Supplementary information to "Amazon Conservation Scenarios"

Roads to be paved

The most important determinant of future patterns of deforestation in the PanAmazon (defined as the Amazon river watershed, the Legal Amazon in Brazil, and the Guiana region) is the paving and construction of highways. Several paving projects are currently planned by the Brazilian government. A 700-km section of the BR-163 highway is slated for paving from the border of Mato Grosso and Pará states to Itaituba, linking the soy production region of Mato Grosso with the river transport system of the Amazon. Other paving projects planned for the Brazilian Amazon include the BR-230 (Transamazon Highway), BR-319 (Manaus-Porto Velho Highway), BR-156 from Amapá state to French Guyana, BR-401 from Roraima state to Guiana, as well as many others of secondary importance (Fig. S1). Outside of Brazil, highway paving is planned across the Andes, linking the lowland Amazon with Pacific ports including Callao in Peru and Arica in Chile. One of these highways (the Interoceanica) links Assis Brasil, in Acre, Brazil, to Puerto Maldonado and Cuzco or Puno in Peru; the other would link Cruzeiro do Sul, Acre, via Pucalpa, to Lima. Paving is also planned for the road from Cárceres, Mato Grosso state in Brazil to Santa Cruz city in Bolivia (Fig. S1). Santa Cruz is a burgeoning population center located inside the Amazon Basin with economic importance even greater than the capital La Paz owing to its large natural gas fields. The Cárceres-Santa Cruz corridor would become the shortest route linking the industrial and highly populated southeastern Brazil, through its agro-business central region, to the Pacific Ocean. Of course the impacts of proposed highway paving on land-use change, migration patterns, and the human populations that already live along these roads will depend upon the effectiveness of regional planning processes and other mitigation measures currently underway[1].

Although other infra-structure investments are also contemplated for the Amazon, including river channelization for fluvial transportation, port construction, hydroelectric plants, and gas pipelines[2,3,4], our analyses focus on the effect of road-paving on future trajectories of land-use change, since the effects of other infra-structure investments are highly uncertain. To incorporate the influence of this planned road paving into the simulations, we established a schedule of likely dates at which paving will be completed based upon analyses of government documents and conversations with government officials, setting the years of completion of all roads slated for paving within the next three decades (Table S1). These new all-weather highways will exert an effect on deforestation not only augmenting the regional rates, but also initiating new deforestation frontiers.

Table S1 Road paving schedule

key	code	road name	tracks to be paved	paving completion
1-1'	BR-230	Transamazônica	from *Araguatins* (TO) to *Itupiranga* (PA)	2008
2-2'	BR-230	Transamazônica	from *Itupiranga* (PA) to BR-163	2012
3-3'	BR-230	Transamazônica	from TO-040 to GO-118 and associated tracks in MA and TO	2025
4-4'	BR-163	Cuiabá-Santarém	from intersection to *Colíder* (MT) to BR-230 (Transamazônica)	2008
5-5'	BR-163	Cuiabá-Santarém	from BR-230 (Transamazônica) to *Santarém*	2008
6-6'			between Alta Floresta (MT) and BR-364, near Ariquemes (RO)	2025
7-7'	BR-319	Manaus-Porto Velho	from 160 km south of BR-174 southwards	2012
8-8'	BR-319	Manaus-Porto Velho	from 195 km south of BR-174 southwards	2018
9-9'	BR-210		from kilometer 75 to kilometer 175	2008
10-10'	BR-210		from kilometer 175	2025
11-11'	BR-401		from *Bomfim* (RR) to *Queenstown* (Guyana)	2012
12-12'	BR-156	Cayenne-Oiapoque	from 150km north of *Santana* (AP) to *Matoury* (French Guiana)	2018
13-13'			east of BR-158 southwards *Vila Rica* (MT)	2008
14-14'	BR-158		between 220km north of *Nova Xavantina* (MT) and 250km south of *Redenção* (PA)	2008
15-15'			east of BR-158, from 220km north of *Nova Xavantina* (MT)	2008
16-16'	MT-130		from 23km north of *Primavera do Leste* (MT) to the intersection of MT-110	2008
17-17'	BR-364		from *Chapada dos Guimarães* (MT) to BR-174;	2012
18-18'			from 85km east of MT-170 northwards	2012
19-19'			from 90km west of MT-170 northwards	2018
20-20'		Cáceres-Santa Cruz	between *Montero* and *San Matias* (Bolivia)	2012
21-21'	GO-255		from *Paranã* (TO) to TO-280	2008
22-22'	TO-280		from GO-255 to TO-040	2008
23-23'	5 N		from 10km west of *Vila Rica* eastwards *Tingo María* (Peru) to 16 N intersection	2018
24-24'	26 B	Interoceanica	from *Cuzco* to *Puerto Maldonado* (Peru) and from there to Assis-Brasil, Acre	2008
25-25’	3 S		from 100km to 300km westwards *Cuzco* (Peru)	2008
26-26’	BR-364, 16B, 5N		from *Cruzeiro do Sul* (AC) to *Mayobamba* (Peru)	2018
27-27’	BR-364		from 90km north of *Senador Guiomard* (AC) to *Feijó* (AC);	2008

Acronyms for Brazilian States: To - Tocantins, PA - Pará, GO - Goiás, MT – Mato Grosso, RO – Rondônia, RR- Rorâmia, AP – Amapá, AC – Acre. Road paving phases comprise: 2001-2008, 2008-2012, 2012-2018, 2018-2025, 2025-2051. Town names are in italic.

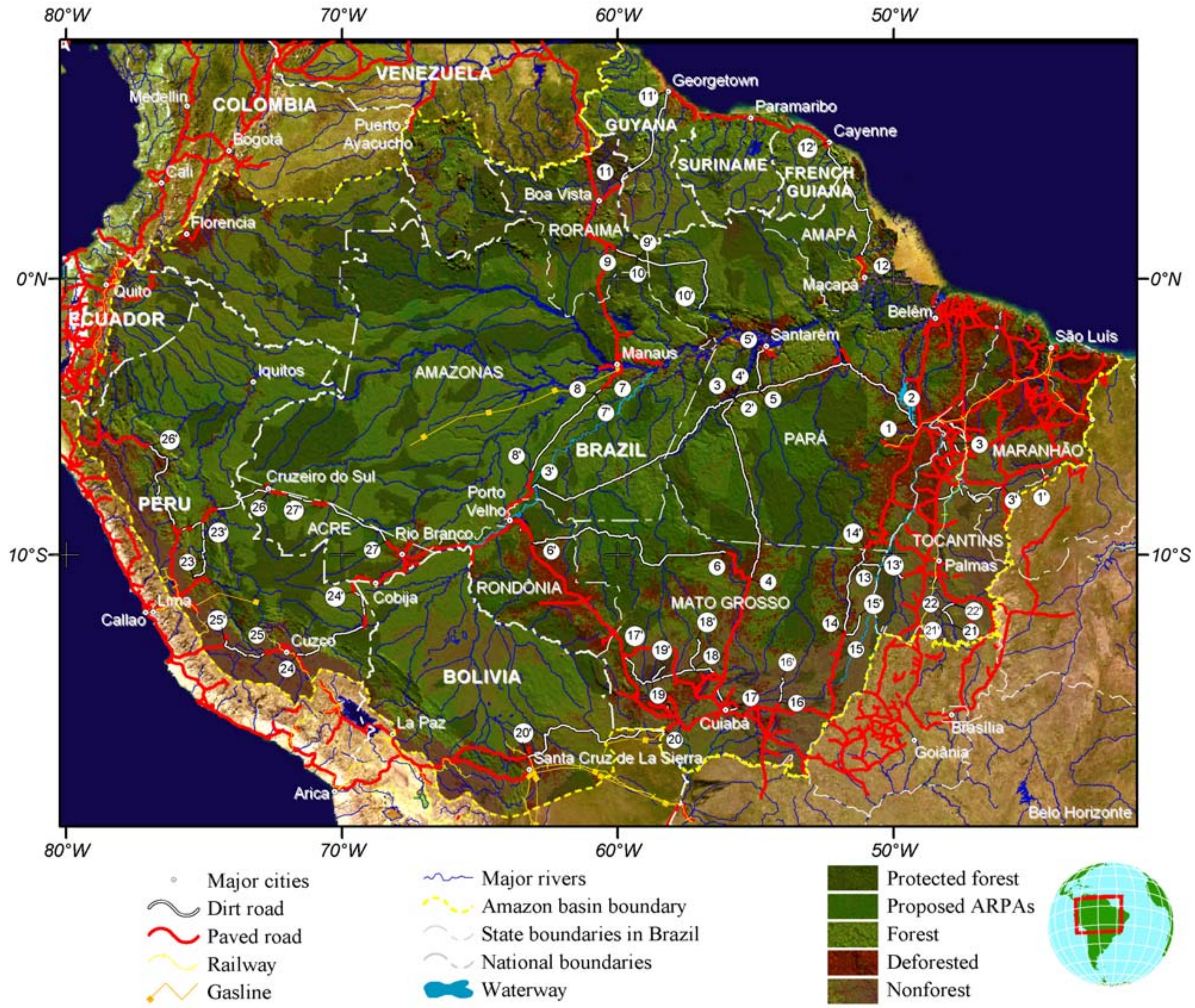


Fig. S1 – Amazon Basin, its major cities, paved and major dirt roads, and existing and proposed protected areas. Road to be paved are indicated by numbers keyed to the paving schedule of Table S1.

General approach

The model architecture embodies coupled models developed within two spatial structures: (1) subregions defined from socioeconomic stratification (Fig. S2) and (2) raster cells. Forty-seven subregions were defined using an anthropogenic pressure index, which was developed to measure the potential for deforestation as determined by socioeconomic and demographic growth[5]. An upper model projects the deforestation rates for the subregions, processing data on deforestation (Table S2), road paving (Table S1), and existing and proposed protected areas (Table S2), and passes them to a spatially explicit simulation model that uses cartographic data for infrastructure (roads, railways, gas pipelines, waterways, and ports), administrative units (state and national boundaries and protected areas), and biophysical features (topography, soil, and vegetation) within a raster grid map of 3144x4238 cells at 1 km^2 resolution. Each subregion therefore has a unique spatial model with customized parameters, consisting of 1) a cellular automata type model that simulates the spatial patterns of deforestation, incorporating a probability map depicting the integrated influence of cartographic data on the location of deforestation, and 2) a *road constructor* model that projects the expansion of secondary road network, and thereby incorporates the effect of road expansion on the evolving spatial patterns of deforestation.

We ran the model for eight scenarios encompassing 50 annual time steps starting in 2001. The baseline scenario, referred to as "business-as-usual" (BAU), considers the deforestation trends across the basin, projecting regional rates by using 2001-2002's figures and their average yearly derivatives determined from 1997 to 2002 (Table S2), and adding to them the effect of paving a set of major roads. The best-case "governance" scenario also considers the paving of a set of major highways and the current deforestation trends across the basin, but now the rate projection assumes an inverted U-curve to reflect the gradual increase of governance throughout the Amazon[1,6]. In these scenarios, road paving follows a predefined schedule (Table S1) and its effect on accelerating deforestation is empirically estimated comparing density of deforested land with mean distance from current paved roads within Brazilian municipalities. Within the governance scenario, deforestation cannot surpass 50% of the forest cover outside of protected areas as required by governmental regulations, while in the business-as-usual scenario this limit is set to 85%. The minimum areas of forest remnants in the business-as-usual (15%) and governance (50%) scenarios are lower than that currently required by the Brazilian government, but we determined that these minima more realistically bracket the range of forest remnant values that will be attained (Fig. S3). Notice that Brazil is the only country to possess such restriction on deforestation on private land, although Venezuela has a moratorium on deforestation and logging for its Amazonian region – specifically the State of Amazonas[7]. The governance scenario also assumes that the network of protected areas will be expanded in the Brazilian Amazon as proposed in the "Áreas Protegidas da Amazônia" (Protected Areas of the Amazon) program – ARPA[8]. Full protection of conservation areas is guaranteed in the governance scenario, whereas, in the business-as-usual scenario, existing protected areas may lose as much as 40% of their original forest cover due to lax enforcement[9]. As a result, deforestation declines as the percentage of deforested land within a subregion approaches these preset limits.

Six intermediate scenarios were also run by varying the following assumptions for the extreme-case scenarios: 1) governance scenario without further road paving 2) governance scenario without the inclusion of ARPA, 3) BAU with expansion of the protected area network to include ARPA plus strict enforcement to guarantee their integral protection, 4) BAU without ARPA plus strict environmental enforcement within protected areas, and 5) BAU with ARPA in a lax environmental enforcement scenario, in which protected areas may lose as much as 40% of their original forest cover, and 6) historical, which assumes only the deforestation historical trend (Table S3).

Table S2 Input data for the subregions

country	Sub	area	forest 2001	deforested 2001	nonforest	2001 gross deforest.	2001 net deforest.	annual derivative	protected forest	pr. forest + ARPAS
Brazil	1	43,775	30,768	10,780	2,227	515	1.67%	5.44%	1,166	22,326
	2	207,144	189,637	8,788	8,719	274	0.14%	15.71%	107,922	167,687
	3	56,179	2,756	21,117	32,306	383	13.89%	2.21%	304	335
	4	40,748	1,158	3,097	36,492	11	0.94%	2.68%	63	63
	5	269,210	162,883	56,170	50,157	1558	0.96%	19.43%	61,412	78,548
	6	85,834	71,849	8,665	5,320	834	1.16%	8.76%	44,472	62,821
	7	175,963	110,351	4,316	61,297	381	0.35%	6.72%	70,765	80,626
	8	39,236	3,093	8,240	27,903	63	2.03%	2.11%	63	63
	9	102,103	74,971	20,207	6,925	1178	1.57%	3.08%	21,482	54,648
	10	52,980	49,804	2,098	1,078	119	0.24%	6.03%	18,631	24,875
	11	30,617	19,978	7,512	3,128	443	2.22%	6.63%	6,275	10,365
	12	88,403	9,157	3,896	75,350	79	0.87%	1.40%	2,804	2,821
	13	138,838	123,394	8,366	7,078	439	0.36%	7.04%	39,049	56,894
	14	60,846	30,976	22,462	7,408	1111	3.59%	2.73%	20,471	20,652
	15	69,300	30,445	9,251	29,603	421	1.38%	1.03%	15,437	20,948
	16	163,545	124,632	7,736	31,176	452	0.36%	12.27%	36,327	79,395
	17	37,934	15,422	20,456	2,056	718	4.66%	3.95%	5,059	5,059
	18	191,112	22,222	20,250	148,640	531	2.39%	1.94%	4,721	5,020
	19	30,111	16,271	13,297	544	759	4.66%	23.88%	890	6,630
	20	38,437	20,486	14,095	3,857	462	2.26%	1.86%	17,007	17,007
	21	73,766	25,785	32,654	15,327	807	3.13%	3.73%	3,446	7,289
	22	205,397	186,245	15,409	3,742	831	0.45%	2.99%	51,972	87,649
	23	54,334	598	5,862	47,875	27	4.47%	0.48%	24	24
	24	106,149	71,947	16,476	17,726	541	0.75%	8.64%	12,432	30,347
	25	40,972	23,784	14,181	3,007	1160	4.88%	11.77%	2,515	3,130
	26	53,804	23,459	12,623	17,722	355	1.51%	3.94%	14,859	14,901
	27	1,647,690	1,481,503	27,080	139,107	1373	0.09%	6.84%	552,217	716,897
	28	227,186	43,877	122,608	60,702	1513	3.45%	8.98%	19,313	19,313
	29	247,891	204,721	24,898	18,272	1475	0.72%	6.54%	71,420	81,264
	30	348,886	82,577	53,262	213,047	1598	1.93%	2.48%	19,235	27,709
	31	123,495	73,870	34,869	14,756	2137	2.89%	2.37%	9,559	17,347
	32	137,145	15,139	37,046	84,961	719	4.75%	1.86%	4,187	4,437
Brazil's total		**5,189,032**	**3,343,757**	**667,766**	**1,177,508**	**23266**	**0.70%**		**1,235,497**	**1,727,090**
Suriname	33	**147,479**	**133,119**	**2,086**	**12,274**	**242**	**0.18%**	0.27%	**17,265**	**17,275**
Venezuela	34	**184,265**	**160,130**	**12,776**	**11,359**	**553**	**0.35%**	2.24%	**57,165**	**57,165**
Ecuador	35	**116,947**	**94,745**	**8,540**	**13,663**	**388**	**0.41%**	2.96%	**22,513**	**22,513**
Guyana	36	**215,409**	**182,233**	**7,390**	**25,786**	**210**	**0.12%**	2.24%	**6,035**	**6,235**
Peru	37	473,714	405,179	24,825	43,710	510	0.13%	0.40%	72,507	72,507
	38	308,544	95,215	37,979	175,349	260	0.27%	2.96%	39,045	39,045
	39	106,404	95,789	5,664	4,952	128	0.13%	0.27%	47,424	47,424
	40	84,861	80,865	1,246	2,751	331	0.41%	2.96%	40,603	40,603
Peru's total		**973,523**	**677,048**	**69,713**	**226,762**	**1,230**	**0.18%**		**199,578**	**199,578**
Bolivia	41	63,756	56,278	1,358	6,120	75	0.13%	2.31%	7,739	7,739
	42	174,898	80,315	6,475	88,108	665	0.83%	2.31%	29,845	29,845
	43	214,509	66,075	1,301	147,133	83	0.13%	2.31%	8,919	8,919
	44	235,287	127,955	30,187	77,144	1,077	0.84%	2.31%	14,781	14,781
Bolivia 's total		**688,450**	**330,623**	**39,322**	**318,505**	**1,900**	**0.57%**		**61,284**	**61,284**
Colombia	45	240,938	231,848	511	8,579	292	0.13%	0.40%	95,478	95,478
	46	204,147	158,658	28,791	16,698	650	0.41%	2.96%	44,205	44,205
Colombia's total		**445,085**	**390,506**	**29,302**	**25,276**	**942**	**0.24%**		**139,683**	**139,683**
F. Guiana	47	85,301	78,760	285	6,257	**143**	**0.18%**	0.27%	**0**	**0**
Amazon		**8,045,491**	**5,390,921**	**837,180**	**1,817,389**	**28,882**	**0.54%**		**1,739,024**	**2,230,901**

areas in km^2, annual derivative ($\Delta fd_{t.}$) is an average calculated from the difference between 1997-2000, 2000-2001, and 2001-2002 annual deforestation rates.

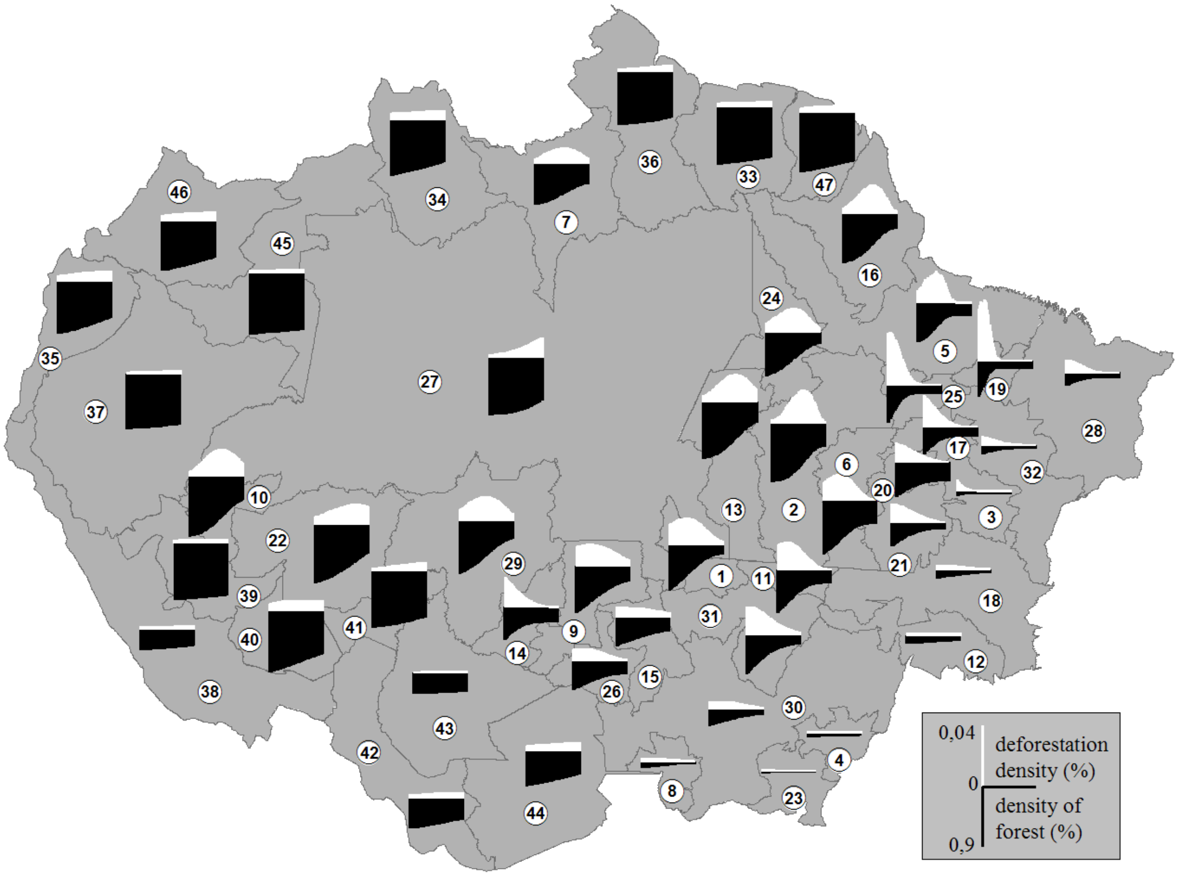


Fig. S2 – Stratification of the Amazon Basin, depicting annual deforestation and forest decline from 2001 to 2050 forecast for the subregions within the BAU scenario. Numbers are keyed to subregions' data in Table S2.

Table S3 Scenario assumptions

scenarios	assumptions: road paving pressure added to the deforestation trend	ARPA included in protected areas	degree of protection for protected areas	minimum % of forest reserve on private land	rates projected by using yearly derivatives	rates asymptotically projected by using yearly derivatives
governance (GOV)	yes	yes	100%	50%	no	yes
governance without further road paving	no	yes	100%	50%	no	yes
governance without ARPAS	yes	no	100%	50%	no	yes
BAU with ARPAS, strict enforcement	yes	yes	100%	15%	yes	no
BAU without ARPAS, strict enforcement	yes	no	100%	15%	yes	no
BAU with ARPAS, lax enforcement	yes	yes	60%	15%	yes	no
historical (no further road paving)	no	no	60%	15%	yes	no
business-as-usual (BAU)	yes	no	60%	15%	yes	no

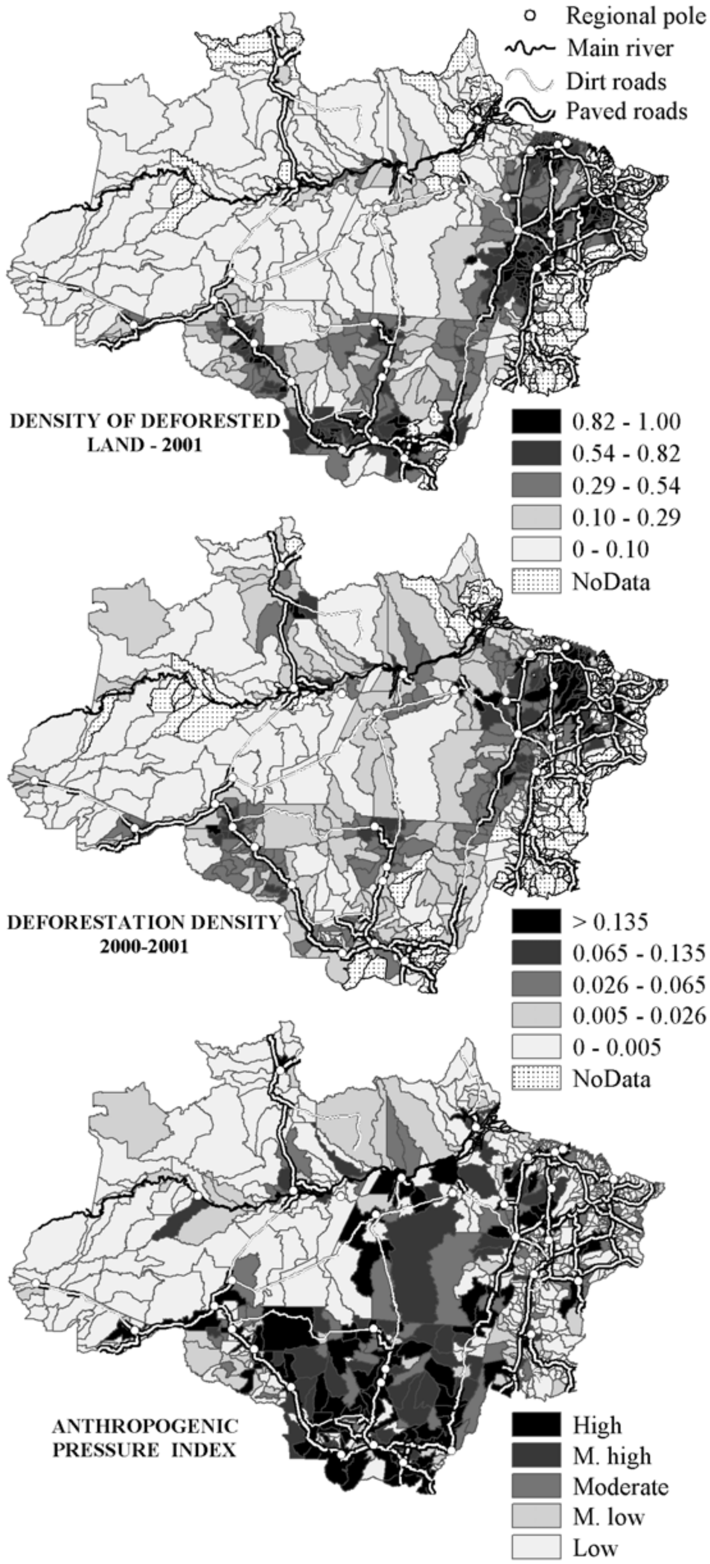


Fig. S3 – Density of deforested land % (deforested land/(municipality's area - nonforest)), deforestation density % (deforestation/municipality's area), and anthropogenic pressure index for the Brazilian Amazon's municipalities. Land cover change from PRODES[10].

Basin stratification

Deforestation rates vary greatly across the basin due to regional differences, including soils, climate, socioeconomic organization, government systems, public policies, environmental laws and degree of enforcement, population characteristics and dynamics, as well as types and age of frontiers. Thus, it is unrealistic to employ a model that projects a single deforestation rate for the entire basin. Instead, the Amazonian basin must be stratified into subregions representative of a network of cities and their surrounding zones of influence. In light of Christaller's *central place* theory[11], we interpret the geographical organization of the Amazon as a hierarchy of regions attracted to central urban markets that possess the greatest supply of services and thus higher economic potential. To address this issue, we developed a method for stratifying the Brazilian Amazon into subregions, which utilizes a synthetic anthropogenic pressure index, tertiary economy level, and regional migratory fluxes[5].

This stratification is developed by first classifying the municipalities according to their intrinsic anthropogenic pressure, an index we developed to measure the potential for deforestation as determined by socioeconomic and demographic growth[12]. It is calculated by applying the Grade of Membership (GOM) fuzzy classification method[13] to demographic, socioeconomic and agriculture census data, such as population density and growth rate, urbanization level and rate; gross domestic products, municipal income taxes and budget; number and types of agricultural implements; production from animal husbandry, agriculture, and forestry; and education, habitation and health parameters. These data were stratified into a five-dimensional space, with axes that we named: (1) demographic concentration and dynamics; (2) economic development; (3) agrarian infrastructure; (4) agricultural and timber production; and (5) social development, which were combined to produce the anthropogenic pressure index for each municipality (Fig. S3). A positive effect on the anthropogenic pressure index is ascribed for the first four dimensions, and a negative effect for the fifth. In a second step, regional development centers were identified and ranked with respect to their supply of services[14], referred to here as the "tertiary economy", as follows.

$$TI_i = \frac{TDP_i}{GDP_i} * (1 - e^{\frac{\ln(0.05) * TDP_i}{TDP_{ref}}}) \tag{1}$$

where TI_i is a ratio between the tertiary economy domestic product (TDP_i) and the gross domestic product ($GDPi$) of a municipality i, standardized by a reference tertiary economy domestic product (TDP_{ref}), specifically the largest regional TDP_i.

Once a hierarchy of regional poles is established, which can include a varying number of economic centers depending on a chosen cut-off threshold, the interaction between a center and a municipality is calculated by the following equation:

$$Iv_{IJ} = \frac{P_I(1 + API_I) * P_J(1 + API_J)}{d_{ij}^{\xi}} \tag{2}$$

where Iv_{ij} represents the gravitational interaction between center i and municipality j, given by their populations (P_i and P_j) and anthropogenic pressure indices (API_i and API_j), weighted by the distance between them raised to the power of ξ, an attrition coefficient so that:

$$\xi = 1 + e^{\left(\frac{\ln(0.001)}{vmt_{ref}} * vmt_{IJ}\right)} \tag{3}$$

where vmt_{ij} is the overall migratory flux between pole i and municipality j and vmt_{ref} is the reference migratory flux, namely the largest intermunicipal migratory flux.

Thus Iv_{ij} measures the dependence of a municipality upon a regional center defined as the attraction exerted by the center's population plus its anthropogenic pressure. This dependence is strengthened by two-way migratory fluxes and weakened by the geographical distance.

The stratification is achieved by assigning to a particular regional center all municipalities where its respective Iv_{ij} is greatest. As shown in Fig. S2, the regionalization map for the Brazilian Amazon is comprised of 32 subregions, to which were added 15 additional subregions, defined for the other countries based only on geographical criteria of contiguity and basin interiority due to paucity of census data.

Data for deforestation projections

Input data for each subregion consist of deforestation rate and its average annual derivative, as well as areal extent of remaining forest, deforested land and protected areas (Table S2). Land cover map for the entire basin is a composite of 2001's PRODES[10], 2000's SPOT Vegetation Map of South America[15], classified 2001's MODIS vegetation continuous field[16], and Bolivia deforestation maps[17]. For the Brazilian Amazon, PRODES data from three time-periods (1997-2000, 2000-2001, 2001-2002) were employed to derive the 2001-2002's deforestation rates and their average annual derivatives within the 1997-2002 period. For Bolivia's subregions, 2001-2002's deforestation rates and their annual derivatives were extrapolated from data compiled[18] from two deforestation mapping projects[17,19]. Because systematic deforestation map series are not available for the remaining subregions that occur in other countries, deforestation rates and their annual variation were assigned by applying figures from subregions of Brazil that were considered similar in frontier type and age (Table S2).

The deforestation projection model

This upper model was implemented in VENSIM, a system-thinking software[20]. This model is designed to project deforestation for each subregion, processing data on historical deforestation, road paving, and existing and proposed protected areas (Tables S1 and S2). Therefore, it generates the deforestation scenarios under which the lower spatial simulation model runs. Deforestation, at a time t, for a basin's subregion is calculated as follows:

$$deforestation_t = forest_t * fd_t \tag{4}$$

where $forest_t$ is the remaining forest within each subregion and fd_t is the net deforestation rate at a time t such that:

$$fd_t = fd_{t-1}(1+\Delta fd_t *(1+acc\_f * ddratio_t)*sat_t \tag{5}$$

Initial net deforestation rate ($fd_{2001/2002}$) is obtained dividing 2001-2002's deforestation by 2001's remaining forest (Table S2). The term Δfd_t represents the average annual derivative of the deforestation rate; acc_f is a constant, between 0 and 1, used to impose a delay in adjusting the deforestation rates in response to the surging pressure coming from road paving, as represented in the equation by $ddratio_t$. Thus, we designed the net deforestation estimate to incorporate a time-lag between the completion of road paving within a subregion and the deforestation that it stimulates. Simulations employ acc_f =4.3, set to make the BAU projection approximate the average forecast deforestation of sensitivity analysis (Fig. S4). In turn, the term sat_t represents an asymptotic saturation factor, as described in equation (10), and the annual derivative of the deforestation rate (Δfd_t) is given as follows:

$$\Delta fd_t = lg\_f_t * \mathrm{ran}(h\_\Delta fd, \mathrm{abs}(mean\_\Delta fd - h\_\Delta fd)) \tag{6}$$

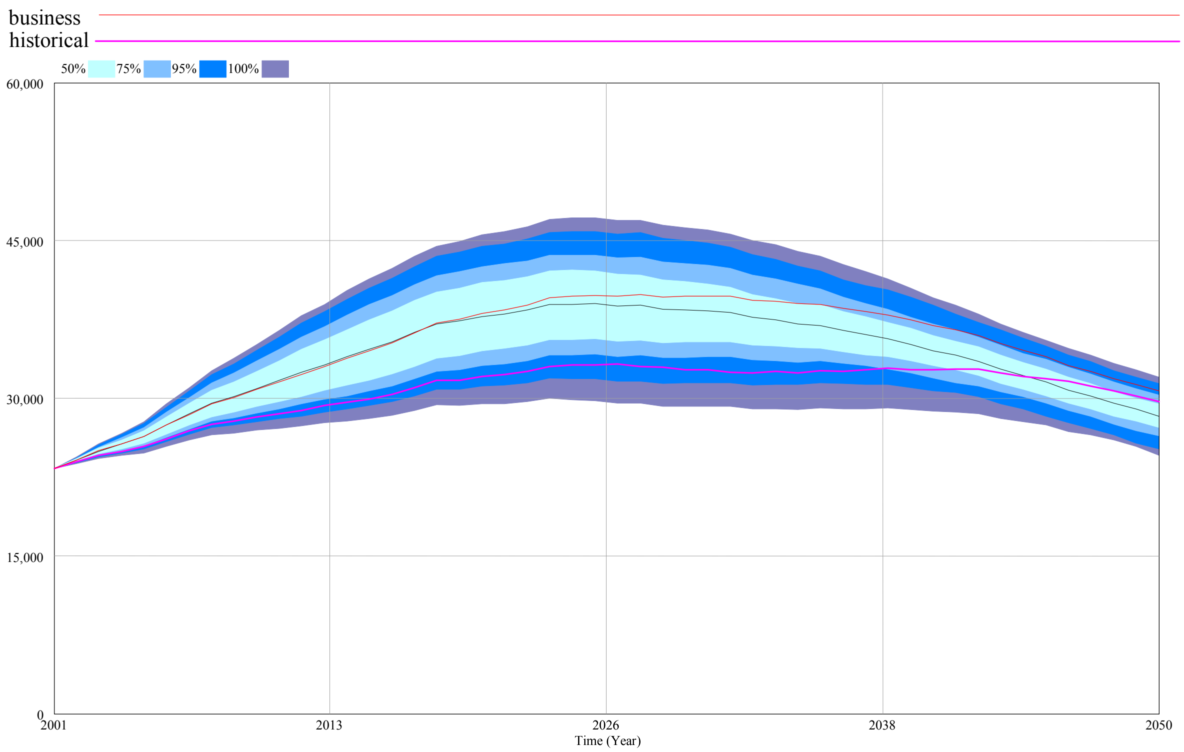


Fig. S4 - Deforestation forecast for the Brazilian Amazon. Output from sensitivity analysis varying forest remnant percentage from 0.1 to 0.2, percentage of protected forest core from 0.6 to 0.8, and acc_f from 0 to 1. acc_f = 0.43 was set to approximate the mean forecast deforestation (black line).

Due to few time periods available to estimate the deforestation rate derivative, subregion's values for this variable were approximated to a regional mean ($mean\_\Delta fd_t$), used together with its historical average ($h\_\Delta fd_t$, Table S2) as input parameters - mean and variance - to a random number generating function – *ran*. For the Brazilian subregions, regional mean annual variations were derived from PRODES deforestation data for the Brazilian states from 1997 to 2002[10], and 1.6% was used for all the other countries. In the business-as-usual scenario, the logistic factor (lg_f_t) is set to 1, leaving Δfd_t constant with only minor random oscillations. For the governance scenario, Δfd_t is projected using lg_f_t output by a logistic curve, that varies as a function of time t (equation 7). In this manner, the model considers that all the measures incorporated within this scenario[1] gradually reduce the current deforestation trend.

$$lg\_f_t = -1 + \frac{0.076}{\left(1 + \exp(0.067 * (-2050 + t)\right)} \qquad 7)$$

The effect of paving a major road through a subregion on its deforestation rate is expressed by the term $ddratio_t$, which is a ratio between an expected density of deforested land owing to the average proximity to paved road and the subregion's current density of deforested land.

$$dd\ ratio_t = \frac{exp\_den\_def}{deforested_t/(forest_t + deforested_t)} \qquad (8)$$

where *deforested* and *forest* represent, respectively, the current areal extents of deforested land and remaining forest for a subregion. The term *exp_den_def* stands for the density of deforested land expected to occur within a certain subregion, incorporating its mean distance to a paved road (Fig. S5), which is preset according to the model's sequence of road paving (Table S1). A regression analysis supplies the coefficients for equation (9), in which *mean_d2paved_road* is the mean distance to paved road in kilometers for a subregion. In this manner, road paving produces an upward effect on deforestation, since *mean distance to paved road* diminishes over time as new road tracks are paved (Fig. S1).

$$exp\_den\_def = 1/(0.050873) * mean\_d2paved\_road + 1.00762) \qquad (9)$$

The asymptotic saturation factor (sat_t) in equation (5) is calculated as follows:

$$sat_t = \frac{forest_t - min\_forest}{forest_t + min\_forest} * \frac{forest_{2001} + min\_forest}{forest_{2001} - min\_forest} \qquad (10)$$

where $forest_t$ and $forest_{2001}$ represent, respectively, the extent of remaining forest for time t and 2001 and *min_forest* is given by:

$$min\_forest = \%for\_re * (forest2001 - prot\_for) + \%prot\_for\_core * prot\_for \qquad (11)$$

The asymptotic saturation factor (sat_t) is introduced in order to compute the influence of protected areas (*prot_for*) and the minimum percentage of forest remnants (*%for_re*), as preset for each scenario, in slowing deforestation.

In sum, the governance scenario departs from the business-as-usual scenario through: (1) the minimum percentage of forest remaining outside of protected areas, reflecting a range of both government land use policies and their enforcement; (2) the expansion, or not, of the Brazilian protected area network to include ARPA; (3) the enforcement of protected areas; and (4) the gradual reduction of deforestation rates below historical rates (Table S3, Figs. S6 and S7).

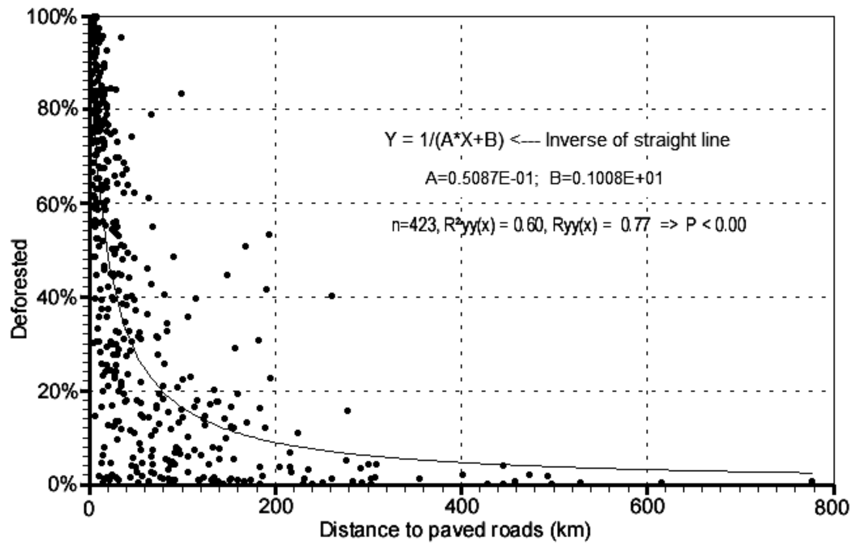


Fig. S5 – Percent of deforested land as a function of distance to paved roads, derived for Brazilian Amazon's municipalities using PRODES 2001 and mean distance to current paved roads.

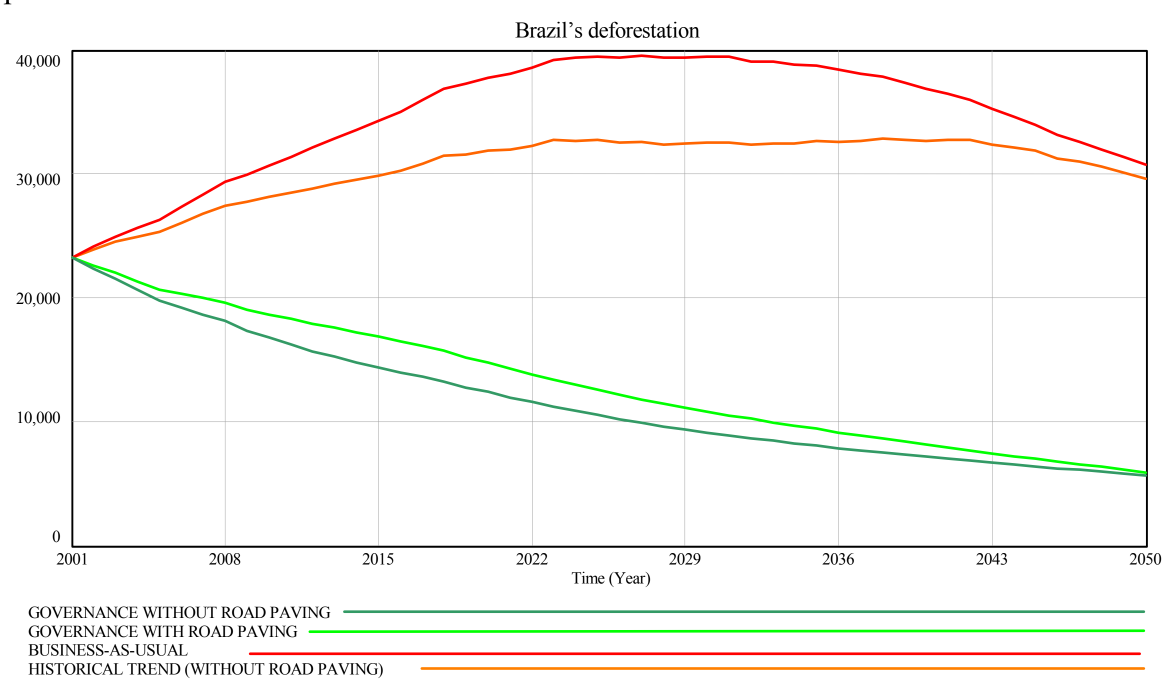
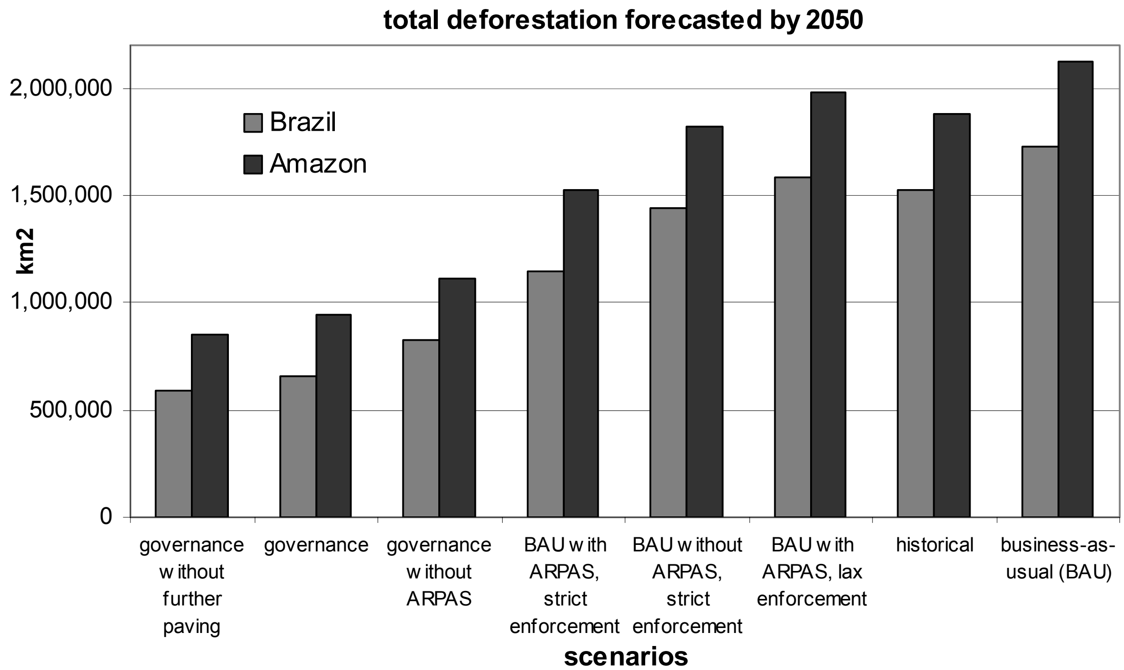


Fig. S6. Forecast deforestation for the Brazilian Amazon for various scenarios.



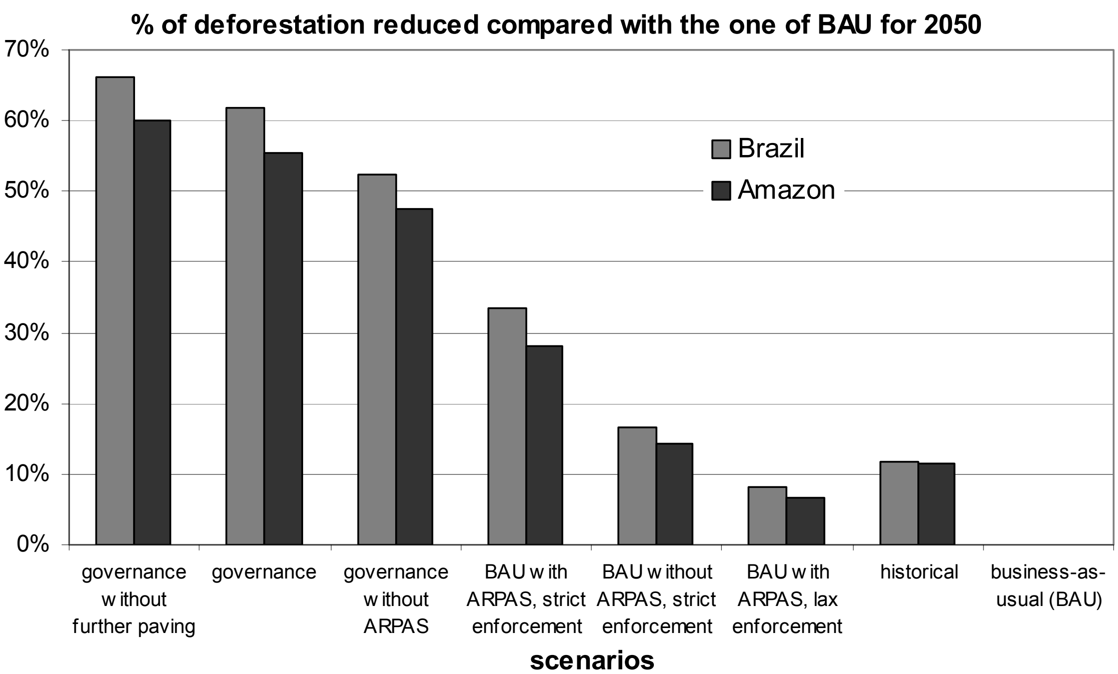


Fig. S7 – Total deforestation* forecasted by 2050 for 8 scenarios and percent of deforestation reduced in each scenario by 2050 using the BAU scenario as a baseline.

**Because the resolution, quality and availability of data sets vary greatly across the basin with Brazil having much better data available than the other countries, the model's results should be viewed as average thresholds that may be reached over the analyzed period rather than as absolute figures.*

Spatially explicit simulation

The spatial model aims to simulate the evolving spatial patterns of deforestation taking into consideration proximate-cause and biophysical variables[21]. Spatially-explicit simulations of deforestation therefore attempt to quantify and to integrate the influences of variables, representing biophysical, infrastructure, and territorial features (e.g. topography, rivers, vegetation, soils, climate, proximity to roads, towns and markets, and land use zoning), on the spatial prediction of deforestation[9]. To incorporate these spatial variables into the simulation, we have developed a cartographic database consisting of a land cover map and ancillary cartographic layers structured into one subset of static data layers and a second subset of dynamic data layers (Fig. S8).

The land cover map for the entire basin, used as the initial landscape in the simulation, is a composite of 2001's PRODES[10], 2000's SPOT Vegetation Map of South America[15], classified 2001's MODIS vegetation continuous field[16] and 1993's Bolivia deforestation map[17]. For Brazil, PRODES 2001 map, at an original resolution of 60 meters, was vectorized and stamped on a 1 km^2-resolution raster. This procedure ensured the capture of fine spatial patterns of deforested land with only minor distortion (Fig. S9). The same procedure was applied to Bolivia data and the resulting composite map was either updated or data gaps were filled in with the SPOT Vegetation map and a deforested mask derived from the 2001's MODIS vegetation continuous field. Finally, a non-forest mask, obtained from vegetation maps[22,23], was laid over the land cover map composite.

Dynamic data layers include: distance to previously deforested land, distance to non-paved roads, and distance to paved roads. Hence, the cartographic database comprises two layers of roads, one of non-paved and another of paved roads. Due to its semi-dynamic character, the latter variable was represented by five different layers depicting sequential phases of road paving, as defined by the simulation paving schedule (Table S1). Roads compiled from various sources (Table S4) were updated by visual interpretation of ortho-rectified Landsat images made available by Tropical Rain Forest Information Center (TRFIC)[24]. Using this database, spontaneous roads (also known as endogenous) were extensively mapped for all the Brazilian Amazon and added to the non-paved road layer.

Static data layers include soil and vegetation maps, an urban attraction factor, altitude, slope, distance to major rivers, distance to gas pipelines and railways, and protected areas. Soil, vegetation, gas lines, railways, hydrographic and topographic data come from various sources (Table S4). Soil and vegetation layers are composites of the more detailed available data. Urban attraction factor is meant to represent the influence of urban centers on deforestation and was calculated using a unidirectional gravity-type model, as follows.

$$Ua_{i,j} = \sum_n \frac{Pop_n}{d^2_{i,j}} \tag{12}$$

where $Ua_{i,j}$ is the urban attraction in a rural cell *i,j*, exerted by summing the populations from all urban centers (Pop_n) in the basin and surrounding major South American cities, weighted by their distances (d) to the rural cell *i,j*.

Protected areas include national and state natural reserves, conservation units, parks and indigenous reserves[25]. For the governance scenario, proposed protected areas by ARPA[8] program were added to the exiting network.

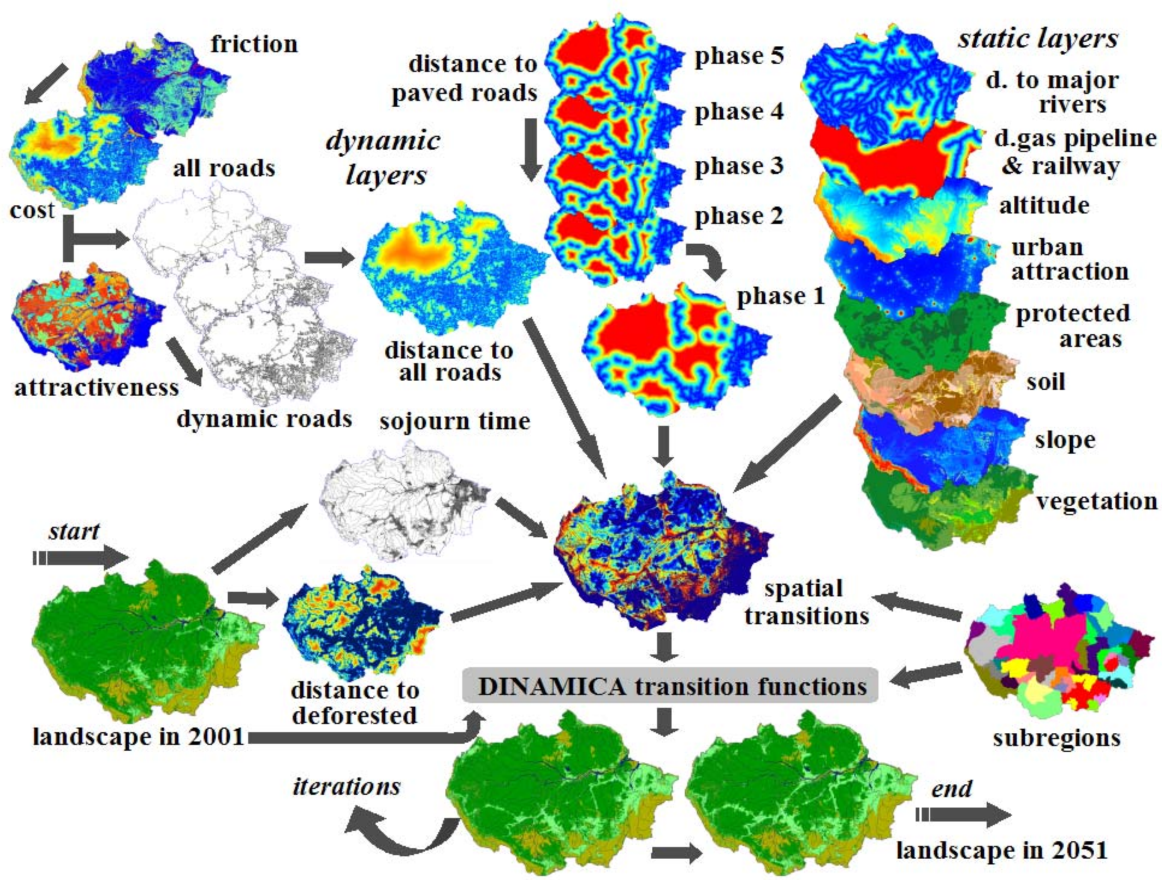


Fig. S8 - Input, derived, and simulated maps with respect to the spatial model architecture.

Table S4 Cartographic data used in the simulation

Layer	Brazil	other countries
land cover (landscape)	INPE (2004); Eva *et al*. (2002); UMD/GLCF (2004)	Eva *et al*. (2002); UMD/GLCF (2004); Steininger et al. (2001)
subregion boundaries	IBGE (2000a)	ESRI (2002); WHRC/IPAM/CABS (2002)
roads	GuiaQuatroRodas (2004)	MM (2001); Berndtson & Berndtson (2001).
major rivers	ESRI (1992); WHRC/IPAM/CABS (2002)	ESRI (1992)
topography	NASA/USGS (2004)	NASA/USGS (2004)
towns & population	IBGE (2000a, b)	FRG (2003)
pipelines & railways	WHRC/IPAM/CABS (2002)	WHRC/IPAM/CABS (2002)
soil	MNE (1973)	FAO (1998)
vegetation	MNE (1973)	WWF (2002)
protected areas	MMA (2004); IUCN & UNEP (2003)	IUCN & UNEP (2003)

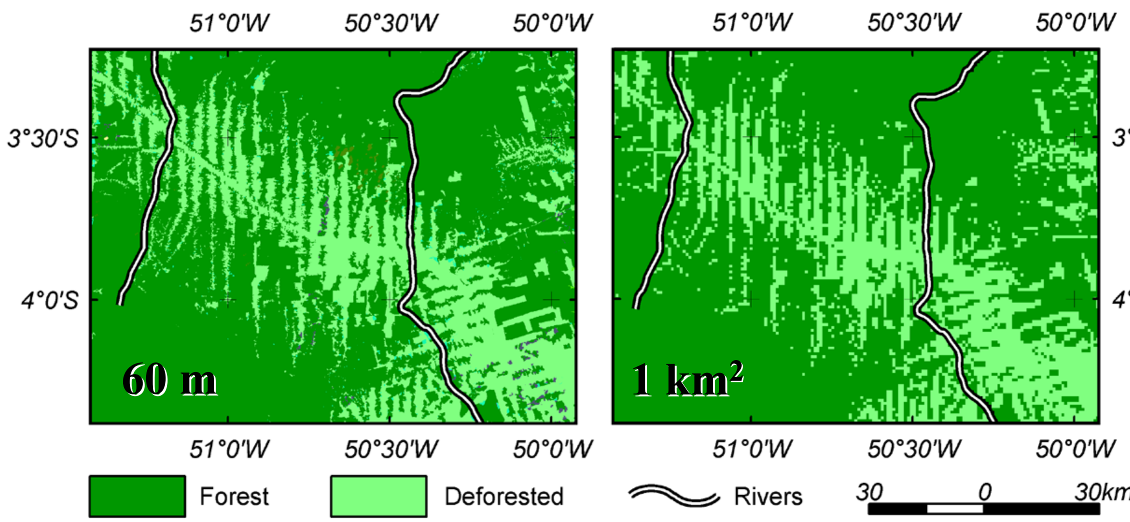


Fig. S9 –Land cover patterns at 60 meters and 1 km^2 resolutions.

Simulation platform

The spatially explicit simulation runs on DINAMICA software[1,26,27]. Among other features, DINAMICA incorporates the concept of phase – defined as a set of time steps with customized parameters. Following the highway paving schedule (Table 1), the simulation time span was divided into five phases, uptading for each new phase the "distance to paved road" layer. Because deforestation tends initially to concentrate in corridors along major roads[1], the expansion of the paved road network drives deforestation to new radiating axes as a new phase begins.

Geographical analyses of deforestation demonstrate that deforestation is both spatially and temporally autocorrelated[28,29,30]. DINAMICA embodies this feedback effect through the calculation of dynamic variables, *i.e.* input variables that are updated after each iteration.

Three types of dynamic variables are included: frontage distance to land cover class, sojourn time, and distance to roads. The first is used to calculate and update the layer "distance to deforested land", the second is applied to track time since the cell has changed its state, and the third is output from the *road constructor* model, a component that drives the expansion of the secondary road network[1]. As input, the *road constructor* model employs a layer of all existing roads, a friction map – used to derive an accumulated transport cost surface -, and an attractiveness map that indicates the areas most likely to be reached by new roads (Fig. S8). In this way, the simulation model also incorporates the effect of road expansion on the evolving spatial patterns of deforestation. Road expansion was set to occur in pulses, first by forming lengthy access routes and then a network of side roads, generating as a result the typical fishbone structure commonly found in the Brazilian Amazon. By setting the parameters: 1) average road segment length per step, and 2) number of map quadrants used to plot road terminations, the road constructor model was adjusted to simulate a road network that slightly exceeds the deforestation front.

Spatial variables can be used to calculate probability (also referred to as "favorability") maps of deforestation. Previous analytical modeling of tropical deforestation included mostly methods such as *multivariate linear regression*[31,32], *logistic regression*[28,33,34,35,36] or *Weights of Evidence*[1]. We applied the *Weights of Evidence* method to analyze the effects of spatial variables on the location of deforestation[9]. This analysis was conducted out in 12 case study areas representative of different types of Amazonian agricultural colonization frontiers, each one comprising a Landsat/TM scene. (Fig. S10). The *Weights of Evidence* models were assessed comparing simulations of 1977-2000 deforestation, with the favorability maps as input, with PRODES 2000's map using image similarity tests based on a fuzzy multiple resolution comparison[9]. Deforestation simulated using *Weights of Evidence* models achieved spatial agreements up to 83% within a window size of 5x5 cells[9], ≈ 1.25 km of resolution.

In general, the *Weights of Evidence* analysis showed that deforestation is attracted by urban centers, avoids both low flooded terrain and elevated and steep slopes; is not influenced by soil quality and vegetation type, and does not necessarily follow the major river network.

Of special interest, this analysis identified the variables "distance to previously deforested land" and "distance to roads" (including paved and non-paved) to be the strongest predictors of deforestation and demonstrated the importance of indigenous reserves on deterring deforestation along the active frontier. The supplied weights of evidence coefficients (Fig. S10) were employed to calculate a favorability map of deforestation - input for the simulation at the basin level -, as follows:

$$P(i \Rightarrow j(x,y)|V) = \frac{e^{\sum_k Wkn_{i \Rightarrow j(V)} xy}}{1 + \sum_{ij} e^{\sum_k Wkn_{i \Rightarrow j(V)} xy}} \tag{13}$$

where V is a vector of k spatial variables, measured at location x,y and represented by its weights W^+_{1xy}, W^+_{2xy}, ..., W^+_{nxy}, being n the number of categories of each variable k. In this way, weights of evidence are assigned for categories of each variable represented by its cartographic layer.

Spatially-explicit simulations were performed for a subset of scenarios processed by the upper projection model, using a land cover map composed of 3144x4238 cells of 1 km^2 resolution, and the model was set to run for a time span of 50 annual time steps starting at 2001. This scenarios subset included the two-extreme case scenarios: 1) governance and 2) business-as-usual (BAU), plus 3) governance without further road paving and 4) historical scenarios. For the BAU scenario, we ran three additional spatial simulations, each isolating the specific effect of paving the following highways: 2) Br-163, 3) Interoceanica, and 4) Manaus-Porto Velho, the two first highways with paving completion by 2008 and the latter by 2010. See detailed results of these runs on www.csr.ufmg.br/simamazonia.

To avoid the time-consuming calibration process - since simulation duration increases exponentially as a function of the cell resolution (e.g., 2 hours and 42 minutes for 2 km^2 and 9 hours and 55 minutes for 1-2 km^2 mixed resolutions on a 3.0 gigahertz PC processor) -, DINAMICA can employ multiple resolution data in a single simulation run. In this way, the input data were divided into two groups according to their resolutions: landscape, sojourn time and road layers at 1 km^2 and static, friction, attractiveness layers at 2 km^2. Besides increasing the performance of some procedures such as the calculation of distance to roads, this feature also reduces the amount of memory required to load the data set. Because DINAMICA's vicinity-based transition functions are set in hectares, the simulation could be fine-tuned using a multi-scale approach, first at 2-km cell and thereafter applying the final simulation script on the 1 km^2 data.

As described above, the simulation is structured in two spatial levels: raster and subregions. Using the concept of subregions, DINAMICA retrieves from a single database a subset of data to perform the subregion's simulation. Each subregion has a unique spatial model with customized parameters, including the coefficients for the *Weights of Evidence*, transition rates, density and length of road segments per step, and average size and shape of the deforestation patches to be formed by the cellular automata transition functions. This allows a very flexible way to set and conduct simultaneous simulations across the various regions of the Amazon basin. Spatial integration between subregions are attained by computing chorographic variables, such as distances to roads and to previously deforested land, continuously over the entire landscape raster map.

In sum, the spatially explicit simulation model features multi-scale vicinity-based transition functions, the concept of phases and subregions, the use of data at various resolutions, feedback through the calculation of dynamic spatial variables, linkage between cellular automata and system thinking software, computation of spatial transition probabilities using *Weights of Evidence* method, and a component that drives the expansion of the road network. Additional information on the model and its results are available at: www.csr.ufmg.br/simamazonia.

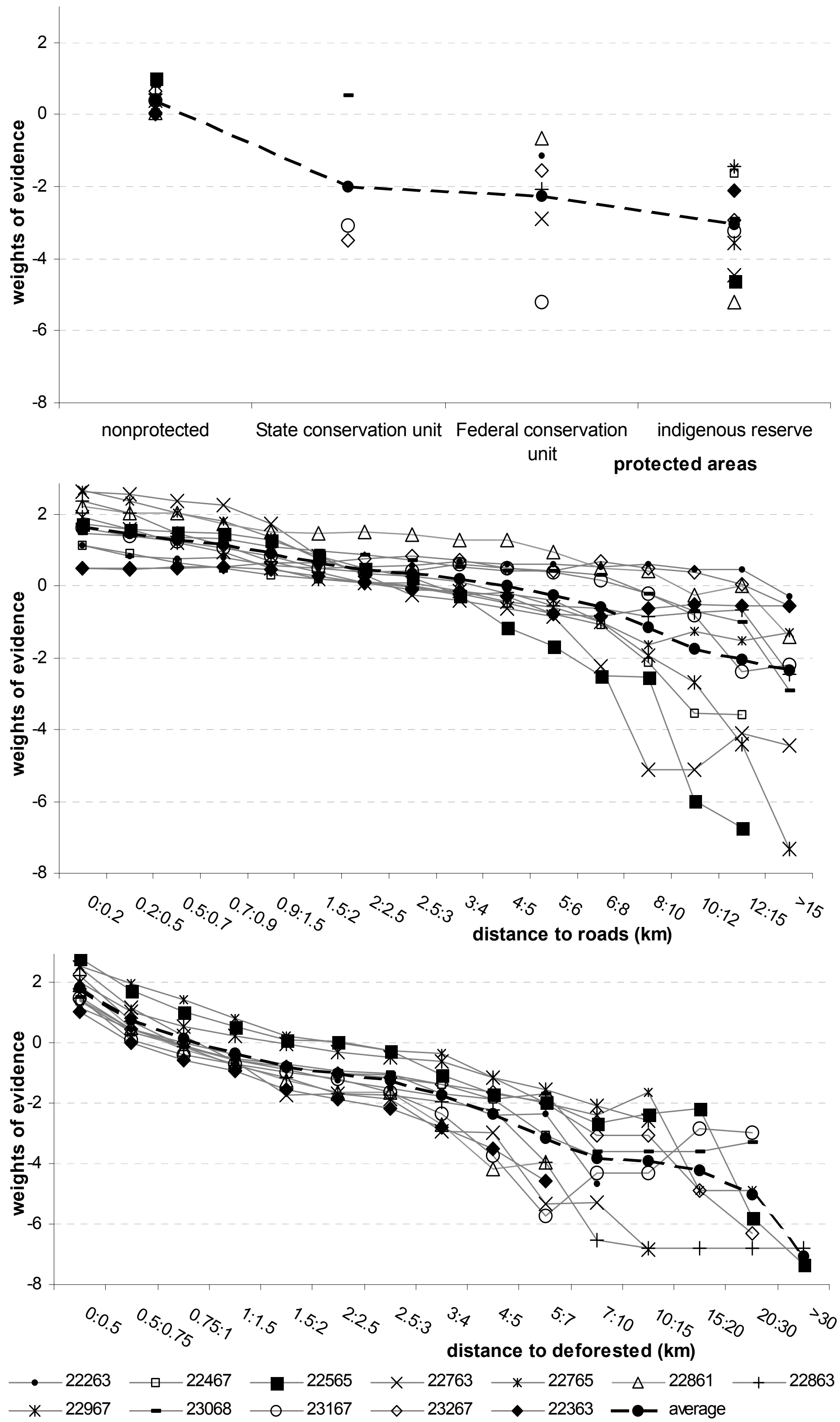


Fig. S10 – Weights of evidence derived for the case study areas. Numbers refer to orbit-points of Landsat scenes.

Disaggregated effects of highway paving

We disaggregated the effects of highway paving by running the model for three additional scenarios, which incorporate all the business-as-usual assumptions, but now have only a single highway paved: 1) the BR-163 (Cuiabá-Santarém) and 2) the Interoceanica (Assis Brasil-Cuzco) paved in the year 2008, and 3) the Manaus-Porto Velho highway paved in the year 2010. The influence of paving each highway alone is analyzed, comparing deforestation forecast within their areas of influence with the results of the historical (current trend but no further road paving), governance without further road paving, and governance scenarios (Fig. S11-S13 and tables S5-S7).

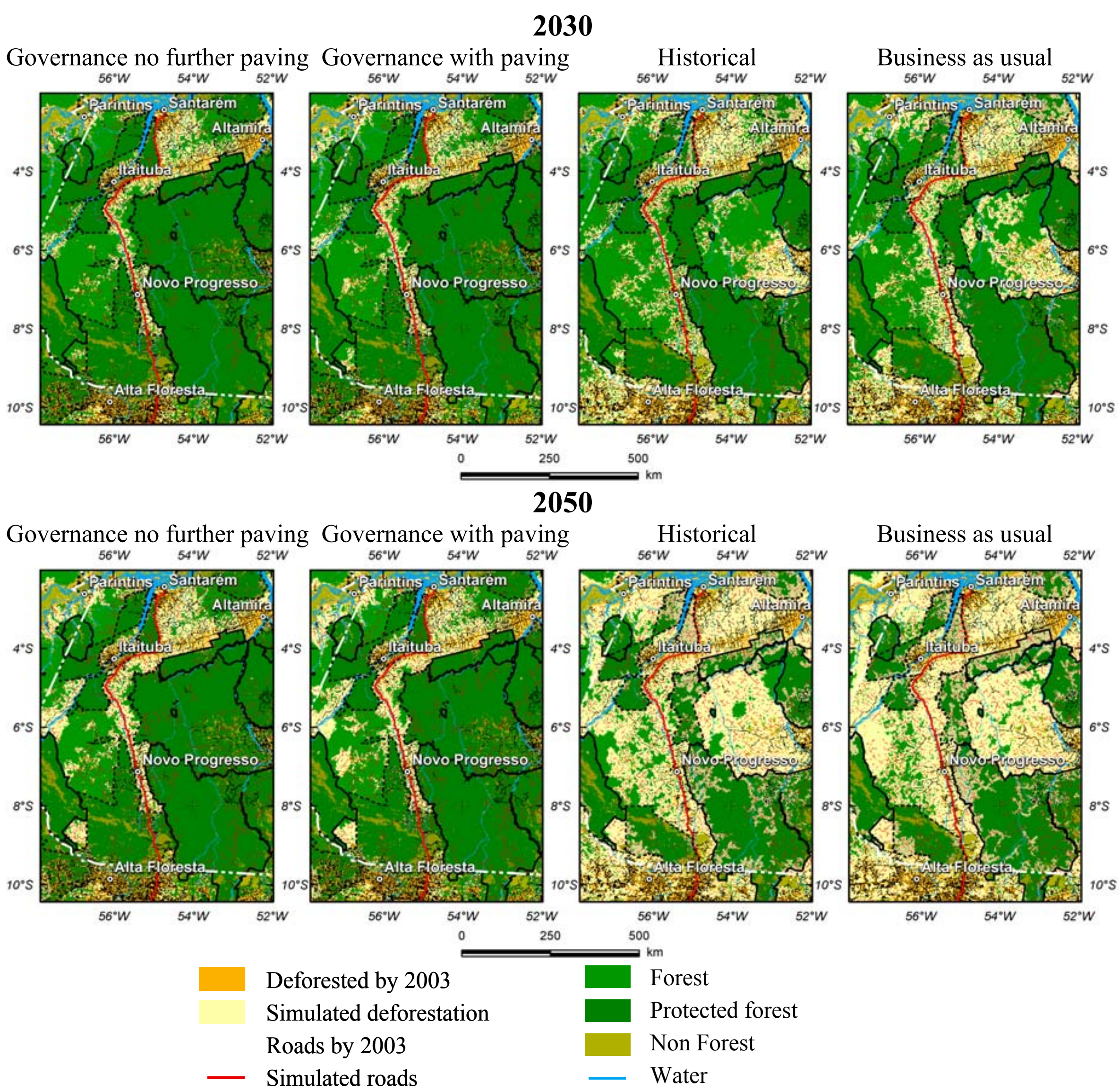


Fig. S11- Results for BR-163 area of influence.

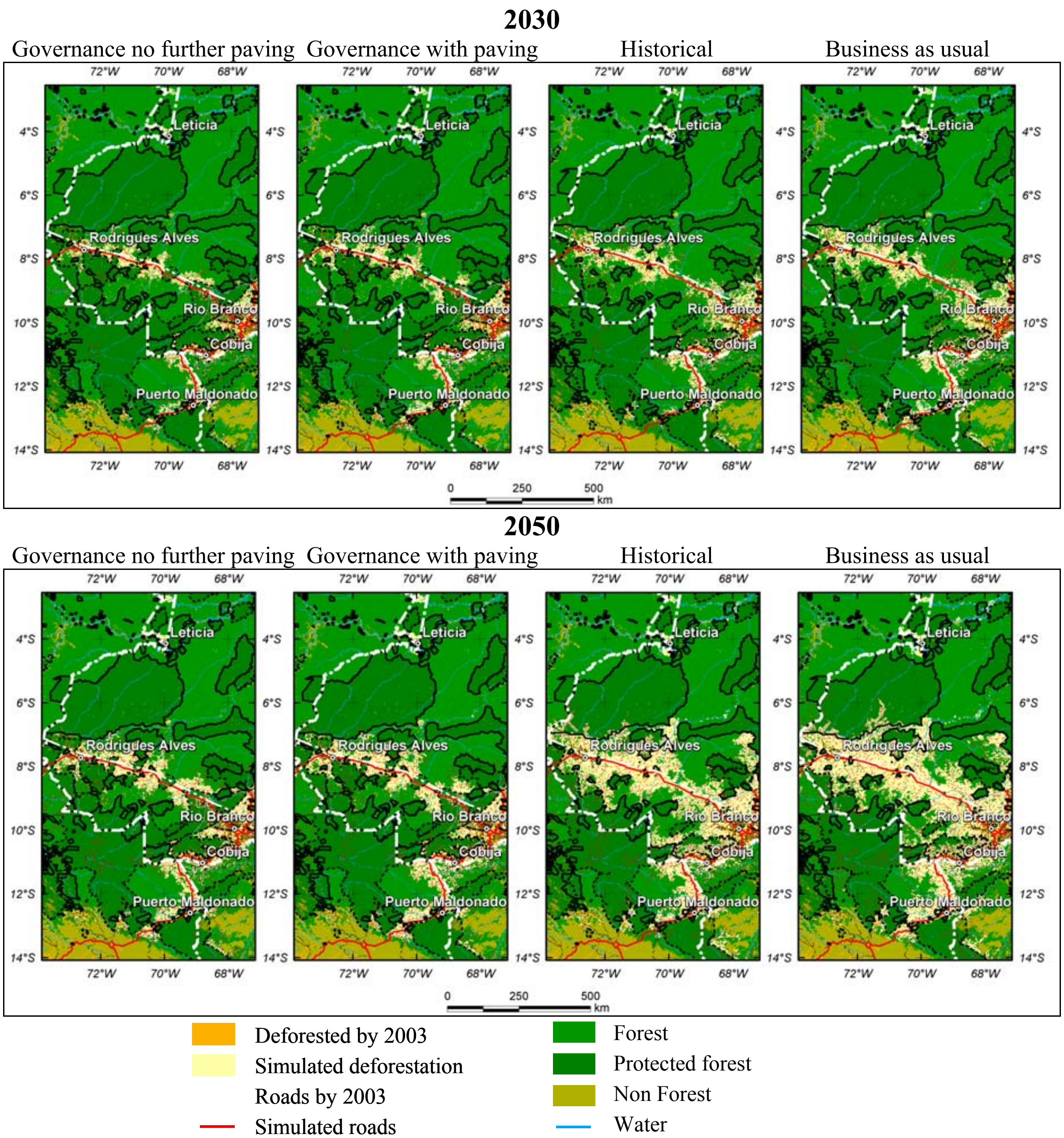


Fig. S12 - Results for Interoceanica highway (Assis Brasil- Cuzco) area of influence.

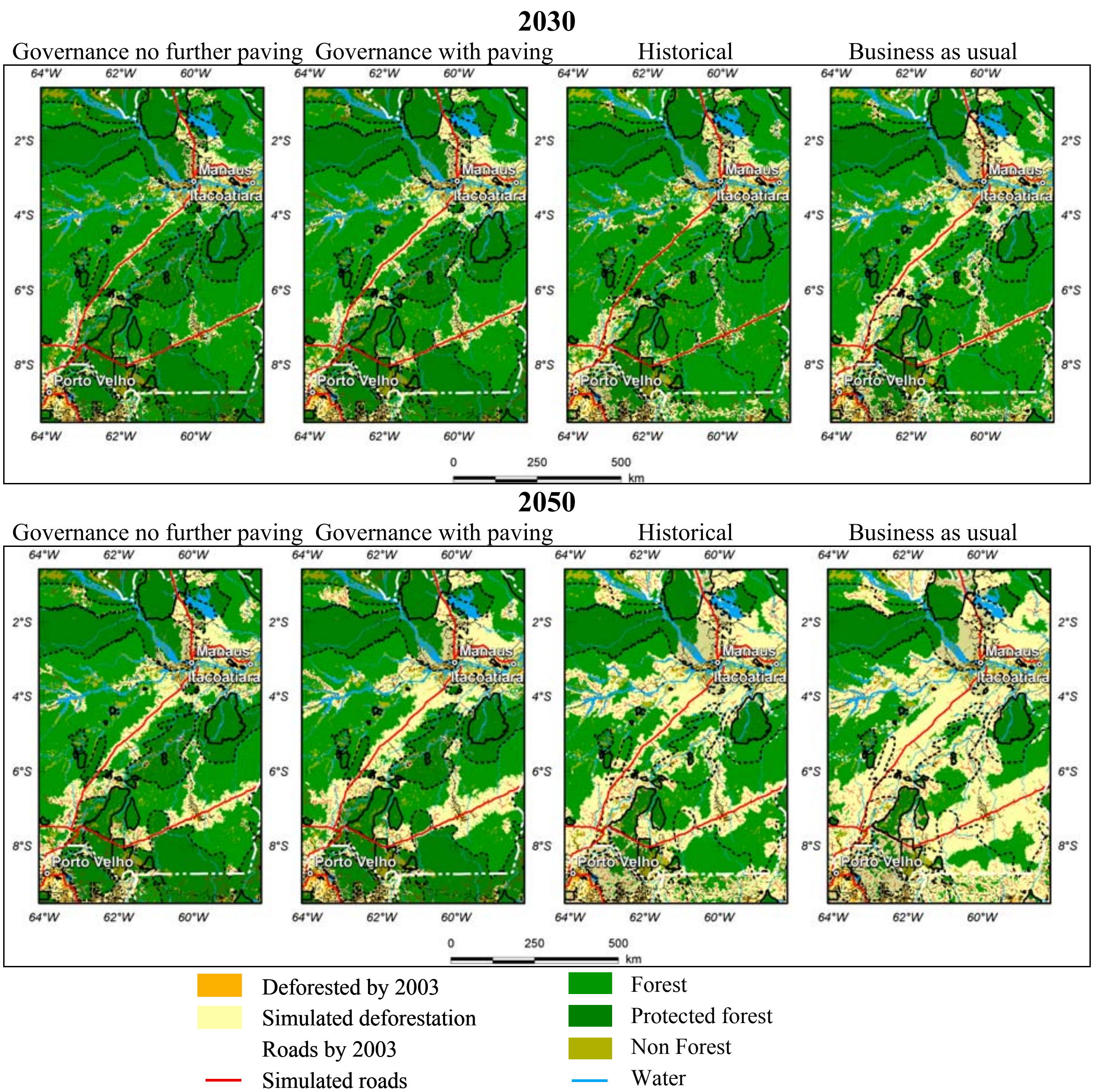


Fig. S13 - Results for Manaus - Porto Velho highway area of influence.

Table S5 Summary statistics for BR - 163 area of influence

	land cover (km2)			net change %		reduction by GO*	
	2003	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
			Business as usual, Br-163 Highway paved in 2008				
Deforested	74,747	247,182	399,992	231%	435%	-65%	-73%
Forest	500,668	335,079	182,270	-33%	-64%	-67%	-75%
Non forest	44,531	37,685	37,685				
			Historical trend, no further road paving				
Deforested	74,747	217,415	372,580	191%	398%	-57%	-71%
Forest	500,668	364,846	209,681	-27%	-58%	-60%	-73%
Non forest	44,531	37,685	37,685				
			Governance plus road paving				
Deforested	74,747	135,618	161,069	81%	115%	0%	0%
Forest	500,668	446,643	421,192	-11%	-16%	0%	0%
Non forest	44,531	37,685	37,685				
			Governance no further road paving				
Deforested	74,747	128,759	153,203	72%	105%	13%	10%
Forest	500,668	453,502	429,058	-9%	-14%	15%	11%
Non forest	44,531	37,685	37,685				

* Reduction in Governance scenario of total deforestation and forest decline.

Table S6 Summary statistics for Interoceanica highway (Assis Brasil- Cuzco) area of influence

	land cover (km2)			net change %		reduction by GO*	
	2003	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
			Business as usual, Interamericana paved in 2008				
Deforested	33,044	112,369	212,400	240%	543%	-30%	-53%
Forest	817,299	738,263	638,232	-10%	-22%	-30%	-53%
Non forest	59,886	59,597	59,597				
			Historical trend, no further road paving				
Deforested	33,044	94,773	179,856	187%	444%	-10%	-42%
Forest	817,299	755,859	670,776	-8%	-18%	-10%	-42%
Non forest	59,886	59,597	59,597				
			Governance plus road paving				
Deforested	33,044	88,535	117,673	168%	256%	0%	0%
Forest	817,299	762,097	732,959	-7%	-10%	0%	0%
Non forest	59,886	59,597	59,597				
			Governance no further road paving				
Deforested	33,044	78,706	106,587	138%	223%	22%	15%
Forest	817,299	771,926	744,045	-6%	-9%	22%	15%
Non forest	59,886	59,597	59,597				

* Reduction in Governance scenario of total deforestation and forest decline.

Table S7 Summary statistics for Manaus - Porto Velho highway area of influence

	land cover (km2)			net change %		reduction by GO*	
	2003	2030	2050	2030	2050	2030	2050
	Business as usual, Manaus Porto Velho Highway paved in 2010						
Deforested	42,806	216,586	443,278	406%	936%	-39%	-56%
Forest	668,485	502,992	276,300	-25%	-59%	-41%	-57%
Non forest	49,782	41,496	41,496				
	Historical trend, no further road paving						
Deforested	42,806	176,743	354,315	313%	728%	-21%	-43%
Forest	668,485	542,835	365,263	-19%	-45%	-22%	-44%
Non forest	49,782	41,496	41,496				
	Governance plus road paving (see road schedule)						
Deforested	42,806	148,730	220,194	247%	414%	0%	0%
Forest	668,485	570,847	499,384	-15%	-25%	0%	0%
Non forest	49,782	41,496	41,496				
	Governance no further road paving						
Deforested	42,806	122,601	184,027	186%	330%	33%	26%
Forest	668,485	596,977	535,551	-11%	-20%	37%	27%
Non forest	49,782	41,496	41,496				

* Reduction in Governance scenario of total deforestation and forest decline.

Table S8 Forest loss per watershed

				losses by 2050 for simulation runs			
	Area (km^2)	original forest (km^2)	current	BAU all roads	historical	Governance (GO)	GO no further paving
Low Amazon	362,230	315,431	4%	52%	34%	25%	19%
Coastal Amapa	96,583	82,702	6%	63%	55%	22%	22%
Coastal Guiana	439,533	402,468	2%	16%	12%	13%	11%
Coastal Marajo	220,872	177,609	9%	79%	81%	27%	27%
Coastal Maranhao	287,036	161,166	78%	92%	92%	82%	82%
Coastal Para	137,992	130,391	65%	93%	94%	81%	81%
Madeira	1,362,132	971,950	15%	58%	51%	36%	33%
Negro	769,046	638,116	3%	29%	24%	13%	11%
Orinoco	234,222	214,869	8%	28%	27%	23%	21%
Solimoes	2,156,425	1,887,060	6%	25%	23%	16%	15%
Tapajos	476,754	362,669	22%	79%	73%	44%	42%
Xingu	614,573	523,302	15%	64%	62%	24%	24%

Table S9 Forest losses per ecoregion

ECOREGION	Area	original forest	current forest	current losses	Losses by 2050 for simulation runs: Inter oceanica	Br163	Manaus Porto Velho	BAU all roads	historical	Governance (GO)	GO no further paving
Apure/Villavicencio dry forests	9,744	7,249	3,569	51%	90%	85%	90%	82%	88%	80%	78%
Bolivian Yungas	90,544	74,563	70,410	6%	41%	41%	41%	42%	39%	26%	26%
Caqueta moist forests	187,852	179,175	170,696	5%	14%	16%	14%	16%	14%	11%	11%
Chiquitania dry forests	185,542	147,741	95,353	35%	70%	71%	71%	73%	71%	59%	59%
Cordillera Oriental montane forests	11,902	10,630	8,964	16%	81%	71%	83%	64%	75%	69%	66%
Eastern Cordillera Real montane forests	61,229	53,738	44,321	18%	55%	56%	58%	55%	52%	48%	43%
Guayanan Highlands moist forests	202,349	193,435	188,496	3%	23%	24%	24%	24%	20%	11%	9%
Guianan moist forests	479,064	453,322	445,087	2%	19%	19%	19%	21%	17%	12%	10%
Japura/Solimoes-Negro moist forests	269,167	249,012	246,750	1%	16%	16%	15%	14%	11%	6%	5%
Jurua/Purus moist forests	242,958	237,529	236,274	1%	14%	14%	15%	14%	10%	4%	2%
Madeira/Tapajos moist forests	661,984	599,873	486,095	19%	69%	69%	67%	71%	61%	37%	34%
Magdalena Valley montane forests	626	368	209	43%	83%	83%	83%	80%	80%	83%	80%
Marajo Varzea forests	82,252	52,094	44,119	15%	87%	83%	83%	80%	83%	26%	25%
Maranhao Babacu forests	105,771	95,699	18,800	80%	97%	97%	97%	97%	97%	89%	89%
Maranon dry forests	14,463	8,142	3,148	61%	96%	94%	94%	94%	98%	90%	89%
Mato Grosso tropical dry forests	414,006	322,516	205,525	36%	75%	76%	75%	75%	74%	50%	50%
Napo moist forests	248,389	232,419	216,522	7%	21%	20%	21%	20%	21%	16%	17%
Negro/Branco moist forests	169,326	157,057	148,828	5%	29%	29%	28%	29%	26%	14%	13%
Orinoco Delta swamp forests	3,893	3,561	3,549	0%	0%	0%	0%	0%	0%	0%	0%
Paramaribo swamp forests	7,724	6,802	5,252	23%	87%	88%	88%	79%	84%	83%	82%
Peruvian Yungas	182,147	98,424	68,329	31%	46%	46%	46%	44%	45%	42%	42%
Purus/Madeira moist forests	174,016	163,796	156,840	4%	71%	73%	77%	74%	62%	40%	34%
Rio Negro campinarana	80,863	51,910	51,539	1%	14%	17%	17%	13%	11%	4%	0%
Solimoes/Japura moist forests	168,227	164,508	164,039	0%	4%	4%	5%	4%	3%	5%	3%
Southwestern Amazonian moist forests	808,919	737,147	709,470	4%	27%	27%	27%	27%	23%	16%	14%
Tapajos/Xingu moist forests	336,575	323,669	297,501	8%	68%	71%	68%	71%	66%	23%	22%
Tepuis	29,845	28,367	26,742	6%	33%	27%	31%	28%	23%	21%	20%
Tocantins-Araguaia/Maranhao moist forests	193,642	180,198	57,367	68%	92%	92%	92%	92%	92%	81%	81%
Tumbes/Piura dry forests	1,474	577	111	81%	91%	91%	91%	89%	94%	89%	87%
Uatuma-Trombetas moist forests	472,996	430,227	410,647	5%	57%	58%	56%	60%	48%	27%	23%
Ucayali moist forests	114,654	108,183	93,721	13%	35%	35%	36%	37%	35%	34%	34%
Xingu/Tocantins-Araguaia moist forests	269,485	249,119	172,868	31%	76%	76%	77%	75%	76%	43%	43%

area figures in km^2

Mammals Analysis – Brief Methodology

A total of 442 non-flying terrestrial mammal species had available Western Hemisphere spatially-explicit geographic range data from NatureServe with ≥1% of their range within the PanAmazon[37]. We selected 382 non-flying terrestrial mammal species (comprising 28 families; 116 genera) with ≥ 20% of their ranges within the Amazon (median 95%: Range 100%-20%) (Fig. S14 and Table S10). For each species, the scenarios model results generated for BAU 2050 and GOV 2050 were applied to determine change in forest cover within each species-specific range. Areas of water were excluded from these baseline calculations. All calculations were performed using IDRISI Kilimanjaro software[38].

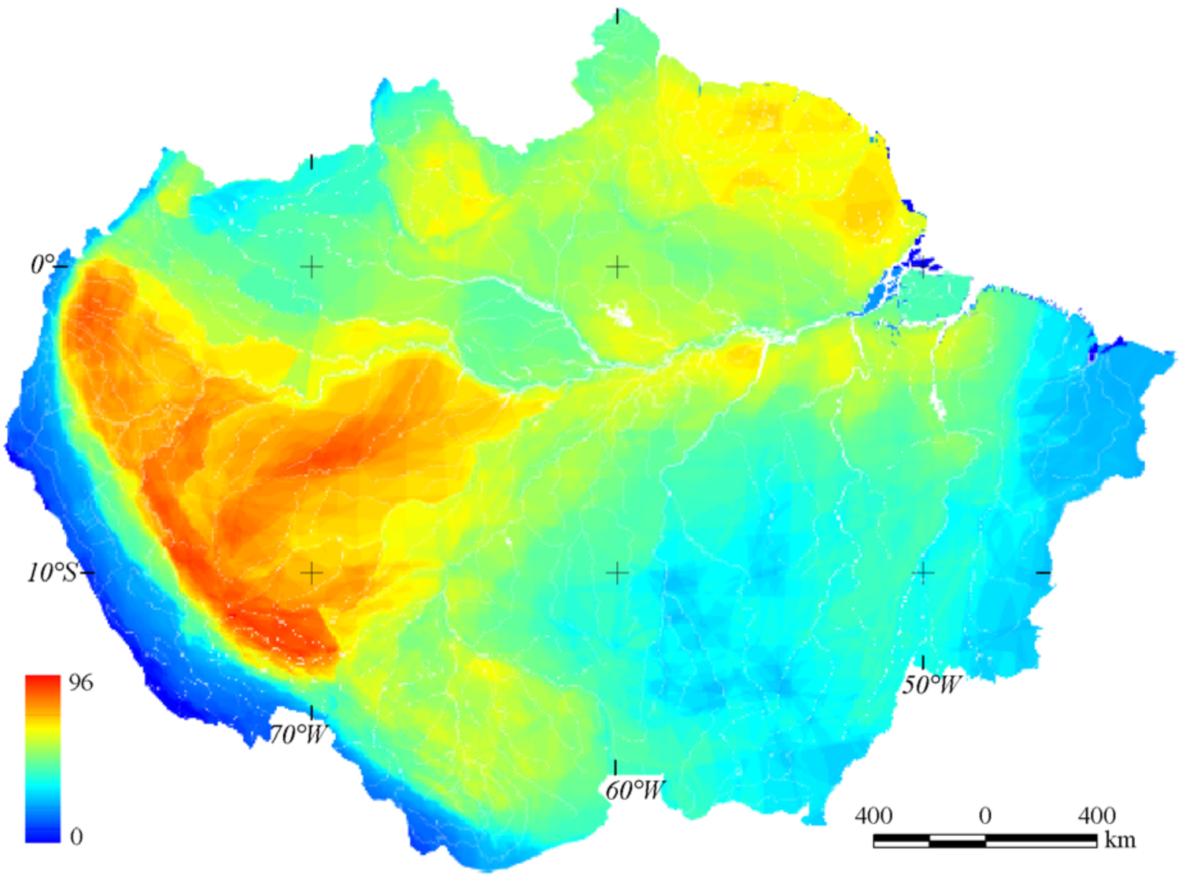


Fig. S14 - Overlay of all mammals with >= 20% of range within the Amazon (n=382).

Table S10 Number of imperiled Amazon mammals under business-as-usual (BAU) and Governance (Gov) scenarios of future land use. Three hundred eighty-two species were examined, each with at least 20% of their range in the Amazon region. 'Imperiled' mammal species (losing ≥40% of forests within their Amazon range) are summarized for each family and scenario. Under the BAU 2050 scenario, 105 species will become imperiled, vs. 41 under the Governance scenario.

Family	total spp.	% of all mammals	number of imperiled species BAU 2050	imperiled species % of total BAU 2050	number of imperiled species Gov 2050	imperiled species % of total Gov 2050
Aotidae	7	1.8	2	1.9	0	0.0
Atelidae	15	3.9	6	5.7	3	7.3
Bradypodidae	2	0.5	1	0.9	0	0.0
Callitrichidae	28	7.3	16	15.2	8	19.5
Caluromyidae	3	0.8	1	1.0	0	0.0
Canidae	5	1.3	0	0.0	0	0.0
Cebidae	10	2.6	3	2.8	1	2.4
Cervidae	6	1.6	0	0.0	0	0.0
Cuniculidae	2	0.5	0	0.0	0	0.0
Dasypodidae	11	2.9	2	1.9	0	0.0
Dasyproctidae	9	2.4	3	2.8	1	2.4
Didelphidae	5	1.3	1	1.0	0	0.0
Dinomyidae	1	0.3	0	0.0	0	0.0
Echimyidae	38	9.9	14	13.3	5	12.2
Erethizontidae	8	2.1	4	3.8	1	2.4
Felidae	9	2.4	1	1.0	0	0.0
Hydrochaeridae	1	0.3	0	0.0	0	0.0
Leporidae	1	0.3	0	0.0	0	0.0
Marmosidae	26	6.8	9	8.6	2	4.9
Megalonychidae	2	0.5	0	0.0	0	0.0
Muridae	129	33.8	21	20.0	11	26.8
Mustelidae	5	1.3	1	1.0	0	0.0
Myrmecophagidae	3	0.8	1	1.0	0	0.0
Pitheciidae	34	8.9	14	13.3	7	17.1
Procyonidae	6	1.6	0	0.0	0	0.0
Sciuridae	12	3.1	4	3.8	1	2.4
Tapiridae	2	0.5	1	1.0	1	2.4
Tayassuidae	2	0.5	0	0.0	0	0.0
Total	**382**	**100**	**105**	**100**	**41**	**99.8**

Estimate of future carbon emissions from Amazon deforestation

Seven estimates of carbon stocks for the Brazilian Amazon forest were made available based on spatial interpolations of direct measurements, modeled relationships with climatic variables, and remote sensing data[39]. The average of these carbon estimates for Brazil's Amazonian forests is 70 Pg, but the estimates varied from 39 to 93 Pg C. We selected two of these estimation methods[40,41] to generate our maps of carbon stocks for the PanAmazon region. Both methods employ RadamBrasil vegetation maps[22], assigning to the vegetation subtypes total biomass stocks according to their average stemwood volumes[22], but applying two different approaches[40,41] that yielded for the Brazilian Amazon, respectively, 94 Pg C, the highest estimate of all seven methods[39], and 63 Pg C, a figure between the average and the lowest estimate[39]. These calculations assumed that carbon content is 50% of wood biomass[39].

To extend these estimates for the entire PanAmazon, we assigned the carbon stocks of RadamBrasil vegetation subtypes, obtained from the two methods, to similar vegetation classes of a map that encompasses all the PanAmazon countries[23], producing as a result two carbon stock maps at 1 km^2 raster resolution. Both maps were overlaid with our 2003 land-cover map to subtract the forest carbon stocks in areas already deforested. This calculation yielded total carbon stocks by 2003 for the PanAmazon of 143 and 96 Pg C, respectively.

The variation between the two biomass estimates that we used to assess carbon emissions from the Amazon is associated with differences in allometric equations, species-specific information on wood density, and the treatment of some forest components (e.g., the inclusion (or not) of palms, small trees and lianas). Since both estimates relied on the same set of RadamBrasil forest plots, which are only one hectare in size, additional uncertainty associated with these estimates includes if the RadamBrasil plots are representative of the full range of heterogeneity and within-plot error associated with the 1 ha plot size. We assumed that these errors extend the uncertainty associated with each biomass map by an additional 20% based upon analyses of error propagation in biomass estimates[42,43]. Thus, to bracket the range of carbon stocks for the PanAmazon, we used the average of 119 Pg C and the uncertainty bound of $\pm$ 28 Pg C, which is the standard error multiplied by 1.2.

We superimposed simulated deforestation by 2050, cell by cell, on these two carbon stock maps, with deforestation by 2003 already discounted, to estimate the range of potential carbon emissions for the extreme-case scenarios (Fig. S15), assuming that 85% of the carbon contained in forest trees is released to the atmosphere following deforestation[44]. Thus this calculation of potential carbon emissions incorporates the different carbon stocks present in the Amazon ecosystems, most likely to be affected by future land-cover change.

By the year 2050, 32 ± 8 Pg of carbon are emitted under the BAU scenario, equivalent to four years of current annual emissions worldwide, contrasted with 15 ± 4 Pg C under the governance scenario. Therefore, the difference between the two extreme-case scenarios could represent an avoidance of 17 ± 4 Pg of future carbon emissions.

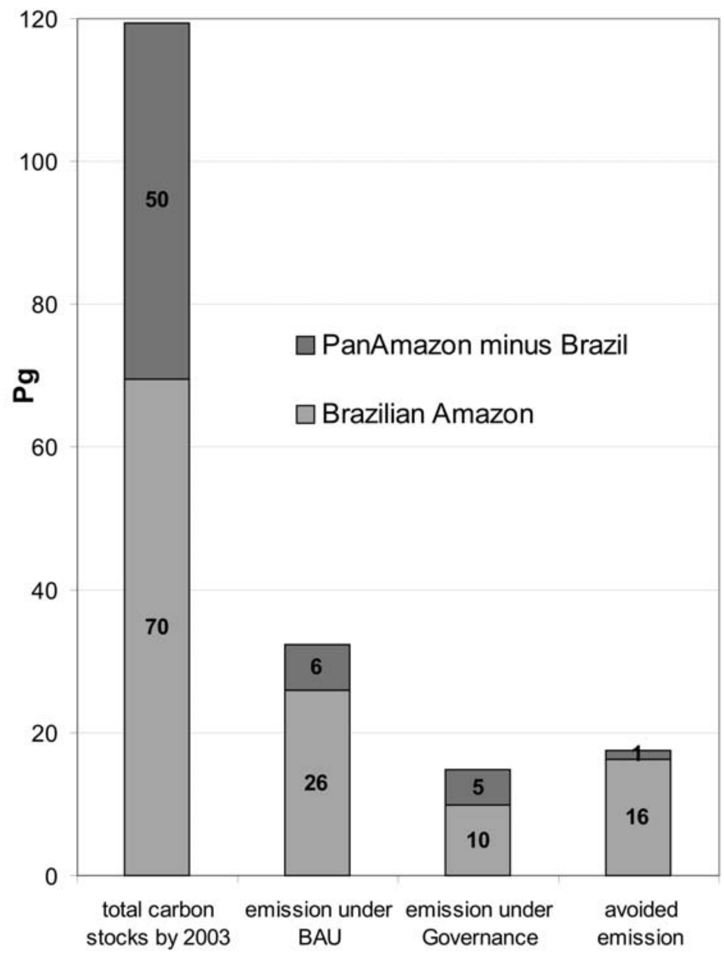


Fig. S15 – Current carbon stocks for the PanAmazon and Brazilian Amazon and estimates of potential future emission from deforestation under BAU (business-as-usual) and Governance scenarios. Avoided emission is the difference in values between these two extreme-case scenarios.

References

1. Soares-Filho, B. S. *et al.* Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: The Santarém-Cuiabá Corridor. *Glob. Change Biol.* **10**, 745-764 (2004).
2. Laurance, W. F. *et al.* The future of the Brazilian Amazon. *Science* **291**, 438-439 (2001).
3. Carvalho, G., Barros, A. C., Moutinho, P. & Nepstad, D. Sensitive development could protect Amazonia instead of destroying it. *Nature* **409**, 131 (2001).
4. Nepstad, D. *et al. Avança Brasil, the Environmental Costs for Amazônia.* [on line] <http://www.ipam.org.br/avanca/participen.htm> (2000).
5. Garcia, R. A., Soares-Filho, B. S. & Sawyer, D. O. Dimensões sócio-econômicas e movimentos populacionais: uma regionalização da Amazônia brasileira. in *XIV Encontro Nacional de Estudos Populacionais* (ABEP, Caxambu, Brazil) [on line] <http://www.abep.org.br/usuario/GerenciaNavegacao.php?caderno_id=030&nivel=1> (2004).
6. Nepstad, D. *et al.* Frontier governance in Amazonia. *Science* **295**, 629-631 (2002).
7. Bevilacqua, M. *et al. The State of Venezuela Forests: A Case Study of the Guayana Region.* (Fundación Polar, World Resources Institute, Observatorio Mundial de Bosques, Caracas, Venezuela 2002).
8. Montiel, F. *Programa Áreas Protegidas da Amazônia - ARPA. Resumo Executivo* [on line] <http://www.mma.gov.br/port/sca/ppg7/doc/arpareex.pdf> (2004).
9. Soares-Filho, B. S. *et al*. Calibration and validation methods for spatial simulation models: application to modeling deforestation in the Brazilian Amazon. *Ecol. Modelling* (submitted).
10. INPE - Instituto Nacional de Pesquisas Espaciais. *Monitoramento da Floresta Amazônica Brasileira por Satélite - Projeto PRODES.* [on line] <http://www.obt.inpe.br/prodes> (2004).
11. Christaller, W. How I discovered the theory of central Places: a report about the origin of central places. in *Man Space and Environment* (eds. English, P. W. & Mayfield, R. C.) 601-610 (Oxford Univ. Press, London , UK, 1972).
12. Monteiro, M. P. & Sawyer, D. Diagnóstico demográfico, socioeconômico e de pressão antrópica na região da Amazônia Legal. in *Biodiversidade na Amazônia Brasileira* (eds. Capobianco, J. P. R. *et al.*) **4**, 308-320 (ISA, São Paulo, 2001).
13. Manton, K., Woodbury, M. & Tolley, D. *Statistical Applications using Fuzzy Sets.* (John Wiley & Sons Inc, New York, 1994).
14. Lemos, M. B., Diniz, C. C. & Guerra, L. P. Pólos econômicos do nordeste e suas áreas de influência: uma aplicação do modelo gravitacional utilizando sistema de informações geográficas (SIG). *Revista Econômica do Nordeste* **30,** 568-584 (1999).
15. Eva, H. D. *et al.* A land cover map of South America. *Glob. Change Biol.* **10**, 731-744 (2004).
16. Hansen, M. *et al.* Towards an operational MODIS continuous field of percent tree cover algorithm: examples using AVHRR and MODIS data. *Rem. Sens. of the Environ.* **83**, 303-319 (2002).
17. Steininger, M. K. *et al.* Tropical deforestation in the Bolivian Amazon. *Environ. Conserv.* **28**, 127-134 (2001).

18. Pacheco, P. Agricultural expansion and deforestation in the Lowlands Bolivia: the import substitution versus the structural adjustment model. *Land Use Policy* (in press).
19. Rojas, D., Martinez, I., Cordero, W. & Contreras, F. *Tasa de Deforestacion de Bolivia*. (Proyecto BOLFOR, Santa Cruz, Bolivia, 2003).
20. Ventana - *Vensim Software – Linking Systems Thinking to Powerful Dynamic Models*. [on line] <http://www.vensim.com/software.html> (2004).
21. Geist, H. J. & Lambin, E. F. *What Drives Tropical Deforestation? A Meta-Analysis of Proximate and Underlying Causes of Deforestation Based on Subnational Case Study Evidence.* [on line] <http://www.geo.ucl.ac.be/LUCC/lucc.html> (2004).
22. MME - Ministério das Minas e Energia*. Projeto Radam - Levantamento de Recursos Naturais* (Departamento Nacional de Produção Mineral, Rio de Janeiro, Brazil, 1973).
23. WWF. *World Wildlife Fund Ecoregions of the Amazon.* in *ESRI Data & Maps* (Environmental Systems Research Institute, Redlands, USA, 2002).
24. TRFIC. *The Tropical Rain Forest Information Center - Hosting for LBA-E Program*. [on line] <http://bsrsi.msu.edu/trfic/LBA_E/> (2004).
25. IUCN. *World Database on Protected Areas* (IUCN and UNEP - WDPA Consortium, Washington DC, USA, 2003).
26. Soares-Filho, B. S., Pennachin, C. & Cerqueira, G. C. DINAMICA – a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. *Ecol. Modelling* **154**, 217-235 (2002).
27. Soares-Filho, B. S., Corradi, L., Cerqueira, G. C. & Araújo, W.L. Simulating the spatial patterns of change through the use of the DINAMICA model. in *XI Simpósio Brasileiro de Sensoriamento Remoto* 721-728 (Instituto Nacional de Pesquisas Espaciais, Belo Horizonte, Brazil, 2003) [on line] <http://iris.sid.inpe.br:1908/col/ltid.inpe.br/sbsr/2002/11.16.12.49/doc/06_257.pdf> (2003).
28. Soares-Filho, B. S., Assunção, R. M. & Pantuzzo, A. Modeling the spatial transition probabilities of landscape dynamics in an Amazonian colonization frontier. *BioScience* **51**, 1039-1046 (2001).
29. Alves, D. S. An analysis of geographical patterns of deforestation in Brazilian Amazônia the 1991-1996 period*. in Patterns and Processes of Land use and Forest Change in the Amazon* (eds. Wood CH & Porro, R) 95-106 (University of Florida, Gainesville, USA, 2002).
30. Alves, D. S. Space-time dynamics of deforestation in Brazilian Amazônia. *Inter. J. of Remote Sens.* **24**, 2903-2908 (2002).
31. Reis, E. & Margulis, S. Options for slowing Amazon jungle clearing. In *Global Warming: Economic Policy Responses* (eds. Dornbusch R. & Poterba J. M.) (MIT Press, Cambridge MA, 1991).
32. Pfaff, A. S. P. What drives deforestation in the Brazilian Amazon? Evidence from satellite and socioeconomic data. *J. of Environ. Econon. and Manag.* **37**, 26-43 (1999).
33. Ludeke, A., Maggio, R. C. & Reid, L. M. An analysis of anthropogenic deforestation using logistic regression and GIS. *J. of Environ. Manag.* **31**, 247-59 (1990).
34. Chomitz, K. M., Gray, D. A. Roads, lands, markets, and deforestation, a spatial model of land use in Belize. *World Bank Econ. Rev.* **10**, 487-512 (1996).
35. Mertens, B. & Lambin, E. F. Spatial modelling of deforestation in Southern Cameroon: spatial disaggregation of diverse deforestation processes. *Appl. Geogr.* **17**, 143-68 (1997).

36. Mertens B., Poccard-Chapuis R., Piketty M. G., Lacques A. E. & Venturieri A. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of São Félix do Xingú in South Pará. *Agricul. Econ.* **27,** 269–294 (2002).
37. Patterson, B. D. *et al. Digital Distribution Maps of the Mammals of the Western Hemisphere, version 1.0*. (NatureServe, Arlington, Virginia, USA, 2003).
38. Eastman, J. R. *Idrisi Kilimanjaro* (Clark University, Massachusetts, USA, 2003).
39. Houghton, R. A., Lawrence, K. T., Hackler, J. & Brown, L. S. The spatial distribution of forest biomass in the Brazilian Amazon: a comparison of estimates. *Glob. Change Biol.* **7**, 731-746 (2001).
40. Fearnside P. M. Greenhouse gases from deforestation in Brazilian Amazonia: net committed emissions. *Climatic Change* 35, 321-360 (1997).
41. Brown, S. & Lugo, A. E. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia* **17**, 8-18 (1992).
42. Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S. & Perez, R. Error propagation and scaling for tropical forest biomass estimates. *Phil. Trans.: Biol. Sciences* **359**, 409-420 (2004).
43. Brown, I. F., Martinelli, L. A., Thomas, W. W., Moreira M. Z., Ferreira C. A. & Victoria, R. A. Uncertainty in the biomass of Amazonian forests: an example from Rondônia, Brazil. *Forest Ecol. and Manag.* **75**, 175-189 (1995).
44. Houghton, R. A. *et al*. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature* **403**, 301-304 (2000).