DEFORESTATION MODELING AND GREENHOUSE GAS EMISSIONS IN THE REGION UNDER THE INFLUENCE OF THE MANAUS-PORTO VELHO HIGHWAY (BR-319)

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ABSTRACT: MODELING OF DEFORESTATION AND GREENHOUSE-GAS EMISSIONS IN THE AREA OF INFLUENCE OF THE MANAUS-PORTO VELHO (BR-319) HIGHWAY.

A simulation of deforestation and emissions over the 2007-2050 period was performed for the Area of Provisional Administrative Limitation (ALAP) along the BR-319 (Manaus-Porto Velho) Highway route. This 153,995 km^2-km area represents approximately 10% of the state of Amazonas. The federal Ministry of Transportation has announced its intention of reconstructing and paving the Highway BR-319, which has been abandoned since 1988. The Amazonas state government's State Secretariat for the Environment and Sustainable Development (SDS) and the federal government's Ministry of Environment (MMA) have plans for creating a series of protected areas within the ALAP. Our simulation compares scenarios with and without the proposed reserves. The highway reconstruction and paving is assumed to be complete by 2011, and associated side roads are opened at specified dates over the period 2014-2024. The deforestation simulation couples the DINAMICA and Vensim software programs and incorporates a series of innovations to allow the total deforestation to respond to improved road access based on the parameterization of the relation between deforestation and the expansion of an access road network observed in satellite imagery of an area in the northwestern portion of the state of Rondônia, which is adjacent to the ALAP. The modeled expansion of endogenous roads is not limited by the assumption that deforestation processes are purely "demand driven." This assumption has prevented other models of Amazonian deforestation from representing the effect on total deforestation caused by decisions regarding reserves because an externally specified deforestation total based on demand implies 100% "leakage" of any reserve benefits. The same limitation applies to the effect of roads in demand-driven models. Some validation of our overall deforestation results is provided by simulation of deforestation in Santo Antônio do Matupi, which is located adjacent to the ALAP in southern Amazonas.

Forest biomass in the ALAP was estimated based on 306 one-hectare plots from the RADAMBRASIL surveys in 13 identified forest types and incorporates a series of recent improvements in estimation methodology. Emissions estimates include additions for the effect of trace-gas releases from burning and decomposition and deductions for carbon was sequestered by regrowth of vegetation in an equilibrium landscape that replaces the forest. Emissions estimates are restricted to biomass (soil carbon is excluded). In the "business-as-usual" scenario for the ALAP with only the reserves that already existed in 2007, the simulation indicates 5.1 million ha deforested by 2050 (33% of the ALAP), with a consequent release of 0.95 billion tons (gigatons = Gt) of CO_2-equivalent carbon. In the "conservation scenario" with both existing and proposed reserves, deforestation reaches 4 million ha by 2050 (22% of the ALAP), releasing 0.64 Gt of CO_2-equivalent carbon. The effect of the proposed reserves is the reduction of deforestation by 6 million ha and of greenhouse-gas emissions by 0.31 Gt of CO_2-equivalent carbon. As an illustration of the potential scale of the value of this reduction, if carbon were valued at US$10/ton this reduction in emissions would be worth US$3.1 billion. As in any simulation, these results depend on a series of assumptions regarding deforestation behavior, in this case largely influenced by the small-farmer areas in which our model was calibrated. Future improvements to better represent the roles of large actors, both legal and illegal, may well result in more rapid clearing of unprotected areas.

Keywords: Amazonia, Carbon, Conservation Units, Global Warming

1. Introduction

The main Brazilian contribution to global warming is Amazon deforestation (Brazil, MCT, 2004). Modeling this process therefore represents a high priority to provide information for measures to mitigate these emissions, including usng the value of reducing emissions by deforestation and degradation (REDD), which is currently one of the key points in the negotiations under the Climate Convention.this study presents simulations of deforestation and greenhouse-gas emissions in an area of the state of Amazonas, which is expected to undergo major reductions in forest cover in the coming decades, as a result of the construction of planned infrastructure (Figure 1). This is the "Area of Provisional Administrative Limitation" (ALAP), a 153,995 km^2 area along the BR-319 Highway, which bisects the state from north to south, linking Manaus (Amazonas) to Porto Velho (Rondônia). This highway has been abandoned since 1988, when bus service between Manaus and Porto Velho ceased. However, the reconstruction of the road is included in the federal government's current Program for the Acceleration of Growth (PAC).

<Figure 1 here >

Rondônia and Amazonas contrast sharply in terms of deforestation (Figure 2). The forests around Manaus are largely intact and deforestation is proceeding at a relatively slow pace, while the state of Rondônia was almost completely deforested except in indigenous lands and protected areas such as national parks and biological reserves. Rondônia is the main source of migrants moving to other areas in Southwest Amazonia, such as the state of Acre and the southern part of the state of Amazonas. Since 1988 when the BR-319 was abandoned, Rondônia is a source of migration to surrounding areas. This movement has increased continuously, as is evident in the recent expansion of deforestation in the accessible portions southern Amazonas, such as Apuí, Santo Antônio do Matupi, Humaitá, Lábrea and Boca do Acre (see Brazil, INPE, 2007). Therefore it is reasonable to infer, without relying on modeling results, that reconstruction of the highway today would result in much more deforestation than was the case over the 1974-1988 period when the road remained open.

<Figure 2 here >

Planned side roads would connect the main highway to all municipal (county) seats along the Madeira and Purus Rivers, providing substantially larger areas to deforestation than simple expansion from the edges of the BR-319. These side roads are not part of the Program for the Acceleration of Growth but are awaited by these municipalities since 1997 (*A Crítica*, 1997). It is likely that the political pressure for the construction of them would be irresistible after the main highway is open, and this can be adopted as premise is building modeled scenarios. The side roads will enable access to most of Madeira-Purus interfluve, which is the narrowest interfluve between any of the tributaries to the Amazon River and which is home to an unusually large number of endemic species. In addition to opening this interfluve to deforestation, one of the side roads is planned to cross the Purus River in Tapauá and continue to Coari, Juruá and Tefé, thus making accessible the large block of intact forest in the western part of the state of Amazonas (Fearnside and Graça, 2006). This would change the geography of deforestation in the Amazon as a whole, where approximately 80% of the deforestation activity has been restricted to the "arc of deforestation" located on the southern and eastern edges of the forest, while the large expanses of forest in the western Amazon have remained intact due to lack of access by road.

The BR-319 would have two important impacts, as indicated by the history of other infrastructure projects in Amazonia. One would be the expansion of deforestation from the edges of the highway and of associated side roads (Figure 3). The other would be to facilitate migration from one end of the highway to the other, creating a flow of population from Rondônia to Manaus. When it arrives in Manaus, part of this population would remain in the city, part in the surrounding rural area (for example, the Agriculture and Ranching District of the Manaus Free Trade Zone (SUFRAMA), and part would continue along the already-paved BR-174 Highway to new deforestation frontiers in Roraima. In the latter case, this would further increase the already high rates of deforestation throughout the southern portion of the BR 174 (Barbosa *et al*., 2008; Barni et al., 2009). The potential for this migration is significant. It is likely that a substantial pulse would occur in 2013 at the end of the construction of the Santo Antônio and Jirau hydroelectric dams on the Madeira River in Rondônia. These dam-construction projects have a total of 20,000 workers, plus an additional population estimated at 80,000 attracted from all parts of Brazil, which will be released almost simultaneously when the dams are completed. It is unlikely that this population of unemployed workers would remain in Porto Velho, and a paved road with bus service to Manaus would cause migration to central Amazonia to be the most attractive option.

<Figure 3 here >

2. CHALLENGES IN MODELING DEFORESTATION

A. BASE LINE SCENARIO

How deforestation should be modeled depends heavily on the purpose of the resulting estimates. It is intended that the estimates of the current study serve as a way to quantify the environmental implications of different possible development decisions, such as the construction of highways and the creation of protected areas. Scenarios with and without the highways or reserves serve as the basis for comparisons. Differences in the areas of forest lost and differences in impacts such as emissions of greenhouse gases provide quantitative measures of the environmental costs and benefits of different policy options.

Obtaining carbon credit under the Kyoto Protocol becomes possible, assuming that reducing deforestation will be eligible for credits under the Clean Development Mechanism (or its equivalent) in the second commitment period of the Protocol (2013-2017) or under a replacement accord. It is likely that the carbon benefit calculation will be based on the criterion of "additionality," i.e. the calculation of avoided emissions that are beyond what would have been emitted in the absence of a mitigation project under the Kyoto Protocol (Article 12). This involves the comparison of the observed outcome of a given project with a hypothetical baseline scenario that represents what would have happened without the project. There are two possible approaches to constructing the baseline scenario. One is to make a simple extrapolation of past trends, reflecting the historical series of estimates of deforestation in the project area, based on satellite images. Calculations of this type ("historical" baseline), also known as "compensated reductions," have a strong attraction because they cannot be manipulated to exaggerate the benefits of a project. However, only under special circumstances will the method provide a reasonable approximation of what would have been emitted in the absence of the mitigation project. The situation under which the historical baseline would work well is where deforestation has been proceeding quickly for some time and a significant amount of forest remains standing and is available for clearing. If a large area of uncleared forest is not available the rate of deforestation will necessarily diminish even without a mitigation project, therefore meaning that the historical baseline generates only "hot air," or carbon credit without real benefit for the climate.

Another situation in which the historical baseline will not work as planned is where very little deforestation has occurred in the past, but a new development, for example, opening a highway, implies significant deforestation in the future. Here the historical baseline will not generate any carbon credit because it is impossible to reduce the rate of deforestation to a level below zero, and any deforestation rate possible under future conditions would be higher than the negligible historical rate. This is the situation that applies to areas selected for this study: Apuí and the BR-319.

The approach that can be applied to reduce emissions from deforestation in the study area is the simulation of a "*Business as Usual*" (reference) land-use change scenario. This has to represent the process of deforestation that is likely to happen without environmental interventions, such as the creation of protected areas and/or a decision to cancel or postpone the road project in favor of one of the other alternative modes of transport, such as a railroad or a new port in Manaus for freight transport via cabotage to São Paulo (see Fearnside & Graça, 2006). For those who grant credit to be satisfied that no manipulation of the baseline has occurred, the baseline scenario must be sufficiently transparent, documented and "conservative" from the perspective of carbon credit (*i.e.*, without any exaggeration of baseline deforestation).

B. MITIGATION SCENARIOS

Any carbon credit to be granted currently by reducing deforestation will be based on the calculation of areas and forest carbon stocks that are observed or measured in the real world after a period of activity of mitigation, and not based on modeled scenarios. Nevertheless, scenarios that include the effects of mitigation activities can be very useful to government decision makers, climate negotiators and potential funders of mitigation projects. The land-use change in future periods must be simulated, as in the 2007-2050 period considered in the present study, thus incorporating a range of possible decisions regarding infrastructure, protected areas and other possible government actions.

3. PREVIOUS MODELS

A. LAURANCE *ET AL*. (2001)

A simulation of deforestation in the Brazilian Amazon region over the 2000-2020 period was produced by Laurance *et al.* (2001, 2005, Kirby *et al*., 2003). This simulation used the historical rate of expansion of deforestation (and additional forms of disturbance, such as logging) on existing highways, to project what would happen if the infrastructure announced under the 2001-2003 "Advança Brasil" Program from were constructed, including the BR-319. The result showed the route of the BR-319 Highway producing a wide band of deforestation, flanked by successive zones of other disturbances (Figure 4). These transitions were represented in a geographical information system (GIS) where transitions occur in areas of territory known as *buffers*" that delineate areas of land located at different distances from features like paved and unpaved roads.

<Figure 4 here>

The simulation of Laurance *et al.* (2001) was a simple compilation of known relationships, for example, between the proximity of highways and deforestation, to extract lessons for policy. The geographical information system used in the model quantified the various overlapping effects of different projects and estimates derived from deforestation and disturbed areas, as well as allowing a rough estimate of greenhouse-gas emissions. The causal relations behind the expansion of deforestation were not included. The model includes the inhibitory effect of multiple classes of protected areas. Adding effects of protected areas and forms of disturbance other than complete deforestation represented significant advantages when compared to other models developed at the same time (for example, Nepstad *et al.,* 2000, 2001). In reality, the effect of reserves, along with the choice of locations as the source of data for historical deforestation, resulted in more conservative estimates of deforestation in the study by Laurance *et al.*(2001) than in the study by Nepstad *et al*. (2000, 2001) (see Fearnside, 2002).

Despite the limitations of the Laurance *et al.* (2001) model, it had an important feature in not being "demand driven" in its representation of deforestation. This means that it not only represented **where** deforestation would happen, but also how much the total amount of deforestation would be. Demand-driven models (such as Nepstad *et al*, 2000; Soares-Filho *et al*., 2004, 2005, 2006) estimate the total amount of deforestation separately based on assumptions concerning factors such as the gross domestic product (GDP), and then only represent where the deforestation happens. The difference is important if the model is applied to evaluate the consequences of individual decisions, such as building a road or creating a reserve. In the case of a purely demand-driven model, the construction of a road does not increase the total deforestation, and the creation of a reserve does not decrease it, because the total deforestation is fixed beforehand without considering the effect of these policy actions. This causes the model by Laurance *et al*. (2001) have findings on total deforestation, while other models with more complexity in their spatial representation, could only indicate the location and not the amount of deforestation, the rate of deforestation being a mere initial assumption of the scenarios.

B. AGUIAR (2006)

Deforestation in the Brazilian Amazon has been simulated using the CLUE (Conversion of Land Use and its Effects) software, developed by the University of Wageningen, the Netherlands (Aguiar, 2006; Aguiar *et al*, 2007). A simulation that is specific to the area of BR-319 also was performed (Rede GEOMA, 2006; Casa, 2007). CLUE produces a spatial representation of deforestation based on such factors as distance to markets, distance to roads, soil quality and status as a protected area (Veldkamp *et al*, 2001; Kok *et al,* 2001; Verburg *et al*., 2002). Relations between land uses and their determining factors are evaluated from of logistic regressions. The spatial resolution is quite coarse when extensive areas are simulated. For example, Aguiar (2006) used a grid cell size of 25 km × 25 km. The program does not include means of calculating the total deforestation, and this culminates in the presumption that the annual deforestation follows a fixed trajectory, which remains constant at one level, increasing linearly by a fixed amount each year, or increasing exponentially by a fixed percentage annually. This severely limits the purposes for which the simulations can be applied. The effects of different policy decisions can not be represented, such as building roads and creation of reserves, because the total annual deforestation is the same, if roads or reserves are created, this only changes the spatial distribution of deforestation, not its total amount. In the jargon that surrounds the Kyoto Protocol, creating a reservation results in 100% "leakage," i.e., the avoided the deforestation within the area of the reserve would simply be moved to another location. This can be seen in Figure 5, where deforestation that would have occurred in proposed reserves along the BR-319 Highway occurred in Boca do Acre (Amazonas), in Acre and in the area around Manaus.

< Figure 5 here >

C. SOARES-FILHO *ET AL* . (2006)

Britaldo Soares-Filho and collaborators have developed a software package called DINAMICA for simulating the spatial distribution of deforestation (Soares-Filho *et al*., 2002, 2003; Soares-Filho, 2004). DINAMICA can operate the program along with the contribution of a non-spatial simulation running in the Vensim software (Ventana Systems Inc., 2007). Recent improvements in the DINAMICA software allow calculations made by Vensim to be run within the own DINAMICA. Based on economic indicators such as GDP growth, the Vensim program calculates the total deforestation during each year to be simulated. The vector of annual deforestation rates is then passed the DINAMICA program that determines where the allocation of deforestation will happen based on weights of evidence, or the probability that each cell in the grid representing the landscape will be deforested. These weights are derived from relationships calculated from pairs of satellite images that indicate the probability of clearing occurring at different distances from roads, considering the influence of soil quality, the influence of protected areas, distance of markets, distance to existing deforestation and other characteristics.

The Vensim model used by Soares-Filho *et al*. (2006) computes the vector of deforestation rates, i.e. "demand" for deforestation, for the entire simulation period (2001-2050) separately from the DINAMICA model. Subsequently, this array is passed to the DINAMICA model, which determines where this deforestation occurs. There is no annual feedback between the two models that would be needed for spatial characteristics to influence the rate of deforestation in the following year. Therefore, the existence of reserves does not change the total deforestation (*i.e.*, leakage is 100%). Using the template for the effect of reservations involves cutting out the areas of reserves and subtracting the deforestation they contain (*i.e*. a "*cookie cutter*" method), which effectively represents zero leakage (*i.e.*, Soares-Filho & Dietzsch, 2008). What limits how much a farmer deforests, and therefore how much the set of all actors deforests in total, is usually the farmer's capacity (*i.e*., opportunity). If the farmer has more money, more manpower, and less risk of punishment, so he would deforest more. The choice of clearing is not directly linked to market regulation, based on the law of supply and demand, but rather on the availability of capital. This is exemplified in the history of ups and downs in Amazonian deforestation rates, which declined from 1988 to a low point in 1991 (recession in the government of Fernando Collor de Mello) and then rose to a peak in 1995 (following the start of the current economc plan), which reflected the availability of money for investing in deforestation (*i.e.*, the ability of farmers to clear).

The DINAMICA software includes routines to simulate building networks of secondary roads and to initiate new patches of deforestation (instead of the expansion from existing patches). These features make DINAMICA more complex than CLUE, and allows representation of some aspects that are known for deforestation in Brazil. Especially important is the expansion of the network of endogenous roads (Souza Jr. *et al.* , 2005) and the process of establishing new frontiers (Fearnside, 1987).

Simulations with DINAMICA indicate the route of the BR-319 Highway forming a huge corridor of deforestation. Virtually the entire Madeira-Purus interfluve is indicated as deforested by 2050 (Soares-Filho *et al.*, 2006; see Figure 6).

<Figure 6 here >

There has been a continuous evolution of the capabilities of DINAMICA and Vensim and of deforestation simulations using these programs (Soares-Filho *et al.*, 2003, 2004, 2006). These simulations have provided useful series of representations of how deforestation is likely to spread under "*Business as Usual*" scenarios. A parallel series governance scenarios have represented what would happen if regulations such as the 1965 Forestry Code (Brazil, 1965) were respected, combined with a decrease in the total deforestation by an assumed amount (for example, Carvalho *et al.*, 2001, 2002; Soares-Filho *et al.*, 2006). These are based on assumptions regarding the overall quantity of deforestation rather than being derived from calculations based on data about how the behavior of deforestation responds to specific policy measures. The usefulness of such governance scenarios is the focus of the discussion about the need for governance, but the scenarios should not be confused with a "with project" scenario for any given set of governance measures, such as the Sustainable BR-163 Program (see: Alencar *et al.*, 2004, 2005) in the case of Cuiabá-Santarém Highway (see Fearnside, 2007). Unlike the scenarios used in the study by Soares-Filho *et al.* (2006), the scenarios of the present study are restricted to the effects of roads and reserves and do not offer governance scenarios.

D. Econometric and Other Models

Other types of modeling, especially econometric models, have been applied to Amazonian deforestation. Usually these apply to a larger scale, representing, for example, the Amazon region as a whole, without being detailed in spatial terms. The data typically come from census information at the level of municipalities or of the “census units” of the Brazilian Institute of Geography and Statistics (IBGE). Examples include the equations developed by Reis & Margulis (1991) and Reis & Guzmán (1994), to associate the rate of deforestation with data on population, percentage of area in agricultural crops, cattle density per km^2, intensity of logging in $m^3\ km^{-2}$, length of roads per km^2, distance from the state capital, and a *dummy* variable to represent differences between the different political units. In this model, the roads are considered as a significant determinant of deforestation. The cost of transport, which depends directly on the availability and quality of roads, has been shown to be a key determinant of deforestation: a 20% reduction in the cost of transport results in an increase in deforestation in the Amazon by 29-32% (Cattaneo, 2001, p. 230). In an analysis by Chomitz & Thomas (2003) designed to test the effect of rainfall on deforestation rates, it was demonstrated that roads increase deforestation, but the magnitude of the increase depends on the control of other variables, such as the impact of pre-existing deforestation, which has an effect that overlaps with that of the highways. Analyses at the municipal level indicate that roads increase deforestation in places where much of the forest remains intact (as is the case in the ALAP of the BR-319), but in places where the process of deforestation is already well advanced additional road construction reduces deforestation (Andersen *et al*, 2002; Reis & Weinhold, 2004). However, subsequent studies on the same IBGE databases, but using data at the level of census units (*i.e.*, with about 20 times more data), indicate that roads are drivers of deforestation at all stages of the process (Pfaff *et al*, 2007).

4. A MODEL FOR DEFORESTATION ON THE BR-319

A. WITH THE DINAMICA SIMULATION APPROACH

1. Conceptual Model of DINAMICA

DINAMICA is an explicitly spatial simulation model landscape dynamics that is based on a cellular automata algorithm. Models based on cellular automata, such as DINAMICA, can be understood as systems of spatial dynamics in which the state of each cell within a spatial arrangement (grid cells) depends on the prior state of neighboring cells, according to a set of established transition rules. Cellular automata are capable of simulating the spatial patterns of deforestation incorporating a probability map depicting the influence cartographic data integrated in the allocation of deforestation of Soares-Filho *et al*. (2006). DINAMICA includes transition functions based on multi-scale neighborhoods, a concept of phases using a stochastic process simulation in multiple steps, a method of spatial feedback from calculations of dynamic variables, a component that directs the expansion of roads, and weights of evidence to calculate transition probabilities of spatial dynamics. This framework has also been designed to engage other styles in a multilevel architecture consisting of sub-models. A schema illustrating the DINAMICA framework and its functionality can be seen in Figure 7.

<Figure 7 here >

Detailed explanation of the features of the DINAMICA program can be found at http://www.csr.ufmg.br/dinamica.

B. PARAMETERS FOR THE BR-319 ALAP

1. Development of the Model of the BR-319 ALAP

The model was developed in two coupled modules, each running on different software. A non-spatial model runs on Vensim 3.0A1 and a spatial model was developed in DINAMICA EGO (a recent version of the program), with spatial resolution of 500 m. These two models exchange parameters in each iteration of the simulation, as shown in Figure 8.

<Figure 8 here >

The Vensim model calculates rates and passes them to the DINAMICA EGO spatial model. Rates of deforestation, "*clearing"* (cutting of secondary forests) and recovery (regeneration of vegetation) are calculated. For the rate calculations the spatial model provides quantitative values that characterize the scenario, such as the areas of accessible forest and the extension of roads that have not produced deforestation. Figure 9 summarizes the information flows in each cycle.

<Figure 9 here >

The first row of the diagram corresponds to the spatial module for construction of roads. It uses the concepts of attractiveness and friction for its operation. The attractiveness is comprised of numeric maps where the areas suitable for agriculture have the highest values and protected areas and flooded areas have the lowest values, and integral protection areas have values of zero. Maps of friction areas with greater steepness, flooded or environmental protection have the highest values. The module therefore increases the road network and makes a new map for the rest of the model. This road-construction module can have its activity regulated depending on the surface of roads that have not yet produced deforestation.

The road maps combined with the land-use maps from the previous cycle generate maps of available forest, to which rates provided by the non-spatial (Vensim) module are applied. This available forest area is one of the main innovations of this spatial model. This surface is closely related to the development of the road network, as well as to the location of environmental protection areas, as will be shown shortly. The available forest is a strip of forest up to 10 km from roads. Within this range is the range of forest land (available forest in a default property such as those from old INCRA settlements along the southern portion of the BR-319) related to small-farmer occupation.

The calculation of rates of deforestation and of secondary-forest clearing, and recovery is related to the land surface, within a 2-km distance from the road. Ranching modifies the forest area within this range. On the left of Figure 10 the series of surface variables that the spatial model sends to the numerical model for the calculation of rates. The numerical module in Vensim calculates the demands for each type of land use and provides the routine for the expansion of deforestation in the spatial model.

< Figure 10 here >

2. Construction of the BR-319 and its Side Roads

Road construction in the DINAMICA model is divided into two instances, consisting of a routine for automatic internal road construction and another for embedding road maps.

The automatic routine or "road constructor" consists of three main modules, automated road construction based on location probability of destinations. The distance to these destinations is regulated by the State of activity. A more active "road constructor" means more distant destinations (penetration roads), and less active one chooses closer destinations (road consolidation). The second module calculates the cost of the path to the destination, this cost is calculated based on friction (Soares-Filho *et al.*, 2002), for example, routes through areas with greater steepness, flooded areas and protected areas produce paths with higher cost. The third module is related to the regulation of the activity. This module compares deforestation on the map corresponding to a given iteration with the map of the road network. Thus, a high proportion of roads that deforestation has produced results in an increased activity of the "road constructor." This is a self-regulatory mechanism that approximates the behavior of the automaton to expected actually.

3. Incorporation of Planned Roads

Planned roads are built into the model in predefined steps relating to expected dates of construction from the master plan of the state. Among these roads, the following segments were included: the central segment of the BR-319 (except for the portion from Realidade to Igapó-Açu) in the year 2011, the new side road from the BR-319 to Manicore (AM-464), currently abandoned, in the year 2014, the new BR-319-Borba (AM-346) side road in the year 2017, the BR-319-Tapauá side road (AM-366) its extension (AM-365) that is planned to connect Tapauá to Coari in 2021, and the BR-319-New Aripuanã side road (AM-360) in 2024.

4. Road Constructor Activity Cycles

The Road Constructor increases its activity when most roads have produced deforestation in their vicinity. Thus the construction activity varies in relation to the saturation of roads with deforestation. The low-activity cycle is related to destinations on the order of 2 km, which generally means a dense, consolidated road network. The average cycle uses destinations double cycle with less active, and the high-activity cycle locates targets up to 6 km away and generally configure penetration roads. This kind of road is guided by preferential paths located on friction maps on which is based on the cost of the paths.

5. Road Constructor with Preferred Paths

The trajectory of the roads is not completely related to the simple calculation of costs and attractiveness, but is also defined by a characteristic spatial pattern of construction in the simulated region. These patterns can be observed in the construction of access roads (“*ramais*” or “*travessões*”) every 15 km along main roads. As well as penetration roads in radial direction the densification of the occupation and land-consolidation roads conditioned by the provision of batches, among other variables that are used for training of the attractiveness and friction maps corresponding to each iteration of the simulation.

6. Existing and Proposed Conservation Units

The model considers the inclusion of existing conservation units and also those proposed in the ALAP of the BR-319.

7. Vensim Model

The Vensim model represents only a skeleton to receive future components to represent the effects of macroeconomic factors and public policies that affect prices and therefore the profit that can be obtained from deforestation. Simulated fluctuations in deforestation rates would be greater with the incorporation of these non-important spatial effects. Fluctuations in internal rates of deforestation in current simulations are due to cycles of stimulation of deforestation by extending the network of roads, increasing in pulses the forest "available" to deforestation, which represents a pattern that is consistent with our understanding of the real time pattern of deforestation (*e.g.*, Fearnside, 1989).

C. SCENARIOS FOR THE REGION

1. Reference Scenario

In the first phase of this study the model runs with the following assumptions for the reference scenario:

I. the protected areas and indigenous lands implemented by 2007 are included in the analysis (see map of conservation units, Figure 11, and the indigenous lands, Figure 12);
II. the implementation of existing conservation units is effective and no deforestation occurs in them;
III. no deforestation in indigenous lands.

<Figures 11 &12 here>

2. Landscape Conservation

Assumptions of the conservation scenario (Figure 13) were:

I. the protected areas and indigenous lands implemented by 2007 are included in the analysis;
II. the proposed conservation units for the BR-319 ALAP are included in the analysis;
III. implementation of the existing and proposed conservation units is effective no deforestation in these areas;
IV. no deforestation in indigenous lands;

< Figure 13 here >

D. SPATIAL DATA ENTRY

Spatial data input to the model are:

I. land cover maps at the starting time (t_1) (derived from PRODES deforestation data for the year 2000; Brazil, INPE, 2007) and at the next time ($t_1 + x$) (derived from PRODES data for 2004, Brazil, INPE, 2007) for calculating the rate of transition and for calculating the weight of evidence, see Figure 14 and 15.

<Figures 14 & 15 here>

II. Maps of static variables (discrete and continuous):
a. Soil type (RADAMBRASIL)
b. Vegetation type (IBGE/SIPAM)
c. Altitude (SRTM)
d. Steepness (derived from SRTM)
e. Distance to rivers (ANA)
f. Distance primary roads (CSR-UFMG)
g. Distance secondary roads (CSR-UFMG)
h. Attractiveness to urban centers (derived from IBGE)

The map of distances to roads is shown in Figure 16.

< Figure 16 here>

3. Map of friction

' The map of friction was prepared from data on steepness and of environmental protection areas in the scenarios. Friction is a variable that influences the activity of the Road Constructer module.

4. Map of attractivity

Map of attractivity (Figure 17) is calculated from the property of areas that serve as attraction poles for human activity, such as agricultural suitability maps, flooded areas and reserves. The latter two have low attractivity. This map also directs the activity of the Road Constructer module.

<Figure 17 here>

E. ESTABLISHMENT OF FUNCTIONAL RELATIONSHIPS

1. Relationship between Roads and Deforestation Rate

Road construction incorporates the forest surface, updated in every iteration, the simulation. This incorporation is defined by a range of 10 km (buffer) on either side of the roads. The surface thus defined is called "accessible forest." Thus, the accessible forest surface may increase at a maximum of 20 km^2 per kilometer of road built in the case of penetration roads. In the case of roads or extensions, increasing the available surface can even have an effect.

The incorporation of available forest area is minimized when there are integral protection areas or indigenous lands adjacent to a cell, these areas do not incorporate the available forest. Road construction is also inhibited by the presence of integral protection areas. In these cases the increment of the available forest surface can be zero when building roads happens near or in protected areas, so the area deforested will not increase even though the roads might be of the penetration type.

This concept implies that the accessibility brought by road construction activity increases deforestation rate positively through the implementation of the internal rates of deforestation according to equation (1) below, in which the deforested area corresponds to the corresponding area deforested in the cycle;

$$\textit{Internal rate} \times \textit{Accessible forest} = \textit{Area deforested} \qquad (1)$$

Where,
Area Deforested represents the total area deforested in any given cycle;
Internal rate refers to deforestation rates calculated from availability in areas accessible to deforestation;
Accessible forest represents the total area of forest that is capable of being used for deforestation.

In this equation if observes that, although the internal rate of deforestation may not vary the deforested area in each cycle varies with changes in forest area accessible.

2. Forest Land and Available Surface

Deforestation activity consists of a constant basal activity associated with a land surface. This area consists of all cells located less than 2 km from the edge of a road. This is related to deforestation activity in small agricultural properties that generally varies little with economic fluctuations. This narrow strip is a very attractive to deforestation, and adjusts in response to variations in the density of the road network.

3. DINAMICA Variables Passed to Vensim

The variables generated in DINAMICA are exclusively surface characters, the main ones are: forest surface area, deforested area, secondary forest area and land area. These variables are embedded in the Vensim numerical simulation model of to produce a rate of deforestation, a *clearing* rate (cutting secondary forest) and a recovery rate.

4. Modifications to the Existing DINAMICA Models

The following modifications were made in existing models developed at the Federal University of Minas Gerais (Soares-Filho *et al.*, 2003, 2004, 2006):

I. DINAMICA spatial Model Coupled with the Vensim numerical model;
II. The Road Constructer activated by the distance from a road to existing deforestation, alternating between activities of construction for extending the network to penetrate into the forest;
III. Road Constructor guided by government plans for future roads.
IV. Search for destinations by the Road Constructer with preference for flat areas and plateaus, avoiding flooded areas;
V. Generating a map of attractiveness to deforestation based on the density of roads;
VI. generation of an accessible surface of based on the forest surface and the road map; this value is supplied to the Vensim model;
VII. Generation of roads without deforestation, supplied to the Vensim model.
VIII. Generation of a surface of forest available for land activity, as defined by a distance ≤ 2 km to a road.

5. Calibration of the Model

DINAMICA-EGO software provides a number of operators specially developed for calibration and validation (Rodrigues *et al.*, 2007). In developing the model of land use and cover change (LUCC) there are different moments in the calibration of the model. One of the tools for calibration of the model is the calculation of the ***transition rate*** class of coverage. In this particular case of deforestation modeling in the region, the transition is modeled of "forest" to "deforested" area. Deforestation data obtained from the PRODES project (Brazil, INPE, 2007) for the period 2000 to 2004 were used for calculation of the transition rate and to analyze the deforestation trend for each year for the 2000-2006 period in different locations in the Central Amazon region, between Porto Velho and Manaus and along the Transamazon Highway (BR-230) (see Figure 18). The annual rate was derived from the annual average calculated for the period 2000-2004. The transition-rate model adopted in this study is calculated from deforestation data only for the first iteration, and therefore it is refreshed at every iteration by the numerical model developed in Vensim.

< Figure 18 here >

6. Model Validation

The overall result was validated by comparison to the Matupi area (Figure 19). Here the quantity and the spatial pattern of simulated deforestation roughly confirm what is observed on satellite images (PRODES) (Brazil, INPE, 2007). However, it should be noted that the type of deforestation represented here is produced by small farmers, like those in the area north of the Samuel dam in Rondônia, where the relationship was established between roads and expanding deforestation. The effects of other actors need to be modeled (see section on future enhancements). In general, these other actors (large ranchers) will produce faster deforestation.

< Figure 19 here >

F. RESULTS ON DEFORESTATION

1. Reference Scenario

The simulation results using the reference scenario are presented in Figures 20 and 21.

< Figures 20 & 21 here >

Table 1 indicates the percentage deforested in a simulation of what would have happened in the forested areas of reserves proposed for protection by the government, if these reserves were not created. One model indicates percentages deforested by 2050 in conservation units range from 0.4 to 77.6% in the reference scenario.

< Table 1 here >

Characteristics:

I. in the reference scenario the deforested area projected for 2050 reaches 33% of the original forest area.
II. the increase in the rate of deforestation between 2004 and 2015 is related to the planned construction of roads and the reconstruction and paving of the BR-319.

2. Landscape Conservation

The results of a simulation considering the conservation scenario presented in Figures 22 and 23.

<Figures 22 & 23 here >

Characeristics:

1. In the conservation scenario projected to 2050 the deforested area reaches 25% of the original forest area.

II. the increase in the rate of deforestation between 2004 and 2015 is related to the planned construction of roads and the reconstruction and paving of the BR-319.

5. Biomass and Emissions

A. FOREST BIOMASS IN THE AREA OF INFLUENCE OF THE BR-319

1. Forest Biomass Estimates in Terrestrial Ecosystems

The total biomass ([11]) of different ecosystems present throughout the area of influence of BR-319 was calculated from data on the volume of timber (m^3 ha^{-1}) in 306 plots (1 ha each) sampled by the RADAMBRASIL project forest inventories carried out between the states of Rondônia (35 parcels; 11.4%) and Amazonas (272 plots; 88.6%) (Brazil, Projeto RADAMBASIL, 1973-1984). Each parcel sampled by the RADAMBRASIL Project in this region of the Amazon represents the result of the total volume of timber trade with circumference at breast height (CAP) greater than or equal to 100 cm (31.8 cm DBH-diameter at breast height), exclusively for forestry systems.

To transform the data on wood volume to biomass per unit area (t ha^{-1}), we used volume expansion factors (VEF = 1.25 for dense forests and 1.5 for non-dense) to add the corresponding volumes for stems of smaller trees (with DBH between 10 and 12.7 cm). The weighted average density of wood species encountered in each parcel was used to convert the volume of trunks to stem biomass. The biomass of crowns was added using a biomass expansion factor (BEF), as described originally by Brown & Lugo (1992) and Brown (1997). This volume for biomass expansion was subsequently refined through systematic adjustments proposed by Fearnside (1992), that add other compartments of the forest biomass that were not covered in Brown &

Lugo (1992). The wood density data were corrected for radial variations based on results obtained in dense forest in the central Amazon (see Nogueira *et al.*, 2005). Non-forest ecosystems (open vegetation with lower abundances of species and individuals) present in the area of influence were not covered by RADAMBRASIL project wood-volume inventories, and are devoid of reliable estimates.

2. Basis of Calculations

To perform calculations, data from all 306 plots selected in the area of influence of the BR-319 were placed in geo-referenced database. This data bank was formatted from two basic sources: (1) the geo-referenced database of the Amazon Surveillance System/SIPAM (Brazil, Amazon Surveillance System/SIPAM, 2004), version 6, for the whole Brazilian Legal Amazon (scale 1: 250,000), along with a set of general information supplied by the IBGE to Amazon Surveillance System of the RADAMBRASIL Project and (2) books (volumes) for surveys of natural resources and theatic maps (soils, vegetation, etc.) of the RADAMBRASIL Project published by the Ministry of Mines and Energy (MME) in the 1970s and 1980s (scale 1: 1,000,000) (Brazil, Projeto RADAMBRASIL, 1973-1984). The overall result of inventories (volume of wood with bark, number of species and individuals) was obtained from the MME publications, whereas the physical basis (location of sampling points) of botanical species inventory was extracted from the database of the Amazon Surveillance System. Although this last source contains uncertainties due to a number of typographical errors in trunk circumference information or commercial at the time, it was possible to use it to obtain estimates of wood density (crucial in the general calculations) for each sample unit according to the species present in each parcel.

Definitions of “phyto-physionomies” (ecosystems) adopted on the basis of calculation were all derived from the IBGE technical manual on Brazilian vegetation (Brazil, IBGE, 1992), which is the reference for the classification of vegetation types in the country. Two large forest groups were formed ("dense forest" and "non-dense forest") to initiate the calculation process that would convert volume to biomass. Both groups represent the first steps in the application of VEF and BEF. In the first group includes all primary formations (alluvial, lowlanders, submontana and montana) defined within the "forest" class, sub-class of “ombrophilouss” formations, subgroup ombrophilous "dense" forest, as determined by the Brazilian classification system. In the case of non-dense forests, all remaining subclasses and subgroups of forest formations are included, as forests rainforest heritage open, campinaranas, deciduous seasonal forests and semi-deciduous, and all contact forest ecosystems (*e.g.* sub-montane ombrophilous contact forest semi-deciduous forest or savanna contact with sub-montane ombrophilous forest).

3. General Estimates

Of 306 parcels sampled, 253 (82.7%) were in the Dense Forest group and 54 (17.6%) in non-dense forest. Ecosystems with the largest number of sample plots were those of the lowland sub-montane ombrophilous dense forest (Db; 156 plots) and alluvial forest (Da; 62): almost all in the state of Amazonas, and the smallest number of samples was in the sub-montane ombrophilous open alluvial forest (Aa; 9), which had only one plot (in the state of Rondônia).

< Table 2 here>

Mean total biomass (not weighted for each ecosystem) based on the present study was 414 t ha^{-1} (277-604 t ha^{-1}) (Table 3). Other terrestrial ecosystems present in the RADAMBRASIL project sample contained a greater number of plots and diluted the variability in the final mean, not showing distortions. All are within the range of results found by most studies done ain the Amazon (300-600 t ha^{-1}) using the direct and indirect measures available in the current literature (Klinge & Rodrigues, 1974; Fearnside *et al*, 1993; Fearnside, 1994, 1997, 2000a,b; Higuchi *et al.*, 1994; Alves *et al*, 1997; Laurance *et al.*, 1999; Nascimento *et al*, 2007).

< Table 3 here>

For comparison, the values calculated here have a difference of -75% as compared to the direct application of the volume expansion factor for biomass by Brown & Lugo (1992), and as compared to the +4.5% refinement presented subsequently by Fearnside (1992) (see Table 3). The values reported here include the most recent adjustments for wood density, ecosystem and state (mean = 0.651 g cm^{-3}), in addition to other refinements, such as previous adjustments for "hollow trees" and "bark," currently covered at other levels of the calculation.

These values for biomass incorporate a number of improvements compared to previous estimates, as problems have been solved with respect to accounting for hollow and irregular trees and form factor (Fearnside & Laurance, 2004; Nogueira *et al.*, 2006), and regular and significant differences in wood density in the arc of deforestation as compared to Central Amazonia, even for trees of the same species (Nogueira *et al.*, 2007).

The calculations presented above use the original forest biomass, without adjustment for the effects of logging or other forms of degradation of the standing forest. Thus, emissions associated with the processes of degradation for deforested areas are implicitly included, but not for degradation of the remaining forest that is not deforested soon thereafter (for example, within a period of three years after logging). In the future, if explicit calculations are made of emissions from logging and other forms of degradation, the biomass used to calculate the emission from deforestation would have to be adjusted accordingly (see discussion in Fearnside, 1997).

4. Map and distributional Characteristics of Biomass

The map with the distribution characteristics of biomass in the ALAP of the BR-319 is shown in Figure 24. Biomass is lower in the southern part of ALAP and increases along the route to Manaus.

< Figure 24 here >

B. ESTIMATES OF CARBON EMISSIONS

The total emission is calculated from the loss of biomass carbon stocks plus the effect of trace gases. Only methane (CH_4) and nitrous oxide (N_2O) were considered, because the effects of other trace gases such as carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHC) are not currently considered by the Intergovernmental Panel on Climate Change (IPCC). The interchangeability of gases was based on global warming potentials (GWPs) from the second assessment report of the IPCC, and are the values that were adopted by the Kyoto Protocol for use during its first commitment period (2008-2012). Using these equivalences, each ton of CH_4 has the impact on global warming of 21 tons of gas $_2$ CO, while each ton of $_2$ the N is equivalent to 310 tons of CO_2, calculated over a time horizon of 100 years (Schimel *et al*., 1996). It should be noted that the fourth assessment report of the IPCC (Forster *et al*., 2007, p. 212) changes these values. In the case of methane, the value of the GWP is increased to 25, a rise of 19% for the impact of this important gas. In the case of nitrous oxide, the GWP has been reduced to 298, a decrease of 4%. For these emissions, the effect of methane will be greater, and the impact assigned to deforestation will increase when this new information is incorporated into international negotiations. Using the current values of the Kyoto Protocol, each ton of carbon emitted has an additional trace-gas impact equivalent to 0.087 t C (tons of carbon), based on 1990 emissions calculated by Fearnside (2000a,b).

Net emissions were calculated from gross emissions, from which the average carbon stock in the equilibrium landscape that replaces the forest was subtracted. This landscape contains 28.5 t ha^{-1} of biomass with a carbon content of 0.45, or 12.8 t C ha^{-1} in biomass (*i.e.*, not considering the soil carbon), based on the matrix of transitions between land-use categories (Fearnside, 1996).

The above calculations of emissions caused by deforestation only include the carbon in living and dead biomass, not the soil carbon. An estimation of soil carbon release by conversion of the Amazon rainforest to the equilibrium landscape replacing it is 5.4 t C ha^{-1} in the top 20 cm of soil, 7.9 t C ha^{-1} in the top 1 m of soil or 8.5 t C ha^{-1} in the top 8 m of soil (Fearnside & Barbosa, 1998). The deeper soil carbon takes longer to be release them from the carbon in the surface soil.

The reference scenario results in the release of 0.9 Gt C by 2050, compared with the release of 0.6 Gt C in the conservation scenario. Most of the difference between the two scenarios is due to the comparatively lower rate of release of carbon in the conservation scenario after the year 2020 (Figure 25).

<Figure 25 here >

6. FUTURE IMPROVEMENTS

Although the current modeling effort has produced what we believe is a step forward in representing the process of deforestation, reflecting the roles of road construction and improvement and the creation of protected areas. This type of "infrastructure-driven" calculation, or, more generally, "opportunity-driven", is essential if the implications of policy decisions are to be evaluated. Nevertheless, "demand driven" models also capture important aspects of the process of deforestation, especially for consolidated frontiers. The development of hybrid models that combine both approaches, and the development of agent-based (actor-based) models, also known as "institutional arrangements" represents the next step.

In addition to macro-economic effects that determine the demand for the products of deforestation, the roles of several important groups of actors need to be modeled explicitly. These include "*grileiros*" (the large illegal appropriators of land), large investors (*i.e.* soy agribusiness and large ranchers) and illegal sources of money, whether or not these sources are combined with ranching (*i.e.*, money laundering with income from drug trafficking, tax evasion, corruption and other illegal sources). Additionally, there needs to explicit modeling of the effect of logging (influencing deforestation by both by building endogenous roads and by providing money to landowners to invest in deforestation). The broader effect of highways on migration also needs to be modeled because this effect not only stimulates the expansion of deforestation along the route of the highway, as represented here, but also its role as a channel for conveying the population to the end of the road in Manaus. Finally, the potential effects of governance need to be quantified and modeled, and this should be done based on data from observations rather than simple assumptions that posit dramatic unprecedented changes in behavior. These improvements mainly represent additions to the non-spatial (Vensim) model.

Future needs also include additional improvements in estimates of forest biomass and carbon stocks, and emissions that are the result of deforestation and disturbance in the forest such as logging, forest fires and edge effects. Analyses should also be made based on carbon stocks, rather than restricting consideration to changes in flows of carbon by reduced deforestation. More generally, future evaluations should include quantification of a wider range of environmental services, including water cycling and the maintenance of biodiversity.

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LIST OF FIGURES

LIST OF TABLES

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[1]In this study, this is understood as the total biomass of plant mass (living and dead) present on each of the terrestrial ecosystems (above + below ground).

Table 1. Proposed reserves and simulated deforestation s*

Conservation Unit	**Deforestation (%)**
RDS Igapó Açu	77.6
RDS Igapó-Açu	74.8
PARNA Nascentes do Lago Jari	64.1
Extension 2. FLONA Balata Tufari	43.6
PARNA Mapinguari	29.1
Samaúma State/National Forest	15.2
RESEX Médio Purus	10.8
Extension 1. FLONA Balata-Tufari	10.2
FLONA Iquiri	10.0
RDS Canutama	9.9
PAREST Matupiri	5.4
RESEX Ituxi	2.6
Extension of Piagaçu-Purus	0.4

*See Fig. 13 for locations of the reserves.

Table 2 - Distribution of plots (forest inventories) of the RADAMBRASIL Project for the dense and non-dense forest classes by ecosystem used in the area of influence of the BR 319.

State	Forest type	Legend	Dense forest	Non-Dense forest	Total
Amazonas	Dense ombrophilous forest (without formation)	D?	8		8
	Dense Alluvial ombrophilous forest	Da	58		58
	Dense lowland ombrophilous forest	Db	156		156
	Dense ombrophilous submontane forest	Ds	8		8
	Open ombrophilous forest (without formation)	A?		1	1
	Open alluvial ombrophilous forest	Aa		9	9
	Open lowland ombrophilous forest	Ab		16	16
	Open ombrophilous submontane forest	As		6	6
	Without information (*)	si	10		10
Rondônia	Dense alluvial ombrophilous forest	Da	4		4
	Forest dense ombrophilous submontane	Ds	2		2
	Open alluvial ombrophilous forest	Aa		1	1
	Open ombrophilous forest of Low Lands	Ab		9	9
	Open ombrophilous submontane forest	As		11	11
	Pioneer formations with fluvial influence	Pa		1	1
	Without information (*)	si	7		7
Total	-	-	253	54	307

(*) 10 plots in Amazonas and 7 in Rondônia were classified as “dense forest” for comparison, even though the data base of Brazil, SIVAM/SIPAM (2004) does not contain this information (ecosystems without definition).

Table 3 - Basic density of wood (g cm^{-3}), volume (m^3 ha^{-1}) and biomass (t ha^{-1}) of forest ecosystems in the area of influence of the BR 319.

State	Ecosystem (legend)	Basic density of Wood (g cm^{-3}) (*)	Volume RADAMBRASIL ($m^3.ha^{-1}$)	Biomass (Brown & Lugo, 1992) t ha^{-1} (**)	Biomass (Fearnside, 1992) t ha^{-1} (**)	Biomass (This study)
Amazonas	D?	0.670	110	228	417	398
	Da	0.615	125	233	427	408
	Db	0.663	119	236	433	413
	Ds	0.668	121	237	434	415
	A?	0.668	42	159	290	277
	Aa	0.633	99	231	422	403
	Ab	0.673	106	248	454	433
	As	0.632	124	258	473	451
	si	0.663	126	242	443	423
Rondônia	Da	0.636	145	257	471	450
	Ds	0.661	116	236	433	414
	Aa	0.631	210	345	632	604
	Ab	0.648	109	243	446	426
	As	0.631	100	232	424	405
	Pa	0.632	166	303	555	530
	si	0.646	104	211	386	369
General average	-	0.651	118	237	433	414

(*) Values of basic density of wood are derived from the general data base for Pan Amazonia (R.I. Barbosa, personal communication).
(**) the values for total biomass of Brown & Lugo (1992) and Fearnside (1992) are only for comparison and are not included in the final results of this study

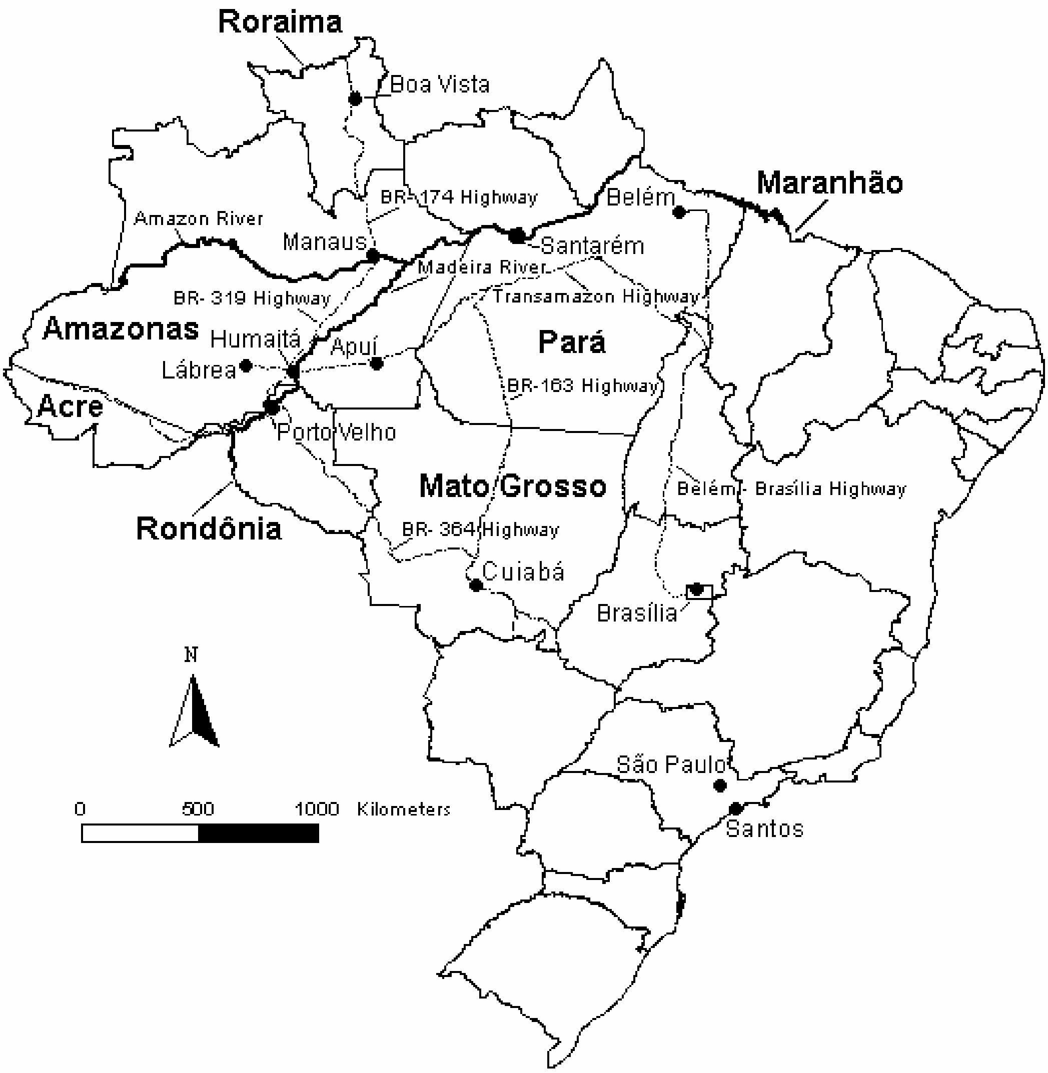
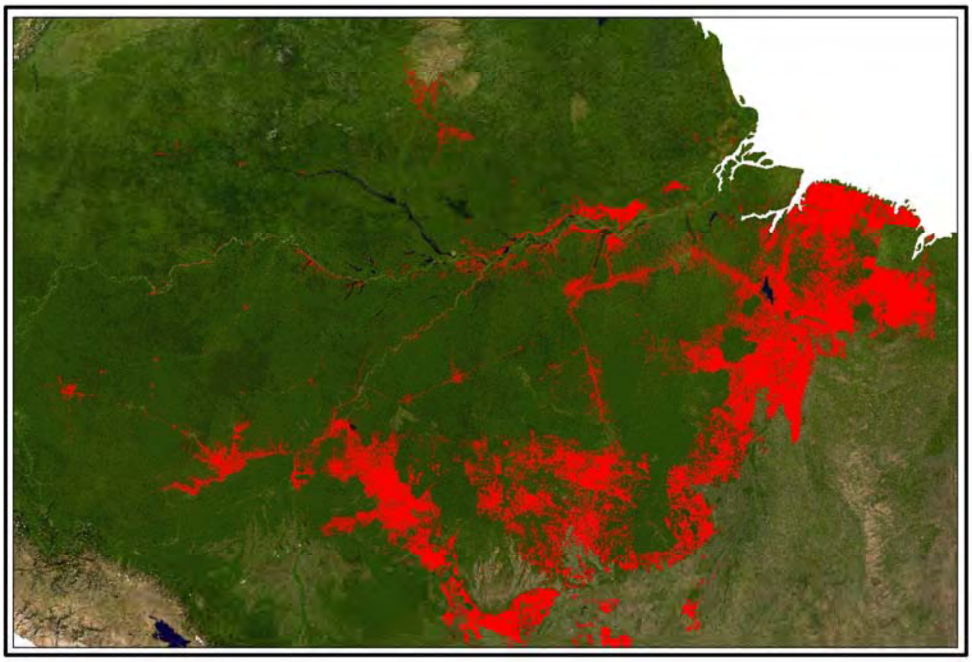

Roraima
Boa Vista
Maranhão
Belém
BR- 174 Highway
Amazon River
Manaus
Santarém
Madeira River
BR- 319 Highway
Transamazon Highway
Amazonas
Humaitá
Apuí
Pará
Lábrea
BR-163 Highway
Acre
Porto Velho
Mato Grosso
Belém - Brasília Highway
Rondônia
BR- 364 Highway
Cuiabá
Brasília
N
São Paulo
0
500
1000
Kilometers
Santos

Fig. 1

Fig. 2



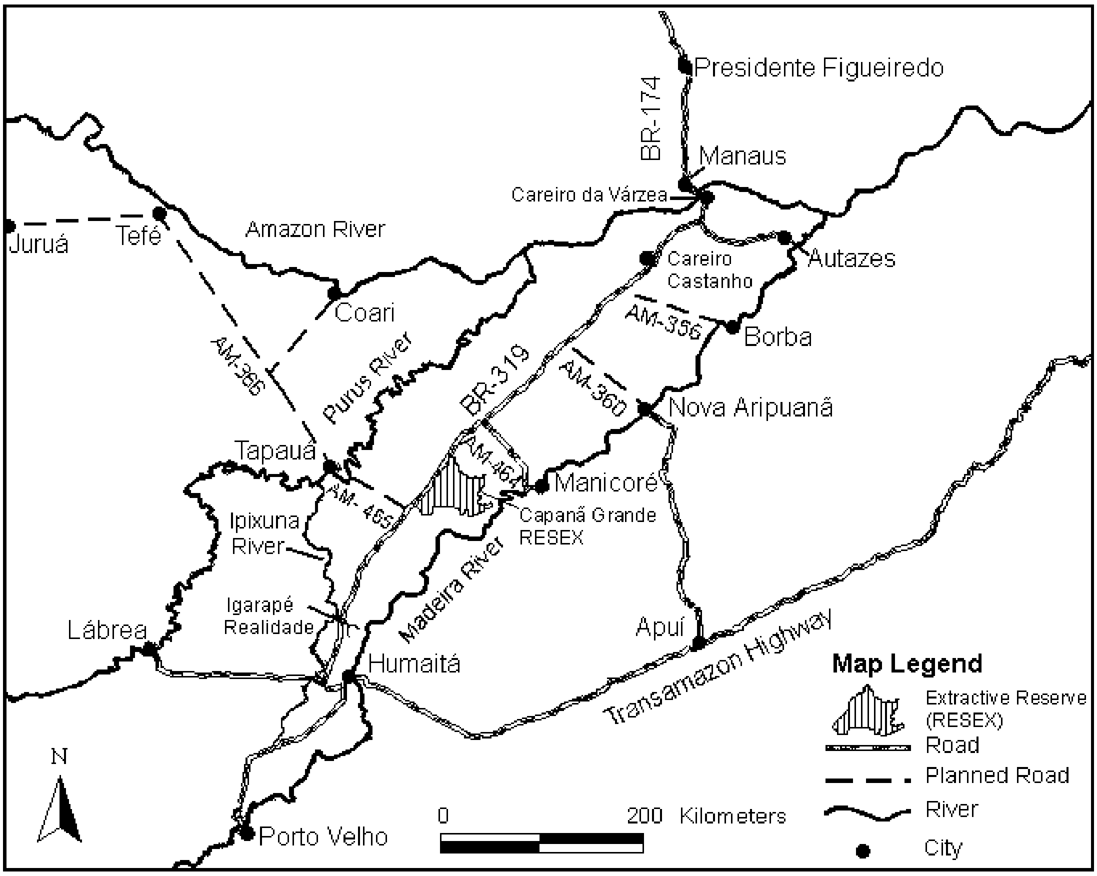

Presidente Figueiredo
BR-174
Manaus
Careiro da Várzea
Juruá
Tefé
Amazon River
Careiro
Castanho
Autazes
Coari
AM-356
Borba
AM-366
Purus River
BR-319
AM-360
Nova Aripuanã
Tapauá
AM-464
Manicoré
AM- 465
Capanã Grande
RESEX
Ipixuna
River
Madeira River
Igarapé
Realidade
Lábrea
Apuí
Humaitá
Transamazon Highway
Map Legend
Extractive Reserve
(RESEX)
Road
Planned Road
River
City
N
0
200 Kilometers
Porto Velho

Fig. 3

Fig. 4

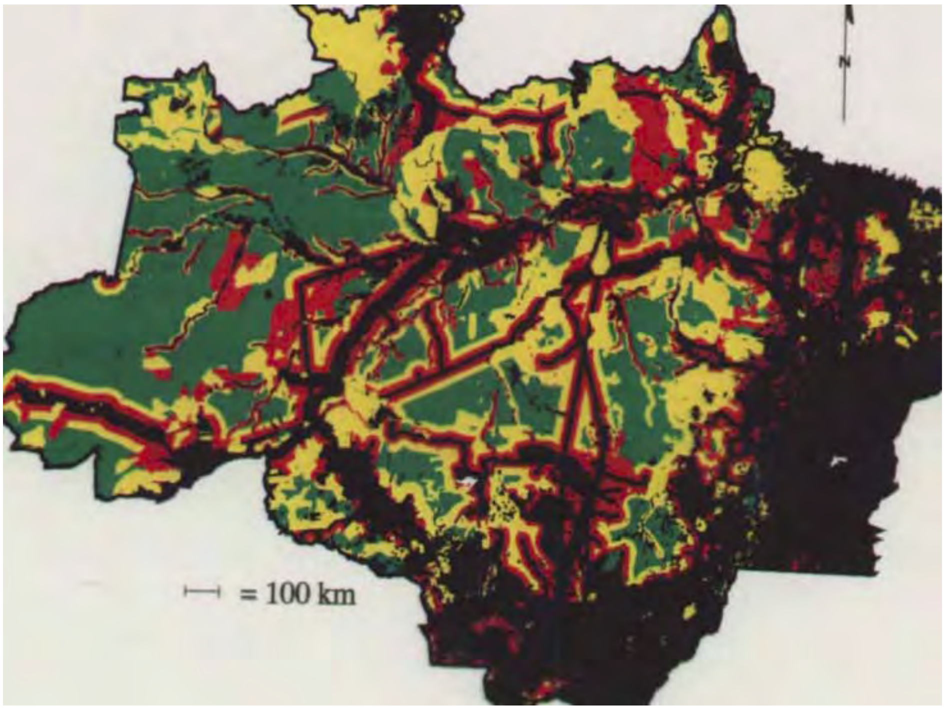
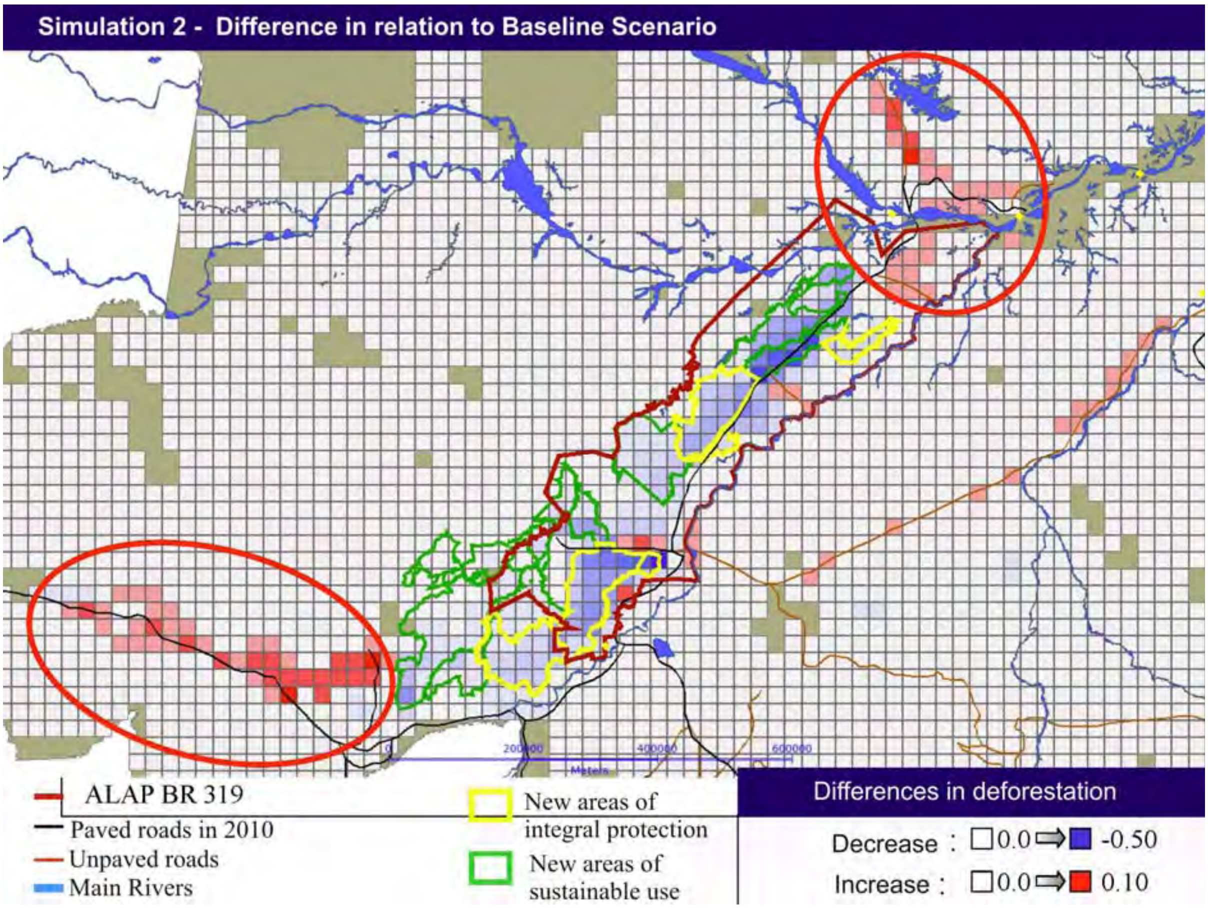


Fig. 5



Simulation 2 - Difference in relation to Baseline Scenario
0
200000
400000
600000
Meters
ALAP BR 319
Paved roads in 2010
Unpaved roads
Main Rivers
New areas of integral protection
New areas of sustainable use
Differences in deforestation
Decrease : 0.0 -0.50
Increase : 0.0 0.10

Fig. 6

Soares-Filho et al., 2006 Model – Business as Usual Scenario

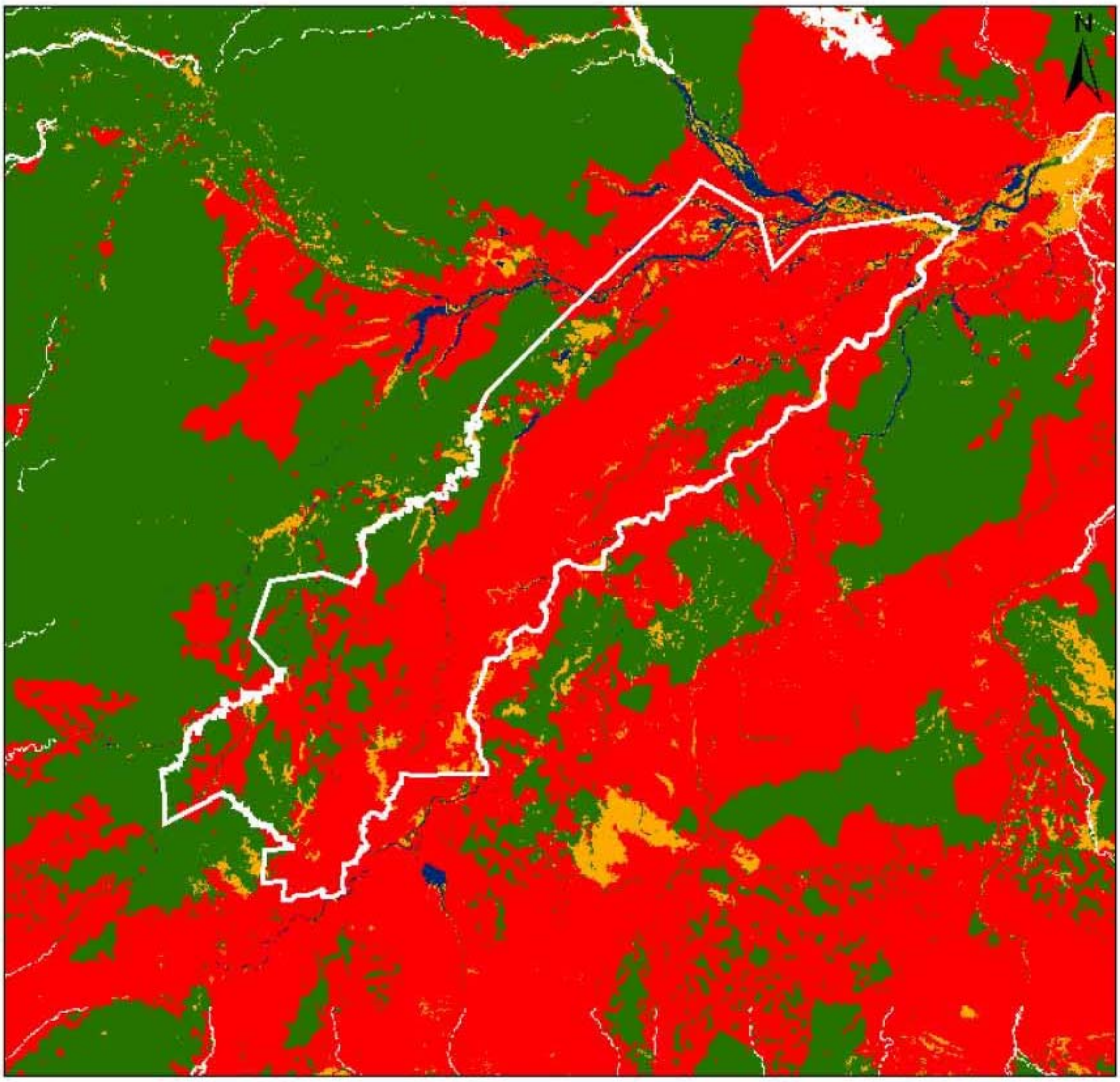


Fig. 7

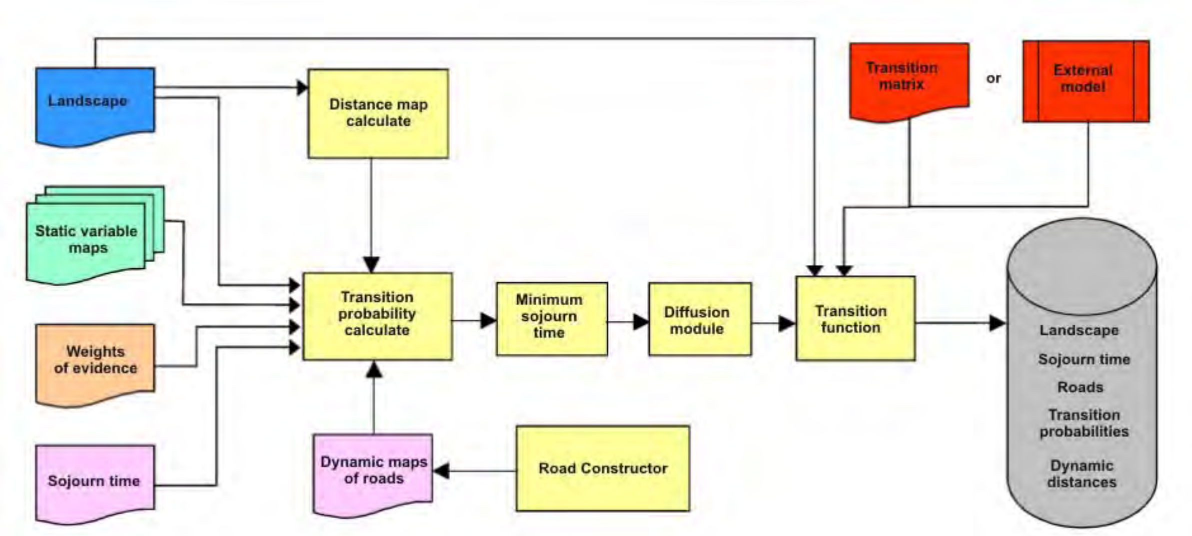
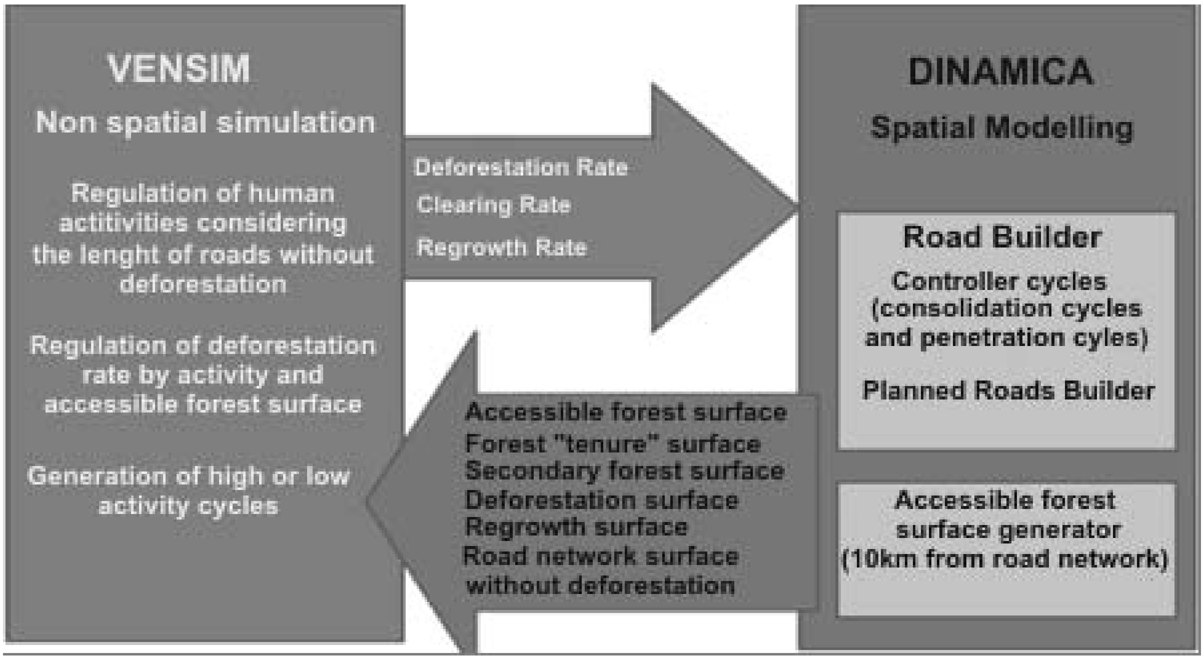
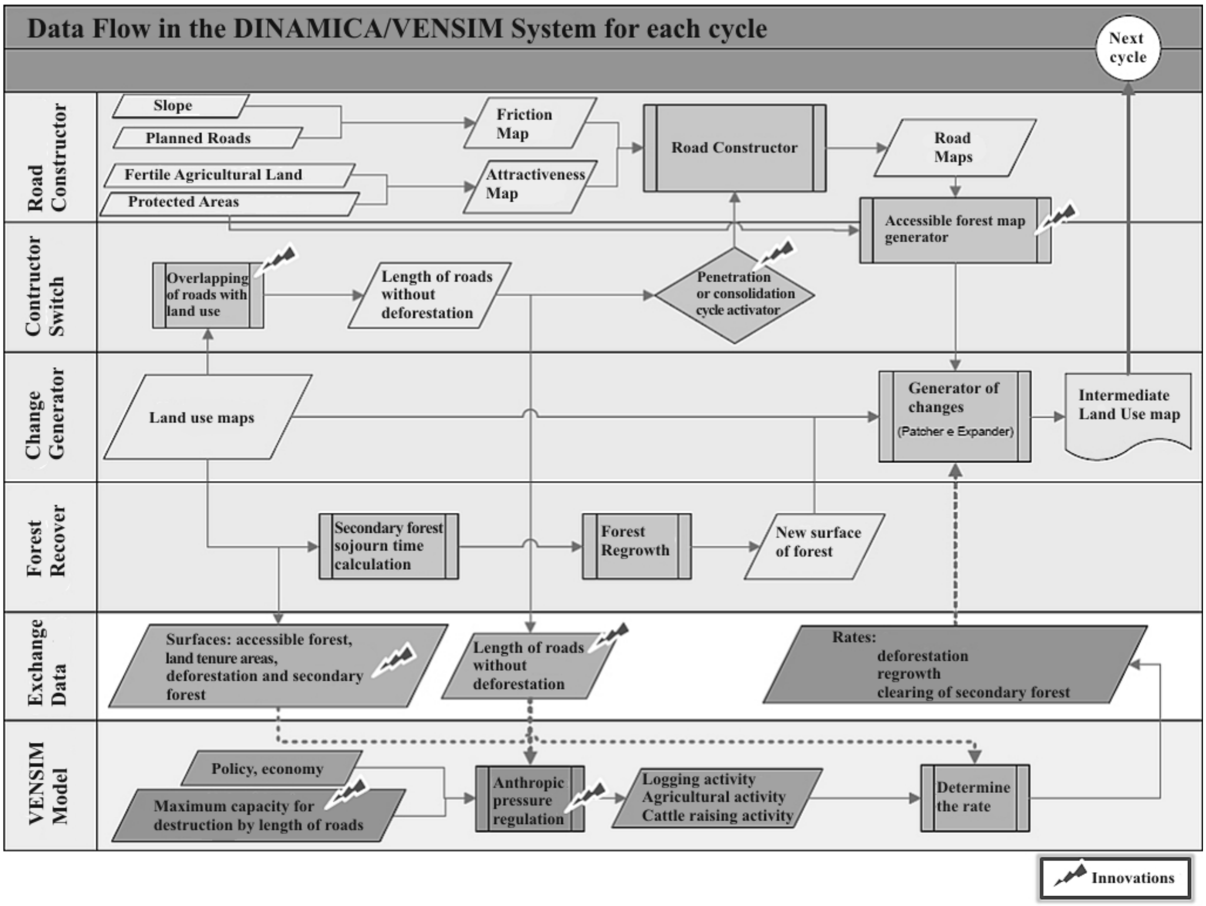

Landscape
Distance map calculate
Transition matrix
or
External model
Static variable maps
Transition probability calculate
Minimum sojourn time
Diffusion module
Transition function
Weights of evidence
Sojourn time
Dynamic maps of roads
Road Constructor
Landscape
Sojourn time
Roads
Transition probabilities
Dynamic distances

Fig. 8



VENSIM
Non spatial simulation
Regulation of human actitivities considering the lenght of roads without deforestation
Regulation of deforestation rate by activity and accessible forest surface
Generation of high or low activity cycles
Deforestation Rate
Clearing Rate
Regrowth Rate
DINAMICA
Spatial Modelling
Road Builder
Controller cycles (consolidation cycles and penetration cyles)
Planned Roads Builder
Accessible forest surface generator (10km from road network)
Accessible forest surface
Forest "tenure" surface
Secondary forest surface
Deforestation surface
Regrowth surface
Road network surface without deforestation

Fig. 9



Data Flow in the DINAMICA/VENSIM System for each cycle
Next cycle
Road Constructor
Contructor Switch
Change Generator
Forest Recover
Exchange Data
VENSIM Model
Slope
Planned Roads
Fertile Agricultural Land
Protected Areas
Friction Map
Attractiveness Map
Road Constructor
Road Maps
Accessible forest map generator
Overlapping of roads with land use
Length of roads without deforestation
Penetration or consolidation cycle activator
Land use maps
Generator of changes (Patcher e Expander)
Intermediate Land Use map
Secondary forest sojourn time calculation
Forest Regrowth
New surface of forest
Surfaces: accessible forest, land tenure areas, deforestation and secondary forest
Length of roads without deforestation
Rates: deforestation regrowth clearing of secondary forest
Policy, economy
Maximum capacity for destruction by length of roads
Anthropic pressure regulation
Logging activity
Agricultural activity
Cattle raising activity
Determine the rate
Innovations

Fig. 10

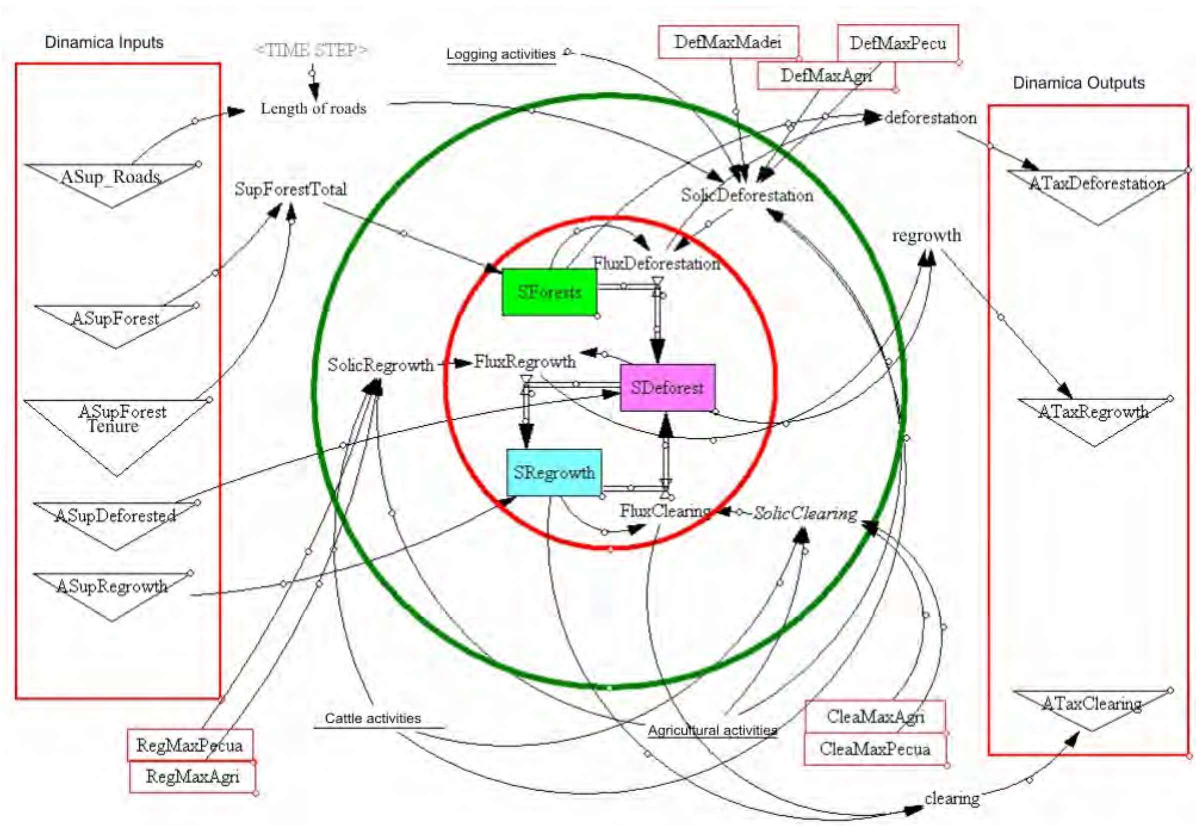
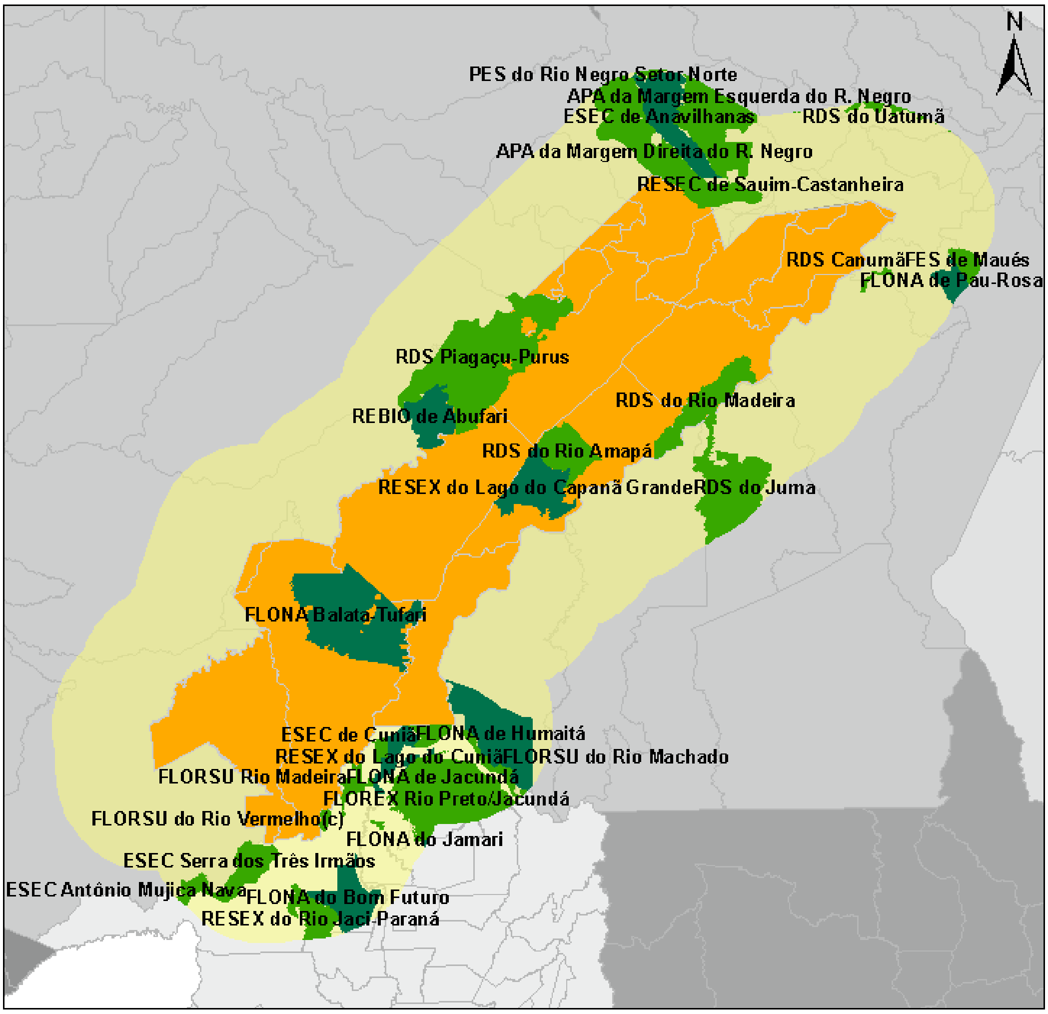

Dinamica Inputs
<TIME STEP>
Logging activities
DefMaxMadei
DefMaxPecu
DefMaxAgri
Dinamica Outputs
Length of roads
deforestation
ASup_Roads
SupForestTotal
SolicDeforestation
ATaxDeforestation
regrowth
FluxDeforestation
SForests
ASupForest
SolicRegrowth
FluxRegrowth
SDeforest
ATaxRegrowth
ASupForest
Tenure
SRegrowth
ASupDeforested
FluxClearing
SolicClearing
ASupRegrowth
ATaxClearing
CleaMaxAgri
Cattle activities
Agricultural activities
CleaMaxPecua
RegMaxPecua
RegMaxAgri
clearing

Fig. 11



N
PES do Rio Negro Setor Norte
APA da Margem Esquerda do R. Negro
ESEC de Anavilhanas
RDS do Uatumã
APA da Margem Direita do R. Negro
RESEC de Sauim-Castanheira
RDS CanumãFES de Maués
FLONA de Pau-Rosa
RDS Piagaçu-Purus
REBIO de Abufari
RDS do Rio Madeira
RDS do Rio Amapá
RESEX do Lago do Capanã GrandeRDS do Juma
FLONA Balata-Tufari
ESEC de CuniãFLONA de Humaitá
RESEX do Lago do CuniãFLORSU do Rio Machado
FLORSU Rio MadeiraFLONA de Jacundá
FLOREX Rio Preto/Jacundá
FLORSU do Rio Vermelho(c)
FLONA do Jamari
ESEC Serra dos Três Irmãos
ESEC Antônio Mujica NavaFLONA do Bom Futuro
RESEX do Rio Jaci-Paraná

Fig. 12

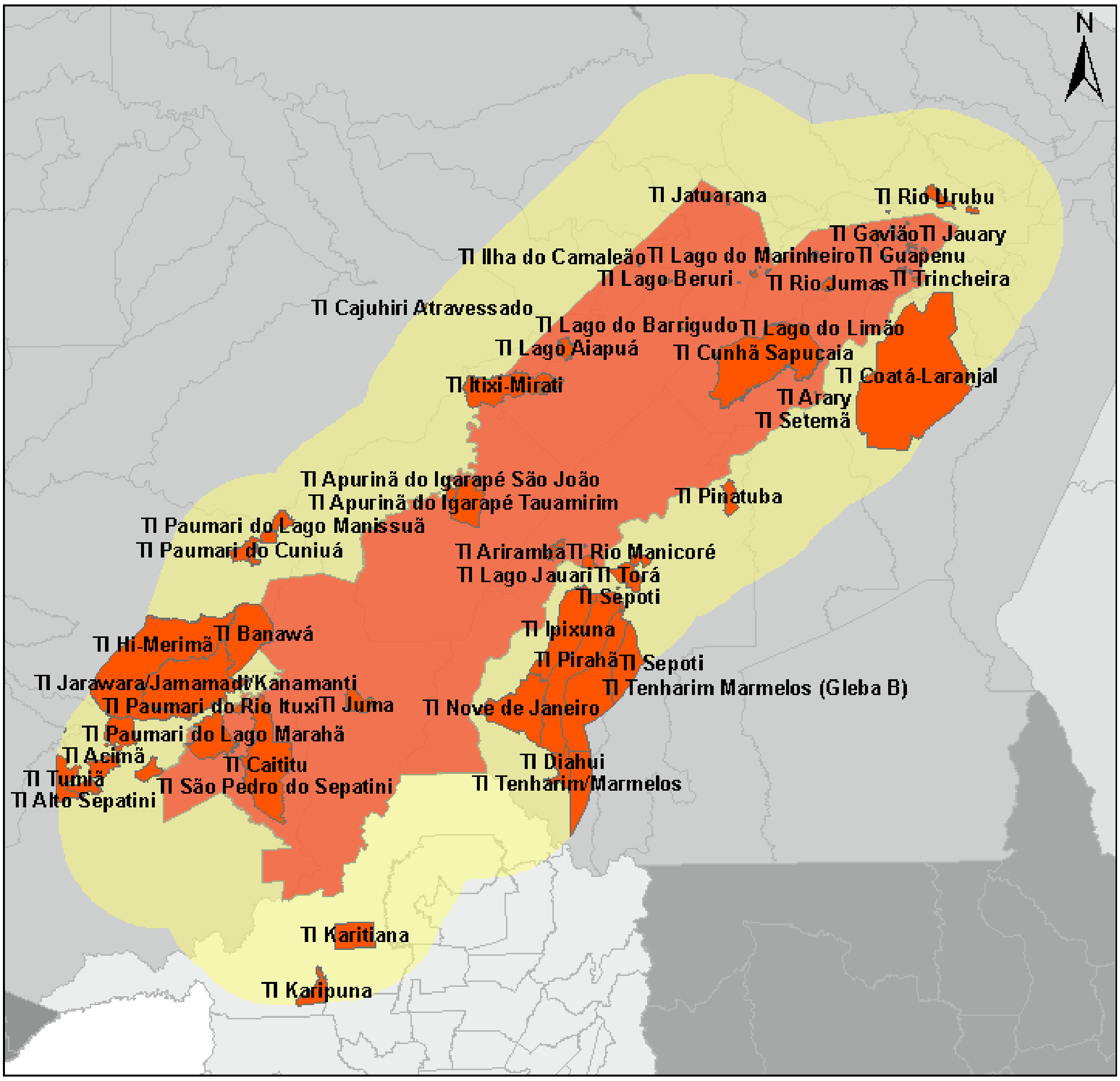
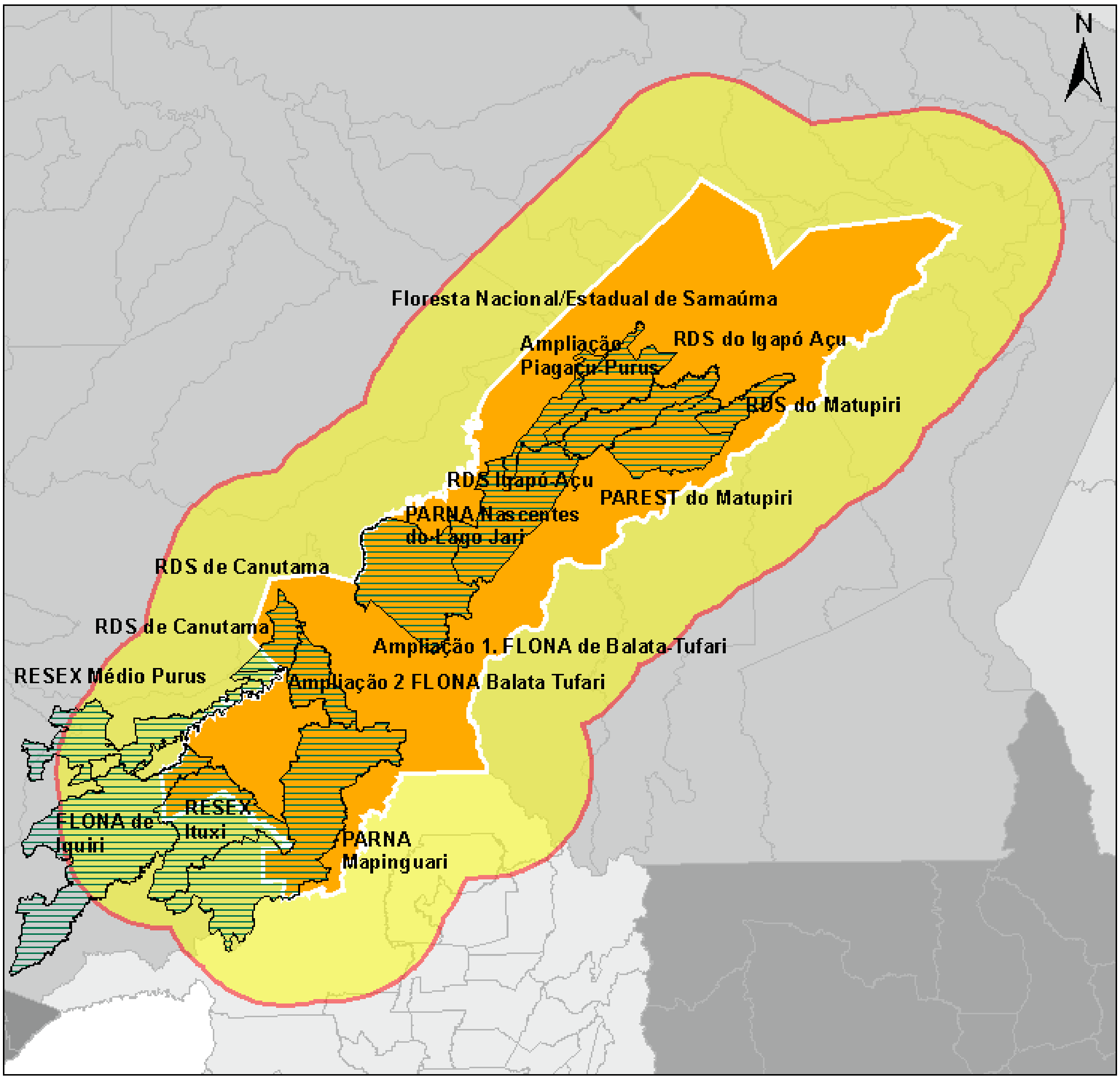
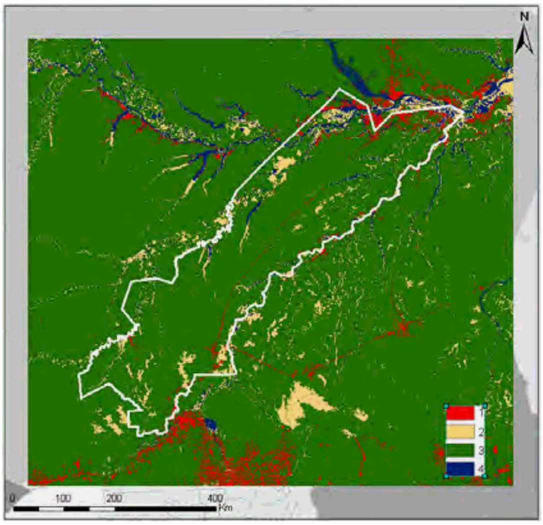

N
TI Jatuarana
TI Rio Urubu
TI Gavião
TI Jauary
TI Ilha do Camaleão
TI Lago do Marinheiro
TI Guapenu
TI Lago Beruri
TI Rio Jumas
TI Trincheira
TI Cajuhiri Atravessado
TI Lago do Barrigudo
TI Lago do Limão
TI Lago Aiapuá
TI Cunhã Sapucaia
TI Coatá-Laranjal
TI Itixi-Mirati
TI Arary
TI Setemã
TI Apurinã do Igarapé São João
TI Apurinã do Igarapé Tauamirim
TI Pinatuba
TI Paumari do Lago Manissuã
TI Paumari do Cuniuá
TI Ariramba
TI Rio Manicoré
TI Lago Jauari
TI Torá
TI Sepoti
TI Ipixuna
TI Hi-Merimã
TI Banawá
TI Pirahã
TI Sepoti
TI Tenharim Marmelos (Gleba B)
TI Jarawara/Jamamadi/Kanamanti
TI Paumari do Rio Ituxi
TI Juma
TI Nove de Janeiro
TI Paumari do Lago Marahã
TI Acimã
TI Caititu
TI Diahui
TI Tumiã
TI São Pedro do Sepatini
TI Tenharim/Marmelos
TI Alto Sepatini
TI Karitiana
TI Karipuna

Fig. 13


N
Floresta Nacional/Estadual de Samaúma
Ampliação
Piagaçu-Purus
RDS do Igapó Açu
RDS do Matupiri
RDS Igapó Açu
PAREST do Matupiri
PARNA Nascentes
do Lago Jari
RDS de Canutama
RDS de Canutama
Ampliação 1. FLONA de Balata Tufari
RESEX Médio Purus
Ampliação 2 FLONA Balata Tufari
FLONA de
Iquiri
RESEX
Ituxi
PARNA
Mapinguari

Figs 14 & 15



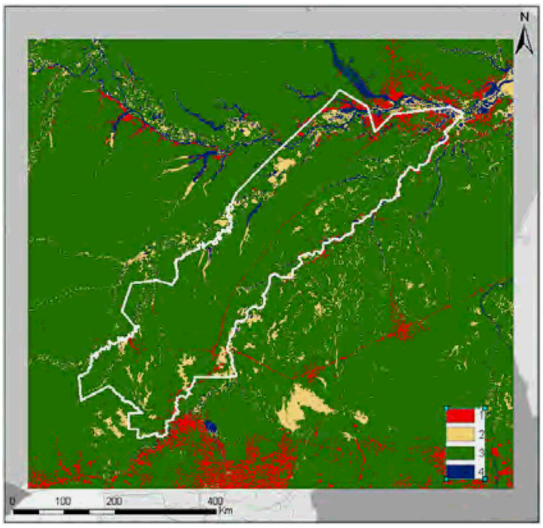


Fig. 16

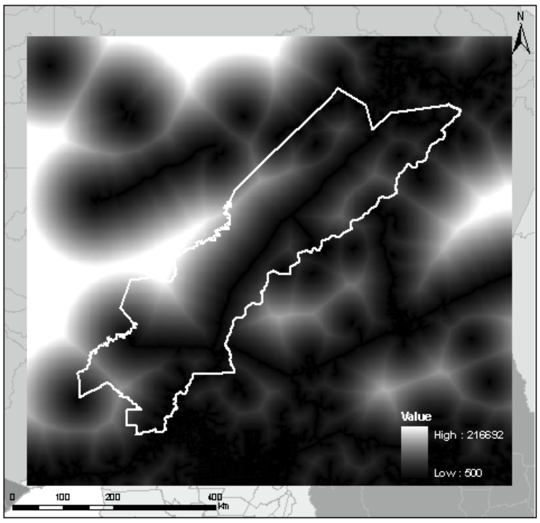
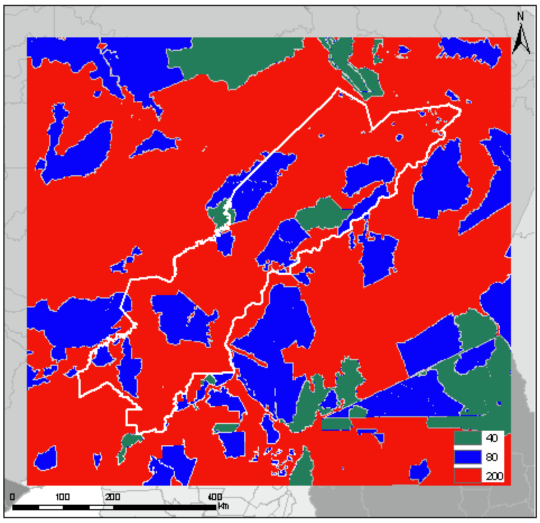


Fig. 17



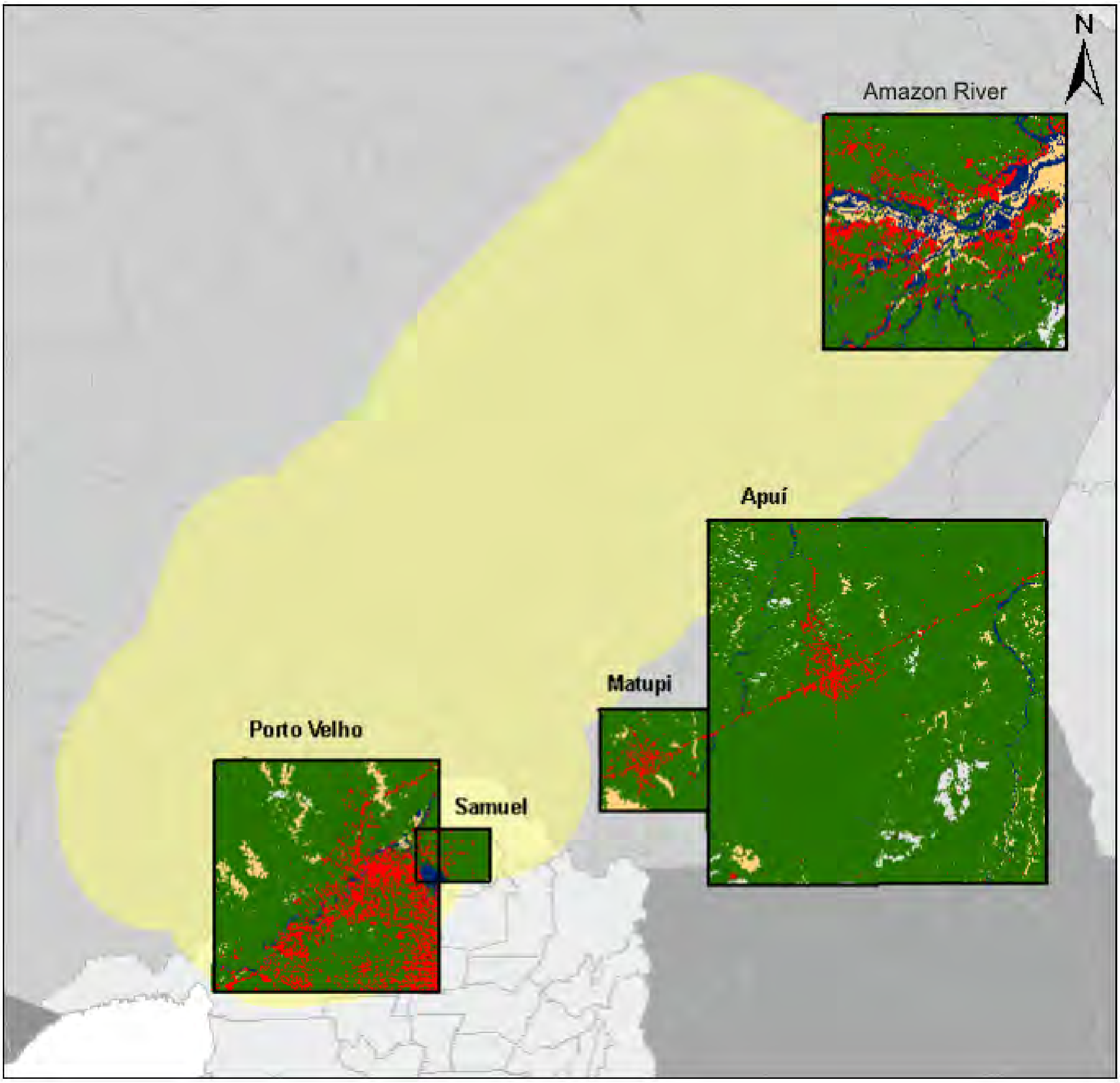


Fig. 18

Fig. 19

Model PRODES data

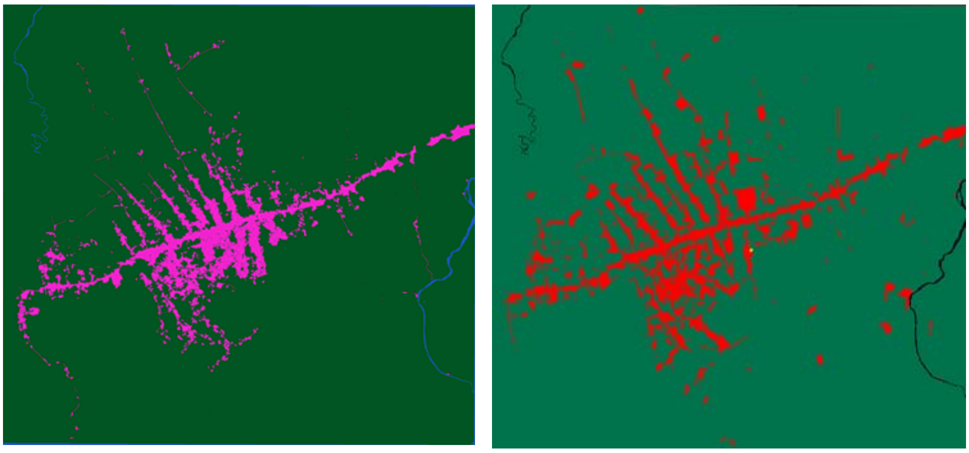


Fig. 20

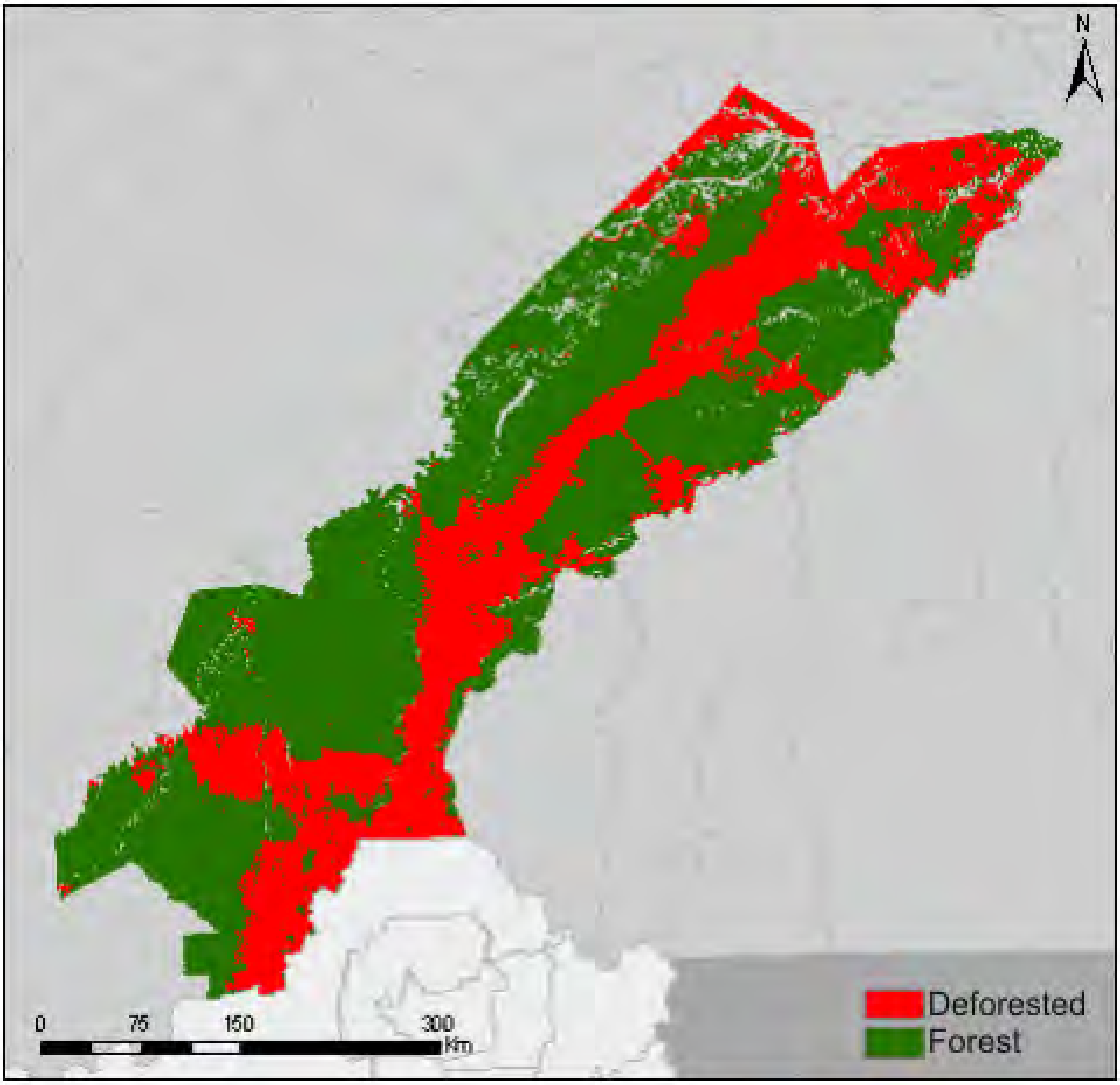
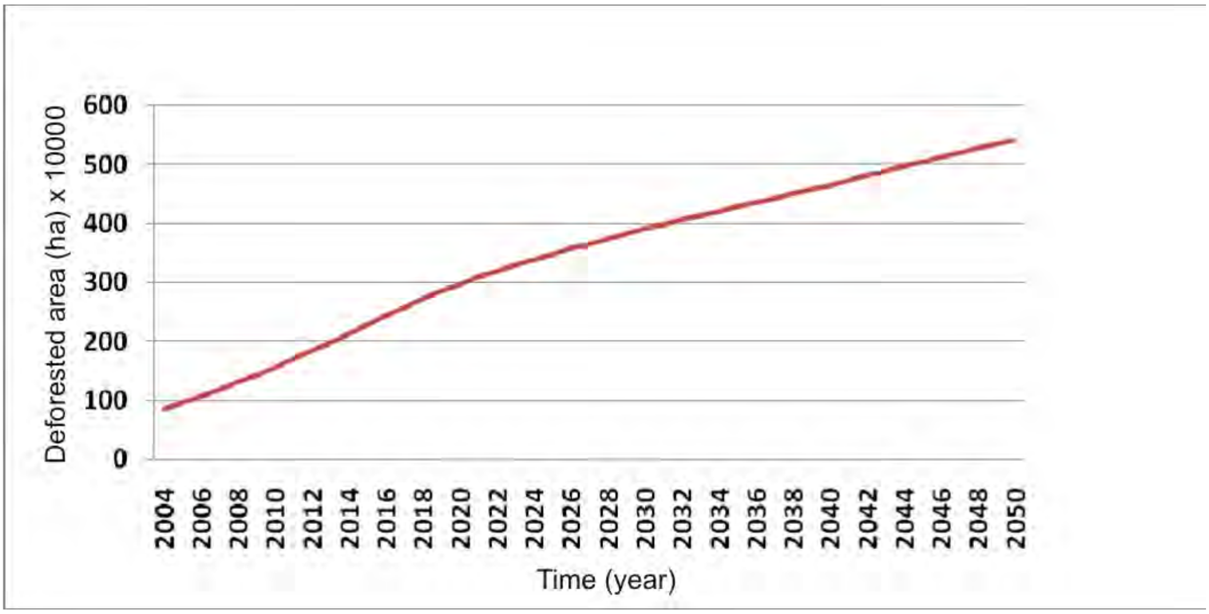


Fig.21



Deforested area (ha) x 10000
600
500
400
300
200
100
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
Time (year)

Fig. 22

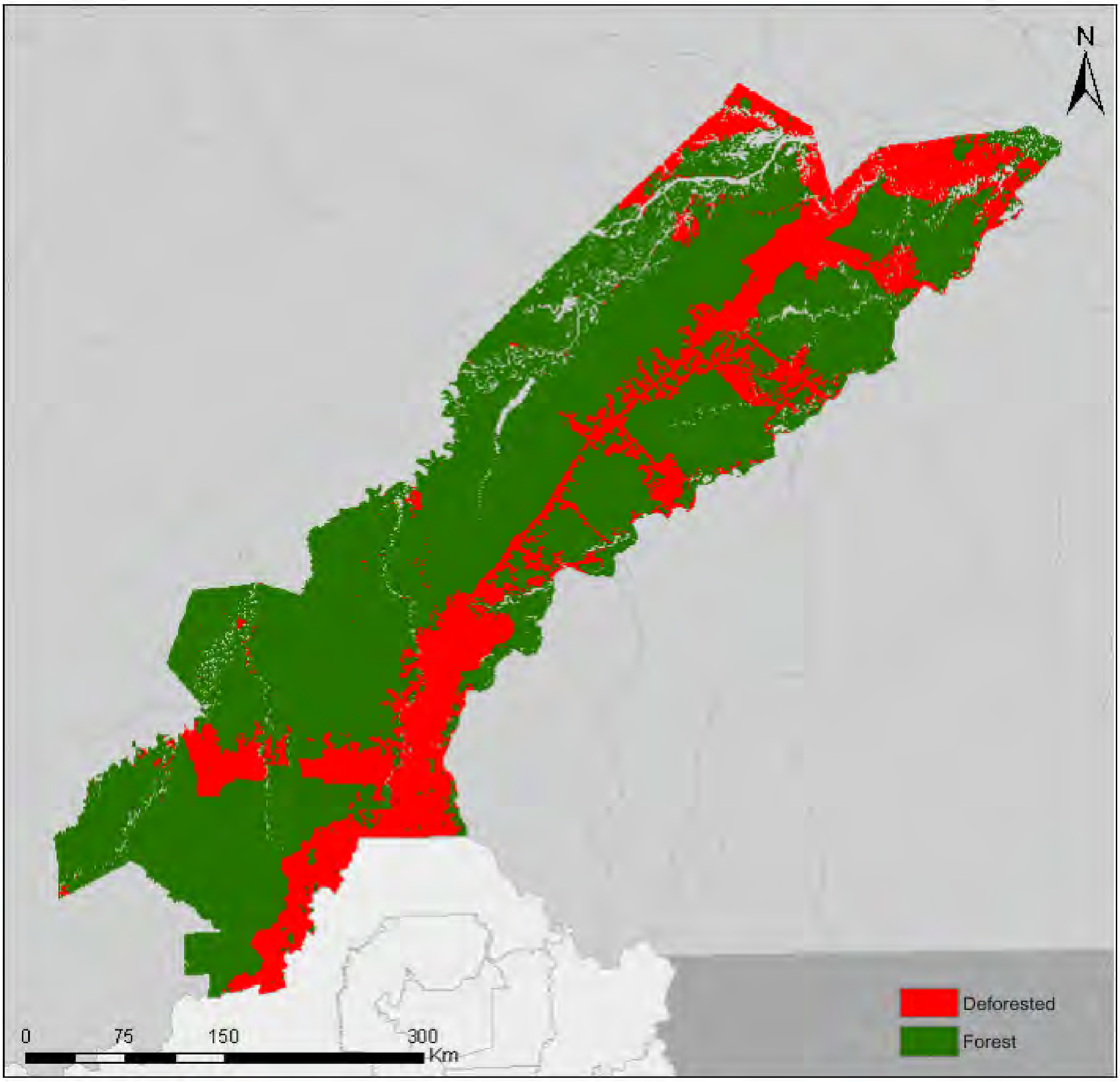


Fig. 23

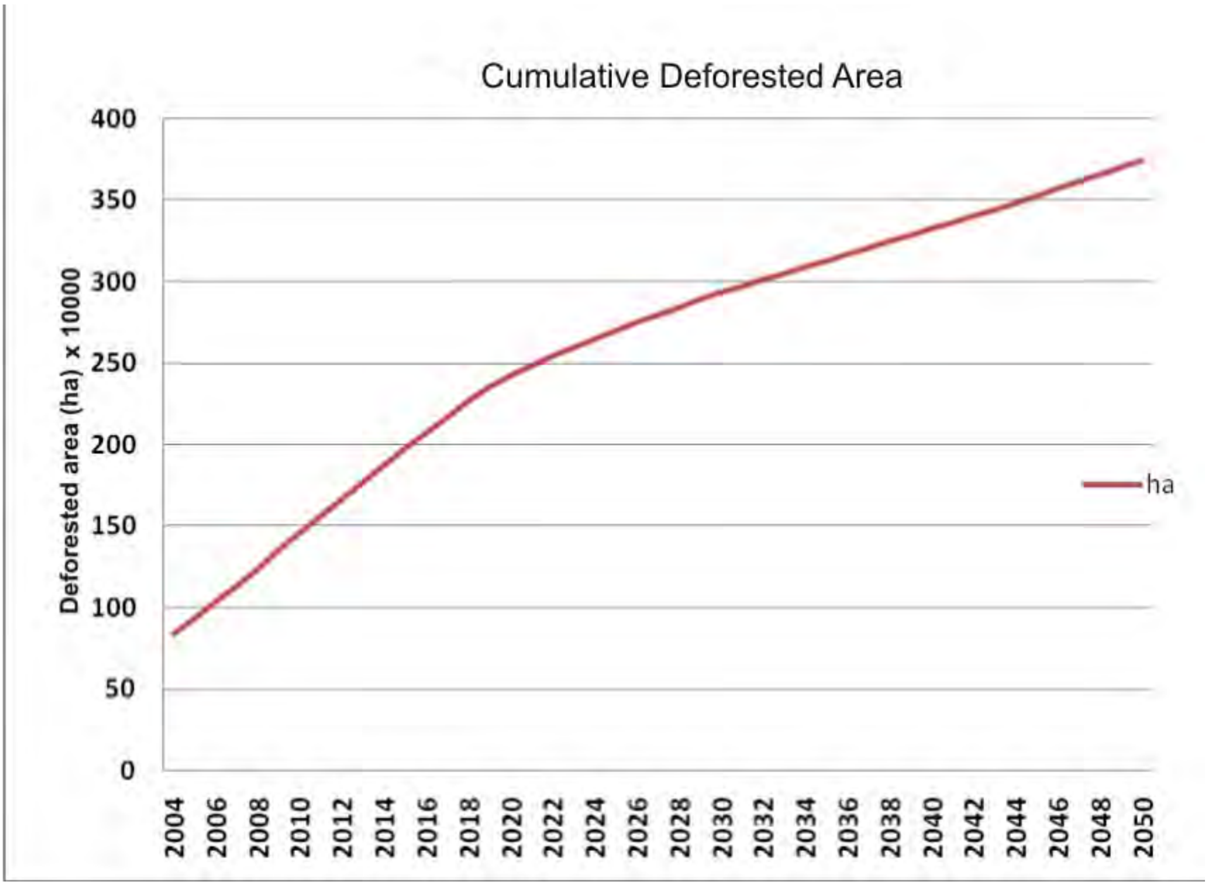

Cumulative Deforested Area
Deforested area (ha) x 10000
400
350
300
250
200
150
100
50
0
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
ha

Fig. 24

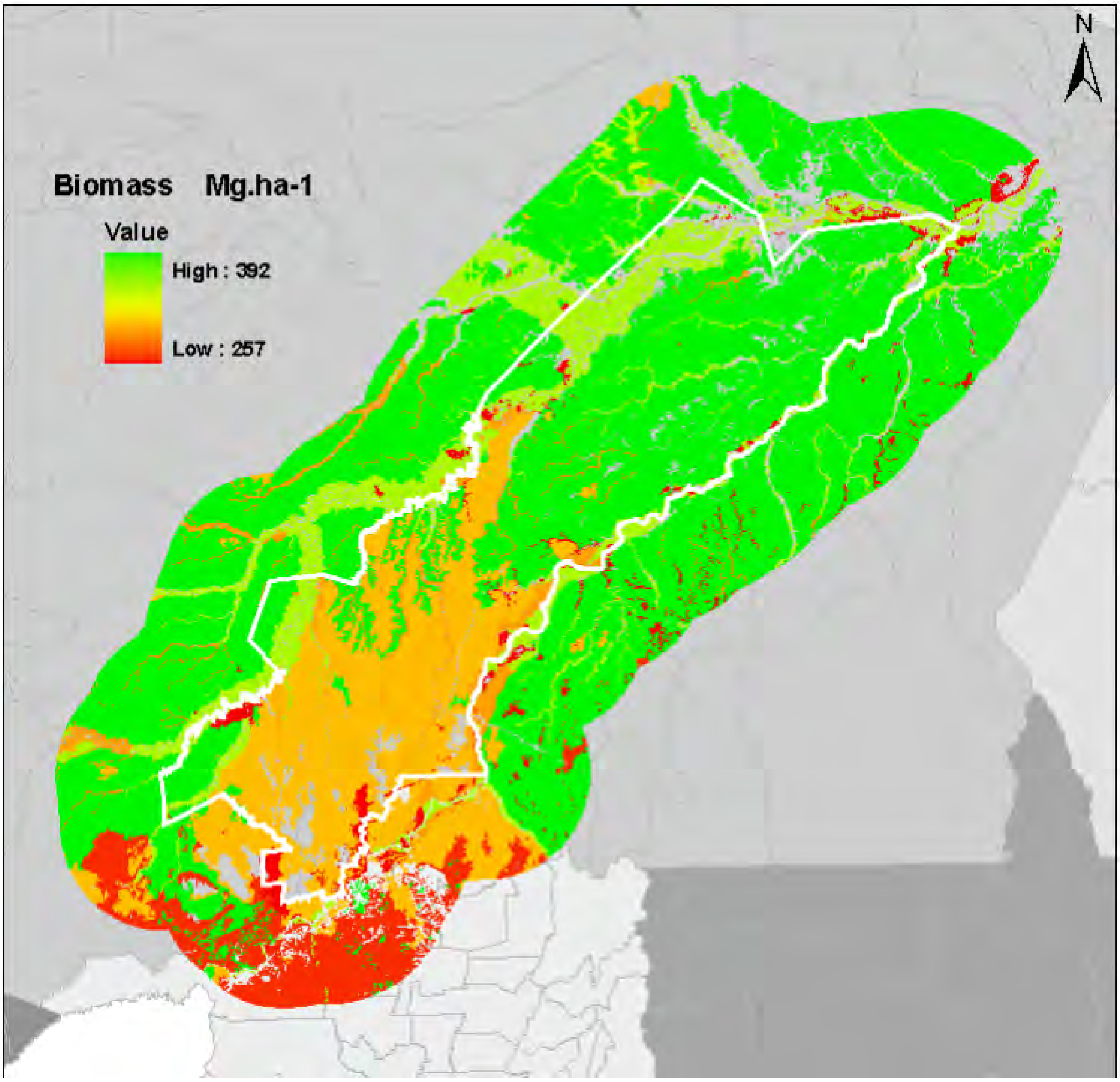


Fig. 25