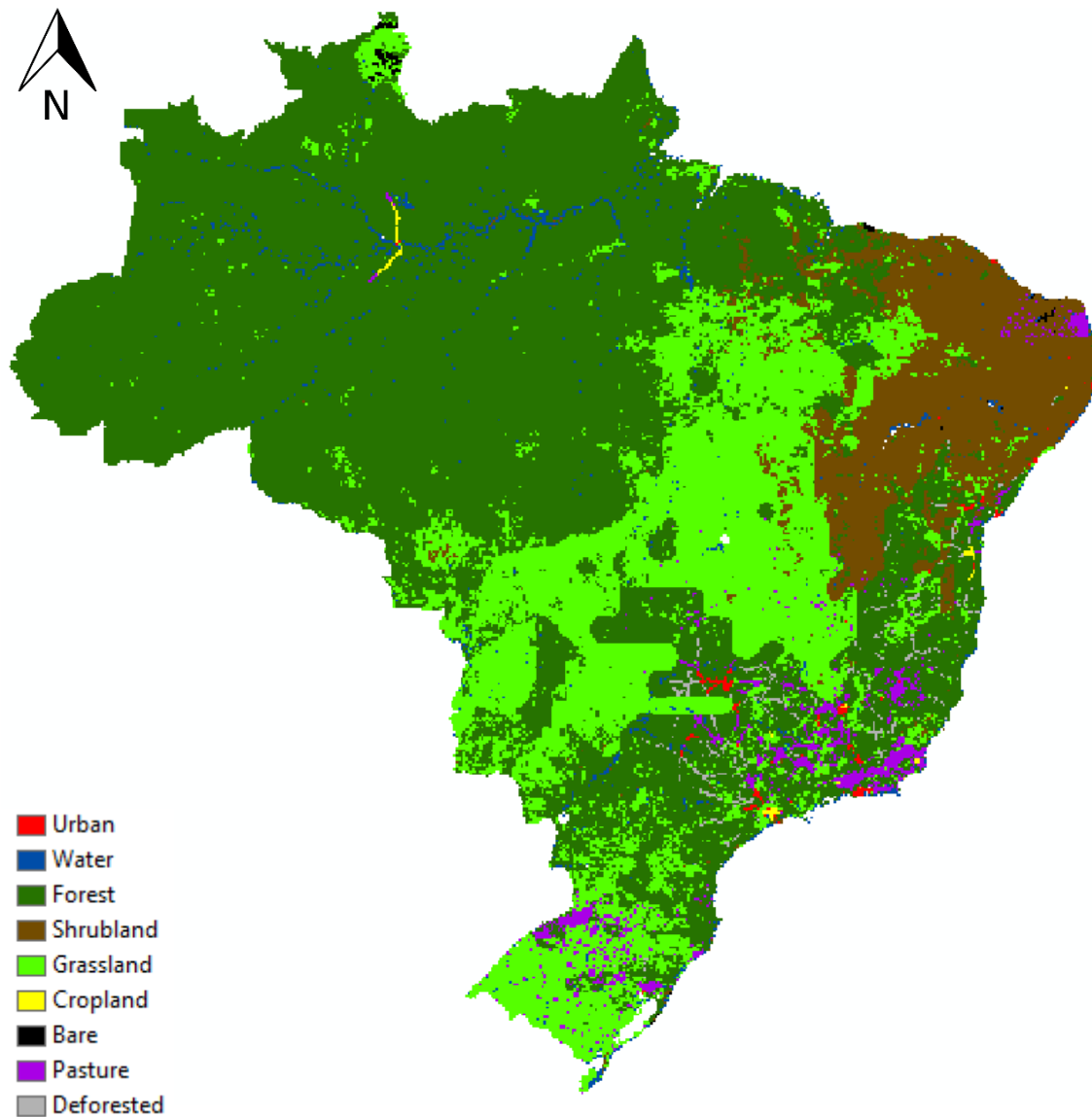


Figure 7: Landuse map of Brazil in 2017 generated by PLUC with "forest" suitability factors

### 3.2.5 Pasture

In this run, the demand for pastures is greatly increased. Compared to the baseline run, the pasture area is increased considerably. This is mostly present along the coastline, and in the north-west. Next to the increase in pastures, the development of cities is also different. Different cities expand than in the baseline run. Some cities stay small, while others expand massively. Some cities even expand greater than in the urban run. Due to the massive expanse of the pasture class, less space is allocated to the other classes and cities that would otherwise not prioritise will now develop. Deforestation around the roads in the Amazon rainforest is greater compared to the baseline run, and cropland areas are developed in other places. The north-west is converted into a massive pasture area due to high yield and road availability.



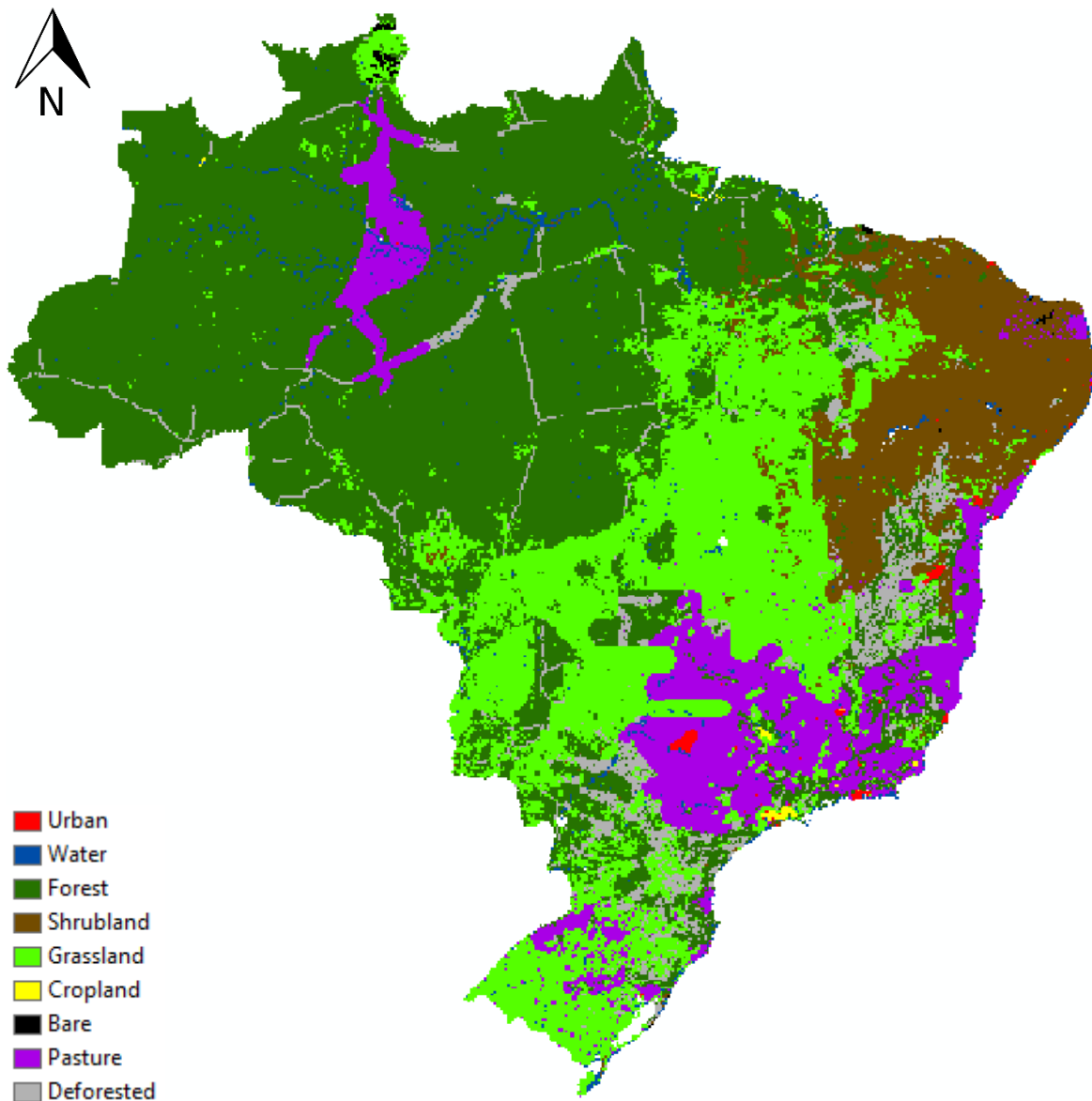
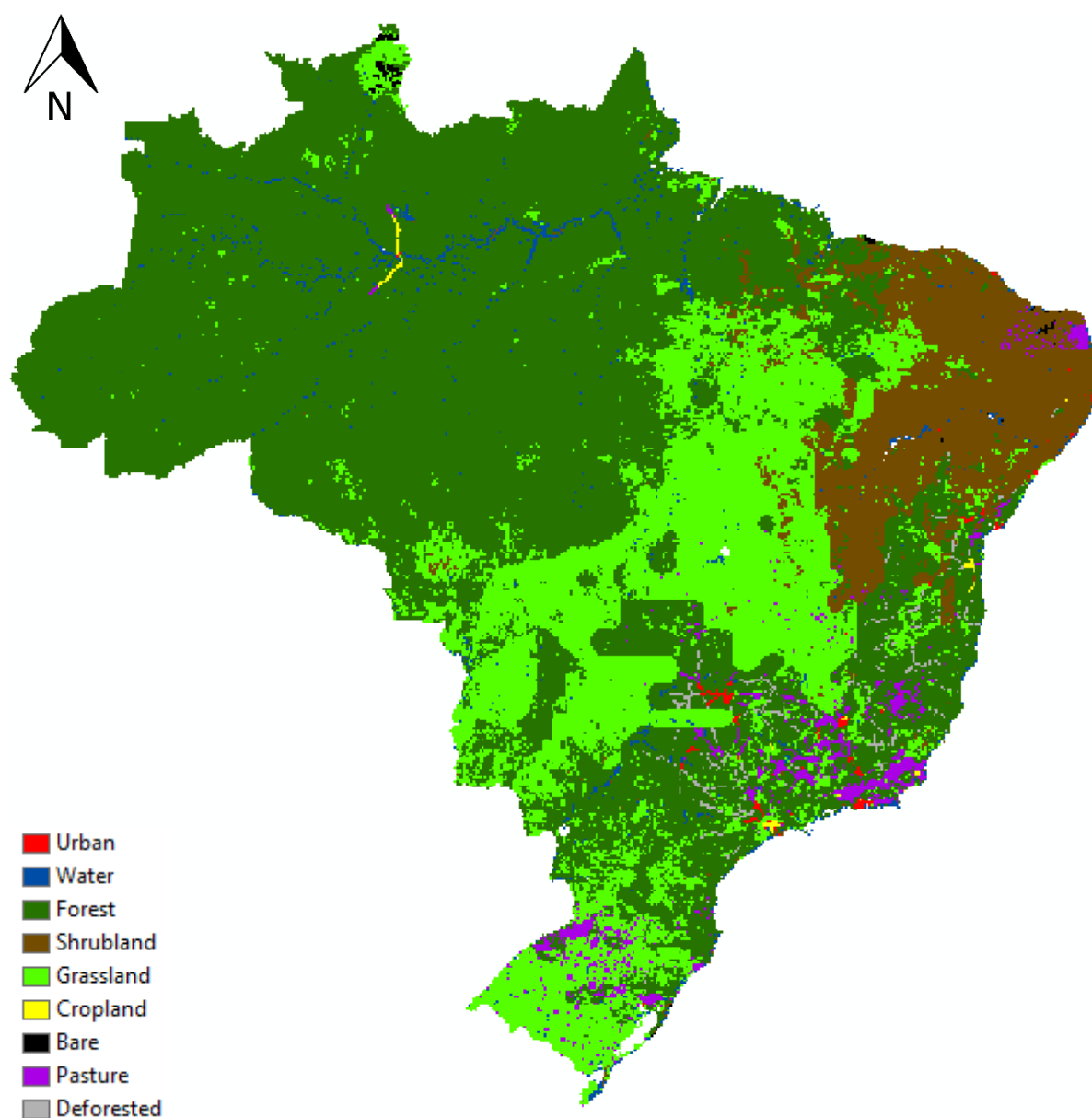


Figure 8: Landuse map of Brazil in 2017 generated by PLUC with "pasture" suitability factors

### 3.3 Recreating landuse2017 map

None of these previous 4 maps attempt to reproduce the landuse for 2017 present insights on the mechanics of the model. *Figures 9-11* represent attempts to recreate the 2017 landuse map. *Figures 9 and 10* provided insights on what suitability factors should changes for the model to provide a map that more closely resembles the landuse of 2017. *Figure 11* presents the best attempt to recreate the 2017 landuse map. While this run is not perfect, general trends can be observed that are similar to the 2017 landuse map. Pasture expansion is greater along the eastern coast, with the area around Rio de Janeiro being the most prevalent. Cities expand comparably, with cities in the east/south-east expanding the most. Next to some similarities with the 2017 situation, there are major differences that should be analysed. Cropland expands differently in *figure 11* compared to the 2017 situation. While most cropland expansion in 2017 is grouped along southern rivers, the model expands cropland around existing patches of cropland along the coast, and deep in the Amazon. City expansion initially looks promising, the model fails to create new cities in previously uninhabited areas. Cities such as Brasilia are present in the 2017 landuse map, but no successful attempt was made that modelled this.



*Figure 9: Landuse map of Brazil in 2017 generated by PLUC with "attempt 1" suitability factors as an attempt to recreate the landuse 2017 map in figure 3.*

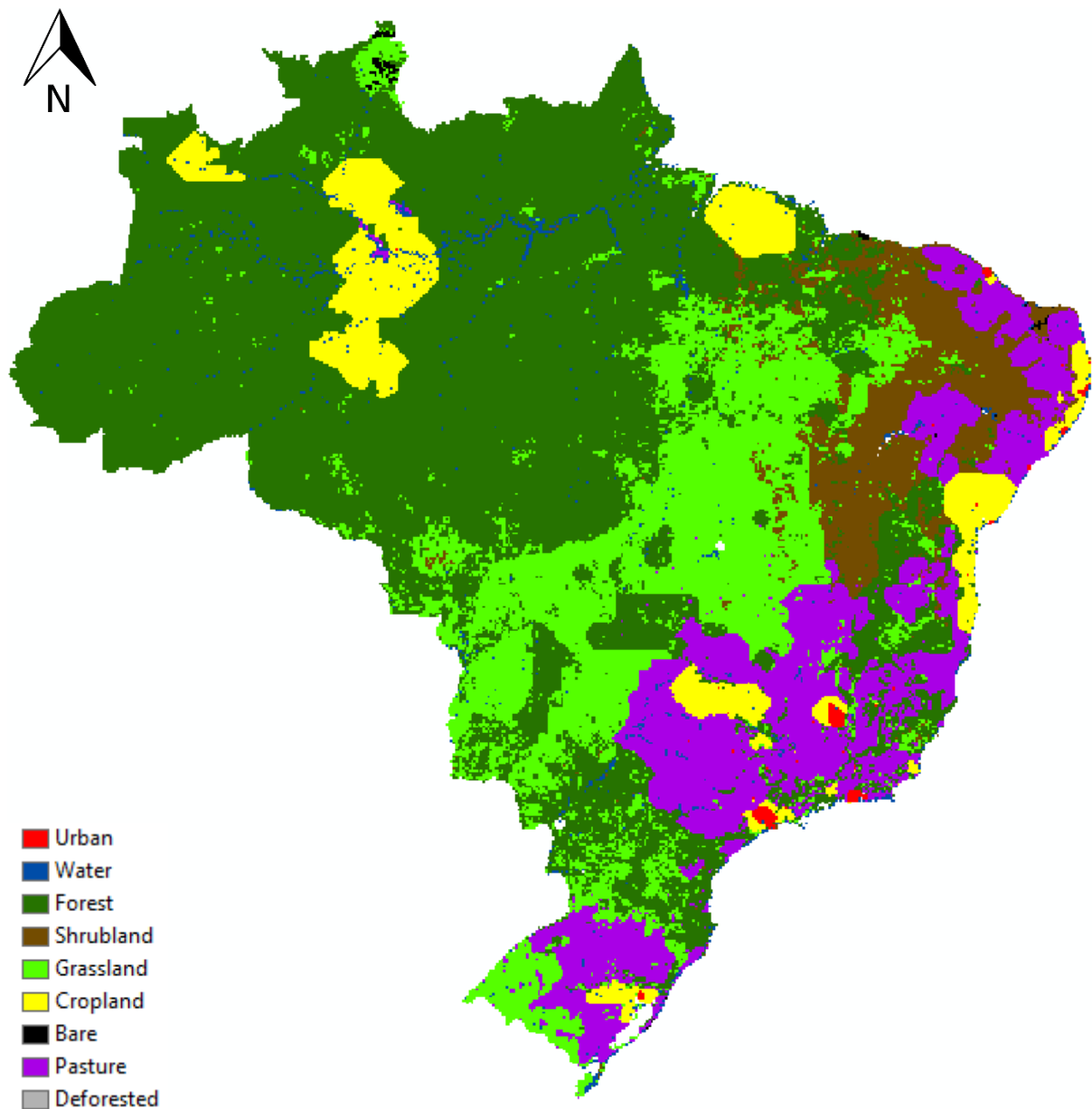


Figure 10: Landuse map of Brazil in 2017 generated by PLUC with "attempt 2" suitability factors as an attempt to recreate the landuse 2017 map in figure 3.

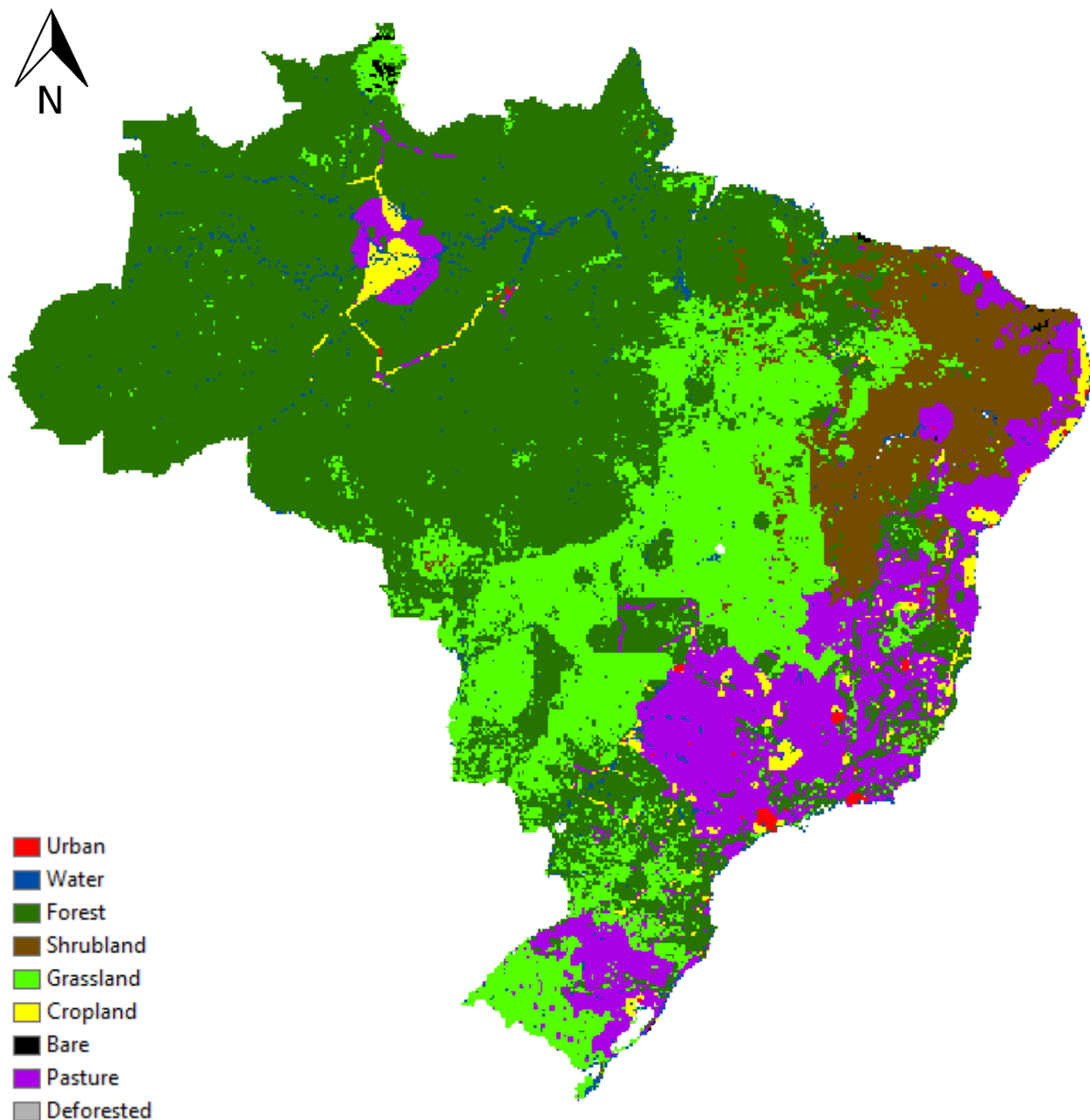
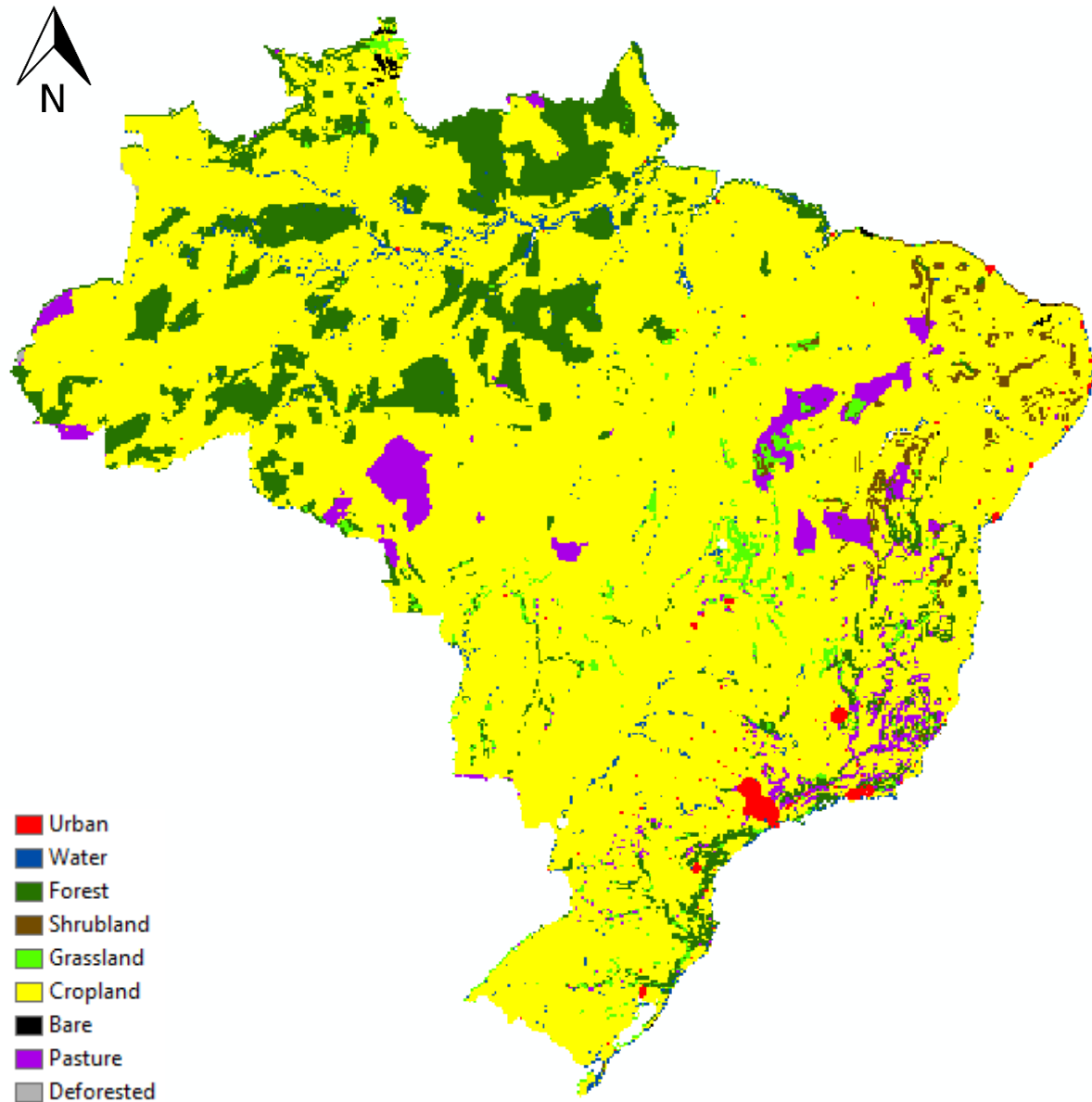


Figure 11: Landuse map of Brazil in 2017 generated by PLUC with "attempt 3" suitability factors as an attempt to recreate the landuse 2017 map in figure 3.

### 3.4 Future predictions

To predict future trends, the best suitability factors were used in combination with the 2017 landuse map. These suitability factors can be found in appendix 8.2.8. These are the same suitability factors used for *figure 11*. This method assumes that historic trends will continue in the future. *Figure 12* presents a landuse map of 2050. This map shows immense cropland expansion. After 33 years, the whole country is covered in cropland. This is due to the high cropland demand, that exponentially increases. After 33 years, almost all land in Brazil is expected to be used for cropland, pastures, and cities. Forests have disappeared, in all regions except for the protected areas, and all grassland and shrubland has disappeared. *Figure 13* extends this to 2100 and presents a cropland covered Brazil, with large cities around the country. Pastureland has been removed in favour of croplands. This is due to the increase in yield per year. If timestep 0 is in 2017, then the yield per raster cell is relatively low. A large demand increase for cropland will then have more effect on the cropland conversion in the next year. If timestep 0 is in 1900, then in the first 117 years, the yield will have increased significantly, and less cropland needs to be added to provide for the demand.

Another method to predict future trends is to apply the best suitability factors on the landuse map of 1900, and extend the model duration to cover until 2100. *Figure 14* present a landuse map of 2100 with the aforementioned methodology. Cropland expansion is not as extreme as in *figure 12-13*, and the Amazon rainforest is preserved. Pasture expands the most, with the east coast being covered in pastures. Deforestation is also reduced in this run, due to reforestation mechanics after 10 years. If an area is deforested for 10 years, it will grow back into a forest which can then be used to fill the forest demand. Due to the aforementioned factors, *figure 14* will be used for future analysis.



*Figure 12: Landuse map of Brazil in 2050 generated by PLUC by applying suitability factors to the 2017 landuse map*

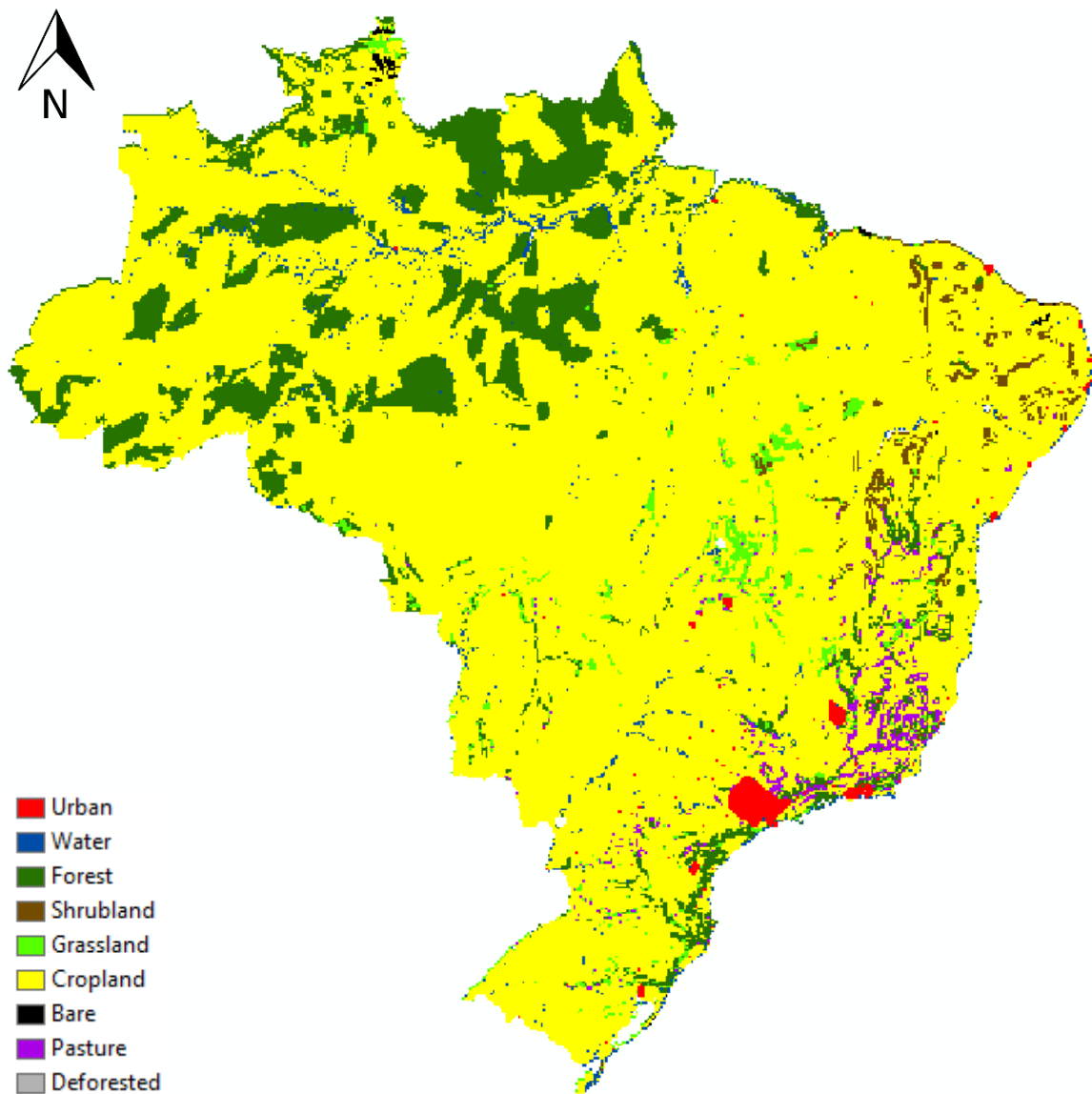
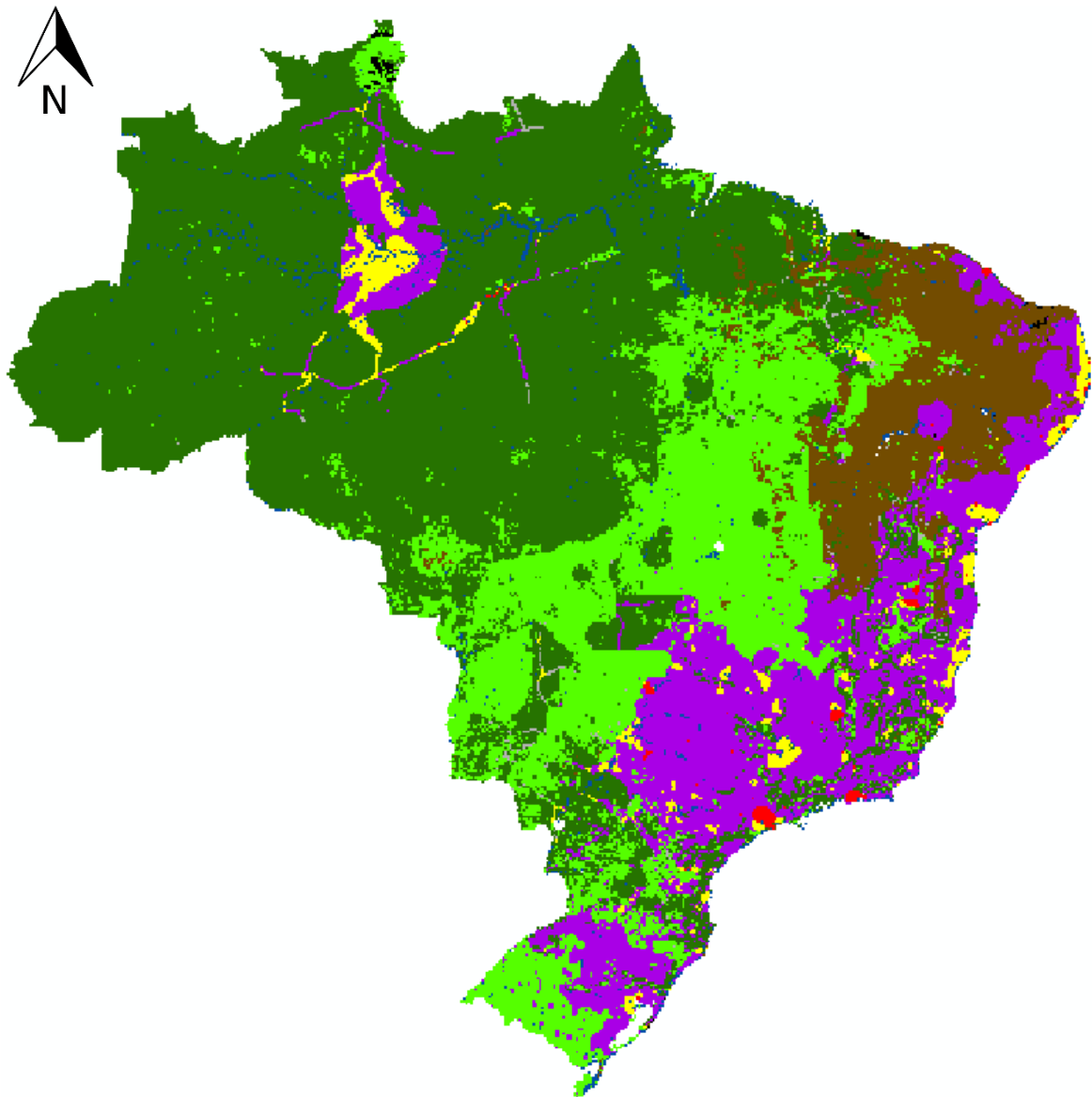


Figure 13: Landuse map of Brazil in 2100 generated by PLUC by applying suitability factors to the 2017 landuse map



*Figure 14: Landuse map of Brazil in 2100 generated by PLUC by applying suitability factors to the 1900 landuse map*

### 3.5 Comparison to the image model

Comparing *figure 14* of the PLUC model to maps of the IMAGE model show some similarities. Relevant maps from the IMAGE model can be found in *figure 15-19*. It should be noted that the IMAGE model does make a distinction between cropland and pastures. The best indicator for these landuse types is agricultural land. The growth and location of agricultural land in the IMAGE model and pastures and croplands in PLUC model are relatively similar, with most of the developments in the east and south-east. While it seems to be of the same magnitude, it is difficult to tell since the PLUC model lacks a unit. The PLUC map has some cropland and pasture development in the middle of the Amazon, while the IMAGE model lacks this development. Furthermore, the IMAGE model shows the development of Biofuel production, a landuse class that is missing in the PLUC model. *Figure 15* shows the development of agriculture in Brazil. In this graph, a division between food crops and grass and fodder crops is made. Food and fodder crops can be seen as a proxy for pasture area, while food crops can be seen as cropland area. The ratio between cropland and pastures in PLUC is comparable to the ratio between fodder crops and food crops in IMAGE.

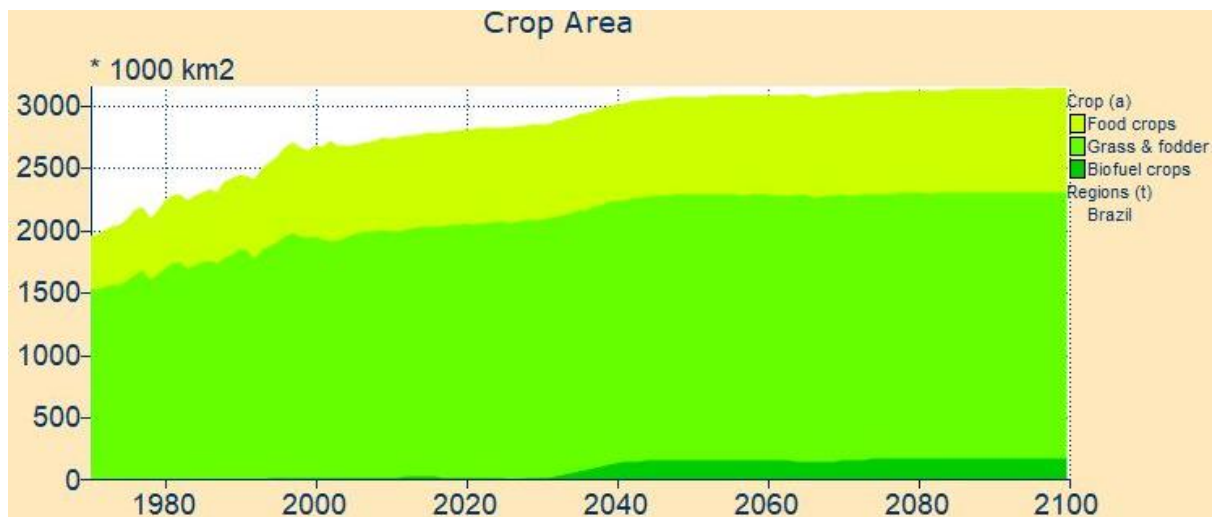


Figure 15: Division of agricultural land in Brazil

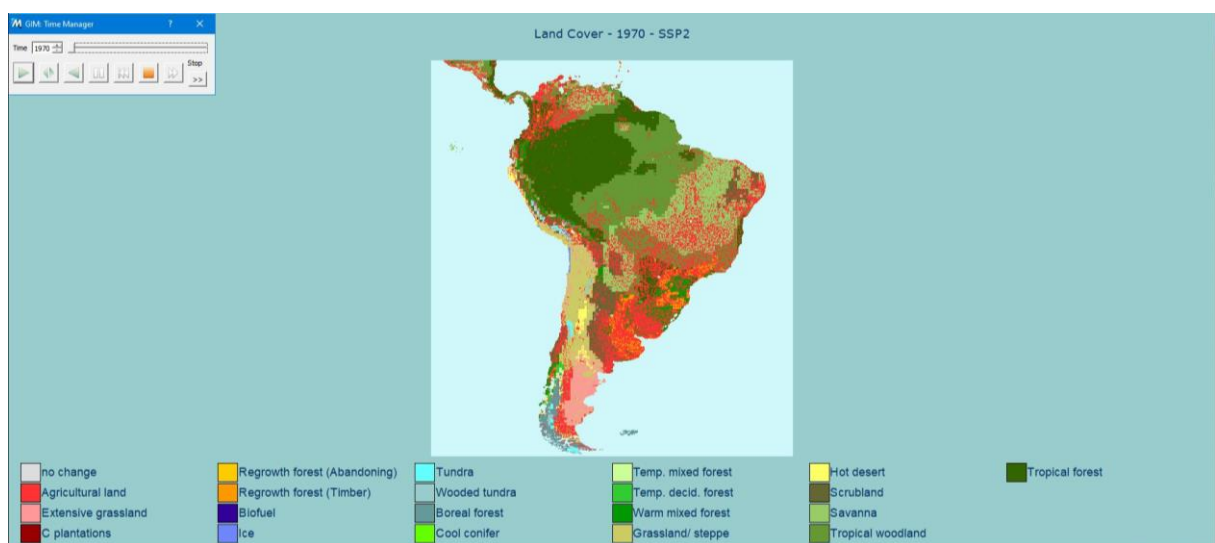


Figure 16: Land cover South America 1970 from IMAGE

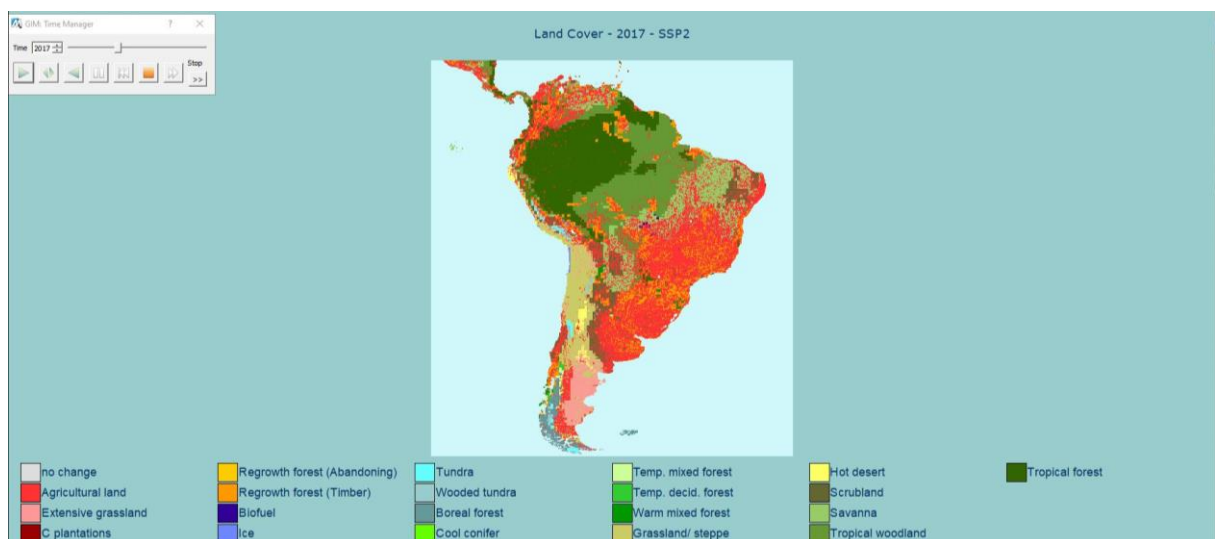


Figure 17: Land cover South America 2017 from IMAGE



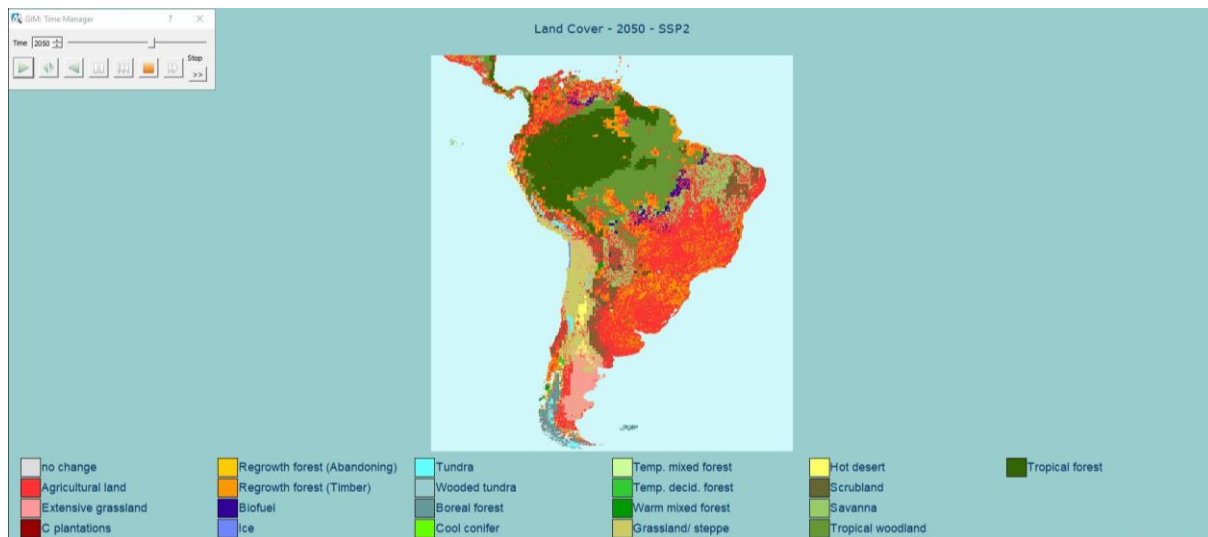


Figure 18: Land cover South America 2050 from IMAGE

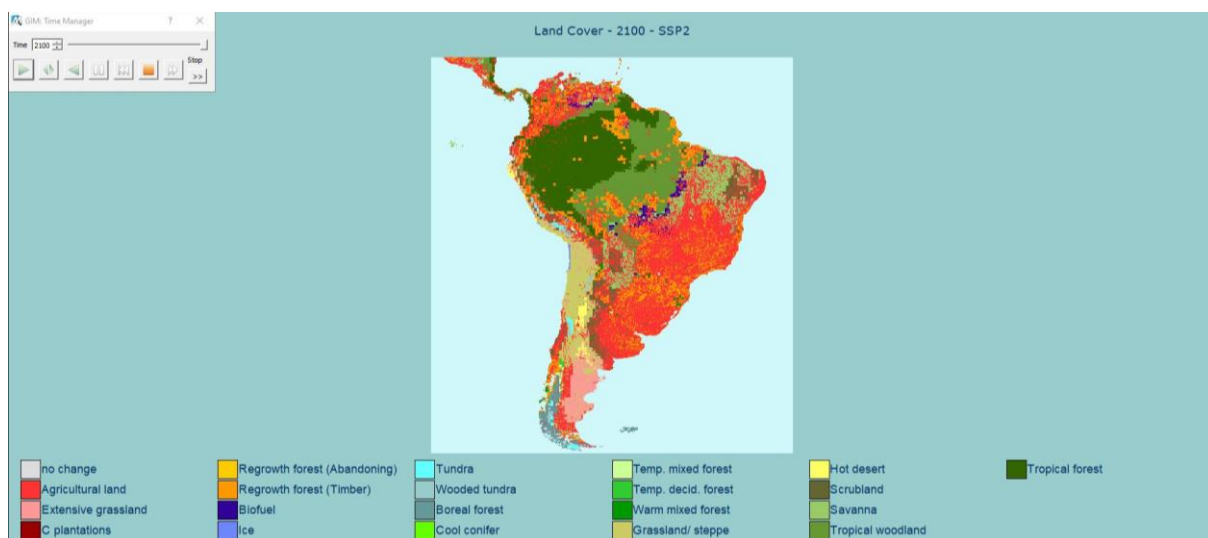


Figure 19: Land cover South America 2100 from IMAGE

### 3.6 Methodology for PLUC modelling

An important result of this thesis is a methodology on how to start with PLUC modelling with any country. In the course Land Change Science (GEO3-2419), students are asked to work with the PLUC model on 5 given countries. Input files for these 5 countries is provided and only a landuse map is required for the model to work. Methodology on how to build these input files is missing. A detailed methodology on how to build these input maps can be found in appendix 1.

## 4. Discussion

### 4.1 Interpretation of the results

In this research the capabilities of the PLUC model were investigated. When comparing the landuse map of 2017 created by the PLUC model to the landuse map of 2017 build with known data, it becomes clear that the PLUC model lacks the ability to accurately portray historic trends. Differences in model output are too great to draw an accurate comparison. While the predictive capacities of the model initially look promising, the lack of temporal data, new

landuse types and accurate cropland and pasture expansion cause the model to be unable to predict future landuse modelling.

## 4.2 Limitations of the model

There are many limitations of the model that prevent it from both describing historic data and make future predictions. The most important limitation is the lack of temporal datasets. Many of the landuse maps the PLUC model uses as an input should be active and change over time. This is not the case for the PLUC model. The roads map is a great example of this. As input data for the 1900 map, a roadmap should be provided. There is no possibility to provide multiple road maps per unit of time, so either a roadmap for 1900 or a roadmap of 2017 should be used as input data. Both will result in unrealistic representations of roads in Brazil.

The model cannot produce new cities in guided locations. Urban expansion is generally found to be along existing city centres. This can be changed in the model by lowering the importance of the “distance to cities” suitability factor, however this results in random city placement. In reality, cities are expected to expand along their centres, and only a select few new cities have been built in the past 100 years. One of those cities is Brasilia, the capital of Brazil. While the model can produce new cities, it does not consider cultural and political reasons of building a city in the centre of Brazil. This model will never be able to replicate the creating of the Brazilian capital since the model does not consider cultural and economic reasons for landuse changes.

NPP is used to show the maximum yield for landuse types of a raster cell. This oversells the ability to turn rainforest into cropland or pastures. Next to NPP, the fertility of the soil is important to determine the maximum yield of croplands or pastures. The model does not consider this, resulting in too much rainforest being turned into cropland or pastures.

The model shows either too much preference to clump landuse types together, or too little preference in clumping them together, resulting in randomness. While proximity to rivers is a suitability factor, the model sees no differences between the Amazon River and the Paraná River. This makes it impossible to expand landuse types in at one river without expanding in at the other.

## 4.3 Limitations of the research and follow up research

Due to time concerns, the total runs had to be limited. Due to this, the full capabilities of the model have not been explored. Further research must be conducted to fully examine the models’ ability to explain historic data and model future landuse change phenomena. It is also not clear whether the used input maps provide a realistic overview of the landuse mechanics. Additional research must be done to build additional input maps and investigate their potential to explain historic and future landuse change trends. During the creation of the landuse maps, factors were chosen to determine the presence of a landuse type. For example, if more than 35% of a raster cell was used for cropland, then that cell would be counted as cropland. These factors were not supported by literature and were chosen predictively. In future research, this must be done differently.

## 4.4 Problems during thesis

The setup for writing this thesis was only 10 weeks. In the past 10 weeks, many problems were faced that stopped progress of writing and researching this paper. Due to the ongoing Covid19 pandemic, most of the work had to be done from home. Online scheduling, less physical contact and need to push myself harder made it more difficult to make progress. Furthermore, there were many technical problems that needed to be solved in order to work with the model. The PLUC model uses a PCraster python command prompt, that can be accessed through the Myworkplace environment. This program is also used in the Land Change Science course (GEO3-2419). In November 2021, this program was updated to a newer python version. This was after the Land Use Change course in the first period, and before the start on this thesis. Due to this update, all the permissions for students had been deleted and access to the

commands had to be manually requested via the technical help desk of the UU. This created a delay that was difficult to fix. Furthermore, the PLUC model ended up not being able to run on the newer python version. So, the PCraster python prompt had to be installed on a local device through guides and videos on the internet. Due to a lack of expansive python knowledge, this was all new information and costs a lot of time.

Once a working python prompt was installed on a local device, maps were made to be used as input files. Due to a developers' oversight, the model was unable to use input maps with a different cell size than 1000. All the maps provided had the same cell size of 0.08333, but due to hard coding in the python script, the model was unable to process the maps. After closely examining the model, a solution was found that bypassed this oversight. For this, the created maps had to be remade from the ground up. The model ended up working 1.5 weeks before the deadline of the thesis. Results still had to be gathered, analysis had to be done, and most had to be written down. The direction of the thesis during this time, was very uncertain. If no results could have been gathered, this thesis had been written about the process of attempting to run the PLUC model. Initially, it was expected that examining the PLUC model and analysing the runs would be most time consuming. However, due to external complications, building the model was more difficult than imagined. There was also no prior methodology present for constructing input maps for the PLUC model, so there were many unknown obstacles. Once the model had delivered results, the output maps were unable to be processed by the ArcGIS PRO program. While there are modules available to fix this issue, for this thesis the output data was processed through ArcMap.

The PLUC model was built by Judith Verstegen for any country and edited for education. The work on the PLUC model has since been discontinued and contact with Verstegen has not been possible due to personal issues with the UU. This made it difficult to understand the model without a developer's methodology.

While this process is not reflected in the results or discussing of this thesis, the work done provided new skills that can be used in later scientific research. Problems with the model have been brought to light, issues with the Myworkplace PCraster command prompt have been faced, and python and modelling skills have been acquired.

## 5. Conclusion

The aim for this thesis was to investigate the capabilities of the PLUC model and to determine whether the PLUC model can model historic landuse trends and predict future landuse changes. The main research question was "To what extent is the PLUC model able to describe the future land use of Brazil? From the results it can be concluded that the PLUC model is able to model landuse change to some extent, but it lacks the temporal changes of the input maps, resulting in too many overgeneralisations and differences with predictions of the IMAGE model. This research also explored to what extent the PLUC model can describe the landuse change of Brazil for the past 117 years. The PLUC model is missing temporal changes in the input map, and the model is unable to make cultural and economic distinctions for cropland and pasture expansion. From this it can be concluded that the PLUC model is unable to describe the historic landuse changes of Brazil over the past 117 years.

## 6. Acknowledgements

I would like to thank Kees Klein Goldewijk greatly for his contributions and support during the thesis. I would have never been able to make the model run if he was not as closely involved as he was now. I would also like to thank Arthur Beusen for providing insights into the python coding. He helped me understand the technicalities of the python model and brought to light developers' oversights that I would not have been able to do. I would also like to thank Sophie Tubbergen and Antoine Virchaux for giving feedback on early versions of the thesis. Finally, I would like to thank Yannick Bouten for helping with GIS related issues and final corrections on the thesis.

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## 8. Appendix

### 8.1 Building the correct input maps for the PLUC model for Brazil

#### 8.1.1 building the 1900 LU map of Brazil

- Download data:
  - o Biome\_cr\_final (artikel: collin prentice)
  - o Cropland1900AD (HYDE)
  - o Pasture1900AD (HYDE)
  - o Uopp\_1900AD (HYDE)
  - o Brazil boundary 2016 (ESRI)
  - o World surface water (ESRI)
- Make sure the coordinate system is set to a new geographic coordinate system
- Clip all 4 rasters to the country border shapefile
  - o Open clip raster tool
  - o Input: one of the 4 rasters
  - o Output extent: country border
  - o Make sure to check “use input features for clipping geometry”
  - o No data value: -9999
- Reclass the biome map
  - o Open the reclassify tool
  - o Input raster: Bra\_biome
  - o Reclass field: VALUE
  - o Press unique to get all the unique values
  - o Reclass based on the table below
  - o (don't mind that some classes are missing, the model needs numbers for the classes)

Number	LU type	New class number
1	tropical rainforest	3 (Forest)
2	tropical woodland (Brazil, India)	3 (Forest)
3	warm mixed forest	3 (Forest)
4	Temp mixed forest	3 (forest)
5	temperate deciduous	3 (forest)
6	boreal forest, Canada, Noord Europa	3 (forest)
7	temperate coniferous, Noord europa	3 (forest)
8	cool conifer	3 (Forest)
9	open grass/savanna	5 (grassland)
10	cool grassland steppe	5 (grassland)
11	closed scrubland	4 (Shrubland)
12	open scrubland	4 (Shrubland)
13	tundra	8 (Bare)
14	hot desert	8 (Bare)

- Note that class 4-7 are not present for Brazil, and classes 1, 2, 6 and 7 will be added now
- Add the urban, pasture, cropland, and water classes
  - o Open the raster calculator
  - o Type the expression:
    - For the urban class:
      - Con(("Bra\_urban" > 5), 1, "bra\_biome\_recl")
      - Output raster: Bra\_LU\_urb
    - For the pasture class:



- Con((( "Bra\_pasture" > 10) & ( "Bra\_pasture" > "Bra\_urban") & ( "Bra\_pasture" > "Bra\_cropland")), 9, "Bra\_LU\_urb" )
  - Output raster: Bra\_urb\_pas
- For the cropland class:
  - Con((( "Bra\_cropland" > 10) & ( "Bra\_cropland" > "Bra\_pasture") & ( "Bra\_cropland" > "Bra\_urban")), 6, "Bra\_urb\_pas")
  - Output raster: Bra\_urb\_pas\_crop
- For the water class:
  - Con(( "Bra\_water" == 1), 2, "Bra\_urb\_pas\_crop")
  - Output raster: Bra\_LU
- The raster should now have 8 classes (1-9 with class 7 missing, this is wetlands, which brazil doesn't have any off)
- Convert the map to an .asc file
  - Open the raster to ascii tool
  - Input raster: Bra\_LU
  - Output: landuse.asc
  - If necessary (dutch pc), open the text file and change all comma's to fullstops

### 8.1.2 building the 2017 LU map of Brazil

- Download data:
  - Biome\_cr\_final (artikel: collin prentice)
  - Cropland2017AD (HYDE)
  - Pasture2017AD (HYDE)
  - Uopp\_2017AD (HYDE)
  - Brazil boundary 2016 (ESRI)
  - World surface water (ESRI)
- Make sure the coordinate system is set to a new geographic coordinate system
- Clip all 4 rasters to the country border shapefile
  - Open clip raster tool
  - Input: one of the 4 rasters
  - Output extent: country border
  - Make sure to check "use input features for clipping geometry"
  - No data value: -9999
- Reclass the biome map
  - Open the reclassify tool
  - Input raster: Bra\_biome
  - Reclass field: VALUE
  - Press unique to get all the unique values
  - Reclass based on the table below
  - (don't mind that some classes are missing, the model needs numbers for the classes)



Number	LU type	New class number
1	tropical rainforest	3 (Forest)
2	tropical woodland (Brazil, India)	3 (Forest)
3	warm mixed forest	3 (Forest)
4	Temp mixed forest	3 (forest)
5	temperate deciduous	3 (forest)
6	boreal forest, Canada, Noord Europa	3 (forest)
7	temperate coniferous, Noord europa	3 (forest)
8	cool conifer	3 (Forest)
9	open grass/savanna	5 (grassland)
10	cool grassland steppe	5 (grassland)
11	closed scrubland	4 (Shrubland)
12	open scrubland	4 (Shrubland)
13	tundra	8 (Bare)
14	hot desert	8 (Bare)

- Note that class 4-7 are not present for Brazil, and classes 1, 2, 6 and 7 will be added now
- Add the urban, pasture, cropland, and water classes
  - o Open the raster calculator
  - o Type the expression:
    - For the urban class:
      - Con(("Bra\_urban" > 20), 1, "bra\_biome\_recl")
      - Output raster: Bra\_LU\_urb
    - For the pasture class:
      - Con((((("Bra\_pasture" > 35) & ("Bra\_pasture" > "Bra\_urban") & ("Bra\_pasture" > "Bra\_cropland")), 9, "Bra\_LU\_urb" )
      - Output raster: Bra\_urb\_pas
    - For the cropland class:
      - Con((((("Bra\_cropland" > 35) & ("Bra\_cropland" > "Bra\_pasture") & ("Bra\_cropland" > "Bra\_urban")), 6, "Bra\_urb\_pas")
      - Output raster: Bra\_urb\_pas\_crop
    - For the water class:
      - Con(( "Bra\_water" == 1), 2, "Bra\_urb\_pas\_crop")
      - Output raster: Bra\_LU
- The raster should now have 8 classes (1-9 with class 7 missing, this is wetlands, which brazil doesn't have any off)
- Convert the map to an .asc file
  - o Open the raster to ascii tool
  - o Input raster: Bra\_LU
  - o Output: landuse2017.asc
  - o If necessary (dutch pc), open the text file and change all comma's to fullstops

### 8.1.3 building the population map of Brazil

- Collect the correct data
  - o Brazil boundary 2016 (ESRI)
  - o urbc\_1900AD.asc (HYDE)
- Import the raster file and the counter border file to a map and make sure the coordinate system is unknown
- Clip the raster file to the extent of the boundary shapefile

- Open clip raster tool
- Input raster: urbc\_1900.asc
- Output extent: country boundary shapefile
- Make sure to check “use input features for clipping geometry”
- No data value: -9999
- Turn the raster into an asc file
  - Open raster to ascii
  - Input: created clipped raster file
  - Output name: pop\_density.asc
  - If necessary (dutch pc), open the text file and change all comma’s to fullstops

#### 8.1.4 building the Protected areas map of Brazil

- Download data:
  - Protarea\_cr.asc (Raster for protected areas)
  - Brazil boundary 2016 (ESRI)
- Import protarea and press yes for “build pyramids”
- Use the clip raster tool to clip out Brazil
  - Input raster: protarea\_cr.asc
  - Output extent: BRA\_country
  - Use input features for clipping geometry: yes
  - Output raster: protarea\_BRA
- Assume that > 50% protected area in a rasterpoint counts as “protected area” for the model
- open Reclassify tool
  - input raster: protarea\_BRA
  - reclass field: VALUE
  - open classify and enter number of classes: 2
  - change the numbers to:
    - 0-50 = 0
    - 50-100= 1
  - Output raster: protarea\_BRA\_TF
- Export the raster to an ASCII file:
  - Open raster to ascii
  - Input raster: protarea\_BRA\_TF
  - Output raster: protected\_areas.asc
  - If necessary (dutch pc), open the text file and change all comma’s to fullstops

#### 8.1.5 building the Suitability maps of Brazil

- Download data:
  - Npp\_cr.asc (FAO)
  - Brazil boundary 2016 (ESRI)
- Import Npp\_cr.asc and press yes for “build pyramids”
- Use the clip raster tool to clip out Brazil
  - Input raster: Npp\_cr.asc
  - Output extent: BRA\_country
  - Use input features for clipping geometry: yes
  - Output raster: Npp\_BRA
- Export the raster to an ASCII file:
  - Open raster to ascii
  - Input raster: Npp\_BRA
  - Output raster: Npp\_BRA.asc
  - If necessary (dutch pc), open the text file and change all comma’s to fullstops

### 8.1.6 building the road map of Brazil

- Download data:
  - o GRIP4\_Region2\_vector\_fgdb
  - o Brazil boundary 2016 (ESRI)
- Import the roads shapefile to a map and repair the map using the GRIP4\_region2 file (in the zip file)
- Clip the shapefile to the BRA\_country file using the clip tool
  - o Input features: GRIP4\_RoadType
  - o Clip features: BRA\_country
  - o Output feature class: Brazil\_roads
- Convert to raster with feature to raster tool
  - o Input features: Brazil\_roads
  - o Field: RoadType
  - o Output raster: Brazil\_roads
  - o Output cell size: 0,083333
- Export the created raster
  - o Output raster dataset: Bra\_roads\_exp
  - o Clipping geometry: Bra\_country
  - o Maintain clipping extent
  - o Rest leave on default
- Clip the created raster using clip raster
  - o Input raster: Bra\_roads\_exp
  - o Output extent: BRA\_country
  - o Maintain clipping extent
  - o Output raster dataset: Brazil\_roadsclick
  - o No data value: -9999
- Convert the raster to an asc file using Raster to ASCII
  - o Input raster: brazil\_roadsclick
  - o Output ASCII raster file: Roads.asc
  - o If necessary (dutch pc), open the text file and change all comma's to fullstops

### 8.1.7 building the pasture map of Brazil

- Collect the correct data
  - o Brazil boundary 2016 (ESRI)
  - o pasture\_1900AD.asc (HYDE)
- Import the raster file and the counter border file to a map and make sure the coordinate system is unknown
- Clip the raster file to the extent of the boundary shapefile
  - o Open clip raster tool
  - o Input raster: pasture\_1900.asc
  - o Output extent: country boundary shapefile
  - o Make sure to check "use input features for clipping geometry"
  - o No data value: -9999
- Turn the raster into an asc file
  - o Open raster to ascii
  - o Input: created clipped raster file
  - o Output name: pasture\_area.asc
  - o If necessary (dutch pc), open the text file and change all comma's to fullstops

### 8.1.8 building the nullmask map of Brazil

- Collect the correct data
  - o Brazil boundary 2016 (ESRI)
- Import the counter border file to a map and make sure the coordinate system is unknown

- Convert the boundary file to a raster using feature to raster
  - o Input features: BRA\_country
  - o Field: OBJECTID
  - o Output raster: BRA\_raster
  - o Output cell size: 0,083333
- Turn the raster into an asc file
  - o Open raster to ascii
  - o Input: created clipped raster file
  - o Output name: nullmask.map
  - o If necessary (dutch pc), open the text file and change all comma's to fullstops

### 8.1.9 building the DEM map of Brazil

- Collect the correct data
  - o Brazil boundary 2016 (ESRI)
  - o World elevation GMTED (ESRI)
- Import the raster file and the counter border file to a map and make sure the coordinate system is unknown
- Clip the raster file to the extent of the boundary shapefile
  - o Open clip raster tool
  - o Input raster: World Elevation GMTED
  - o Output extent: country boundary shapefile
  - o Make sure to check "use input features for clipping geometry"
  - o No data value: -9999
- Rescale the cell size to 0,083333 to match the other maps
  - o Open rescale function
  - o Input: created clipped raster file
  - o Output: Bra\_DEM\_rescale
  - o Check if the extent and raster cell size of the created raster is the same as the other maps
  - o If not: export the World Elevation GMTED file and fit it to one of the already created raster maps and manually set cellsize to 0.083333
- Turn the created raster into an asc file
  - o Open raster to ascii
  - o Input: created clipped raster file
  - o Output name: DEM.asc
  - o If necessary (dutch pc), open the text file and change all comma's to fullstops

### turning the created .asc files into .map files

- Open PCraster 3.8 via my workplace if possible, else open PCRaster on a local device with python version 3.8
- Built 3 clonemaps (Nominal, ordinal, scalar) for converting the asc files into .map files.
  - o In the command prompt, type the following command: "*mapattr name\_of\_clonemap*" with "name of clonemap" being nominal\_clone, ordinal\_clone or scalar\_clone.

- This will open the following menu :

```
creation of map: nominal_clone

number of rows      : *NOT SET*
number of columns   : *NOT SET*
data type           : nominal
cell representation  : small integer
projection           : y increases from bottom to top
x upperleft corner  : 0.0
y upperleft corner  : 0.0
cell length         : 1.0
angle (degrees)     : 0.0
file id             : 0
```

- This should be filled in with the header of the asc files
- Open an .asc map with Notepad++
- The file should resemble the following:

```
ncols      542
nrows      469
xllcorner  -74.0000424
yllcorner  -33.7500225
cellsize   0.0833333
NODATA value -9999
```

- These values should be used as input for the clone maps, so filling the menu in should like the following:

```
creation of map: nominal_clone

number of rows      : 469
number of columns   : 542
data type           : nominal
cell representation  : small integer
projection           : y increases from bottom to top
x upperleft corner  : -74.0
y upperleft corner  : -33.75
cell length         : 1000.0
angle (degrees)     : 0.0
file id             : 0
```

- Cell length should always be 1000, even if the cellsize in the asc file is different
- Create 3 of these maps: nominal, ordinal and scalar
- Turn the asc file into a .map file
  - Type the following command: “*asc2map -a Name\_of\_created\_asc\_file.asc Name\_of\_created\_asc\_file.map -clone Correct\_clonemap.map*”
  - Example: “*asc2map -a dem.asc dem.map -clone scalar\_clone*”
  - The correct data label clone map should be used
- This should be done for all the .asc files which results in 9 maps, where 2 maps (suitability\_res03\_crav6190h\_sxhr\_cer.map and suitability\_res03\_crav6190l\_sxlr\_alf.map) are the same but renamed.

## Input file for the landuse model runs

### 8.2.1 Input data for baseline run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	4	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.3
Cropland	3.9	1.1	0.2	0.1	0.1	0.1	0.2	0.2	0	0	0.1
Pasture	1.8	0.8	0.2	0.1	0.1	0.1	0.15	0.15	0.1	0	0.1
Forest	1	xxx	0	0.25	0	0.2	0.05	0.3	0	0.2	0

### 8.2.2 input data for urban run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	15	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.3
Cropland	3.9	1.1	0.2	0.1	0.1	0.1	0.2	0.2	0	0	0.1
Pasture	1.8	0.8	0.2	0.1	0.1	0.1	0.15	0.15	0.1	0	0.1
Forest	1	xxx	0	0.25	0	0.2	0.05	0.3	0	0.2	0

### 8.2.3 input data for cropland run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	4	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.3
Cropland	15	1.1	0.2	0.1	0.1	0.1	0.2	0.2	0	0	0.1
Pasture	1.8	0.8	0.2	0.1	0.1	0.1	0.15	0.15	0.1	0	0.1
Forest	1	xxx	0	0.25	0	0.2	0.05	0.3	0	0.2	0

### 8.2.4 input data for pasture run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	4	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.3
Cropland	3.9	1.1	0.2	0.1	0.1	0.1	0.2	0.2	0	0	0.1
Pasture	15	0.8	0.2	0.1	0.1	0.1	0.15	0.15	0.1	0	0.1
Forest	1	xxx	0	0.25	0	0.2	0.05	0.3	0	0.2	0

### 8.2.5 input data for forest run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	4	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.3
Cropland	3.9	1.1	0.2	0.1	0.1	0.1	0.2	0.2	0	0	0.1
Pasture	1.8	0.8	0.2	0.1	0.1	0.1	0.15	0.15	0.1	0	0.1
Forest	0.1	xxx	0	0.25	0	0.2	0.05	0.3	0	0.2	0

### 8.2.6 input data for attempt 1 run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	5	1.5	0.2	0.1	0.1	0.15	0.1	0.15	0	0.1	0.1
Cropland	200	0.8	0.3	0.1	0.1	0.05	0.1	0.2	0	0.15	0
Pasture	18	0.8	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0	0.1
Forest	0.1	xxx	0	0.1	0	0.2	0.1	0.3	0	0.3	0

### 8.2.7 input data for attempt 2 run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	5	1.5	0.2	0.1	0.1	0.15	0.1	0.15	0	0.1	0.1
Cropland	400	0.8	0.3	0.1	0.1	0.05	0.1	0.2	0	0.15	0
Pasture	18	0.8	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0	0.1
Forest	0.01	xxx	0	0.1	0	0.2	0.1	0.3	0	0.3	0

### 8.2.8 input data for attempt 3 run

	Demand	Yield	Neighb	Dis2road	Dis2water	Dis2city	Pot_yield	Popdens	Cattledens	Edge	Current_LU
Urban	5	1.5	0.2	0.1	0.1	0.15	0.1	0.15	0	0.1	0.1
Cropland	100	0.8	0.1	0.1	0.25	0.1	0.1	0.2	0	0.05	0.1
Pasture	18	0.8	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0	0.1
Forest	0.1	xxx	0	0.1	0	0.2	0.1	0.3	0	0.3	0