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Effects of Governance on Availability of Land for Agriculture and Conservation in Brazil

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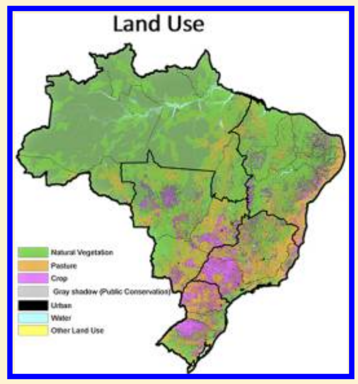
S *Supporting Information*

ABSTRACT: The 2012 revision of the Brazilian Forest Act changed the relative importance of private and public governance for nature conservation and agricultural production. We present a spatially explicit land-use model for Brazilian agricultural production and nature conservation that considers the spatial distribution of agricultural land suitability, technological and management options, legal command, and control frameworks including the Atlantic Forest Law, the revised Forest Act, and the Amazonian land-titling, "Terra Legal," and also market-driven land use regulations. The model is used to analyze land use allocation under three scenarios with varying priorities among agricultural production and environmental protection objectives. In all scenarios, the legal command and control frameworks were the most important determinants of conservation outcomes, protecting at least 80% of the existing natural vegetation. Situations where such frameworks are not expected to be effective can be identified and targeted for additional conservation (beyond legal requirements) through voluntary actions or self-regulation in response to markets. All scenarios allow for a substantial increase in crop production, using an area 1.5−2.7 times the current cropland area, with much of new cropland occurring on current pastureland. Current public arrangements that promote conservation can, in conjunction with voluntary schemes on private lands where conversion to agriculture is favored, provide important additional nature conservation without conflicting with national agricultural production objectives.



1. INTRODUCTION

In 2012, the Brazilian parliament passed the revised Forest Act (FA) (1),[1] which is the major legal framework for conservation of natural vegetation (NV) on private land. Implementation is currently underway. The long revision period has encompassed considerable research efforts;[2−4] debates took place throughout Parliament's plenary sections and have continued since then;[5−7] national scientific societies have issued a comprehensive statement on the suggested changes;[8] environmental and rural civil society organizations have followed and engaged in discussions about the revision and implementation;[9] and specific follow-up studies and opinions have been published.[10−12] However, the relation of the revised FA to other public and private legal and regulatory frameworks is not yet clear.

Most NV in Brazil is found on private land where it is only partially protected. The FA regulates agricultural land use and its expansion in various ways by defining requirements on NV conservation and restoration. The FA protects NV on geographically delimited areas regarded most environmentally sensitive, e.g. riparian floodplains, steep slopes, and high altitudes (Areas of Permanent Protection), and defines a variable percentage of the farmland to be preserved, ranging from 80% in the Amazonian Forest Biome, to 20% in most parts of Brazil.[2]

The recent revision of the Brazilian FA resulted in a weaker protection of NV and less demanding requirements on restoration planting and promotion of natural regeneration on agricultural land. The main strategies involved in the reduction of protection and regeneration requirements were (i) the compliance rules on the farmland established before July 22, 2008; (ii) the extensive possibilities to compensate legal deficits outside the farm boundaries by using NV in surplus on farms in other regions; and (iii) the exemption of small farms from having to perform restoration. Because the FA implementation is still not finished, it is not yet possible to assess precisely how much of the restoration required if the previous version will remain, but several studies indicate that the protection of NV has decreased importantly and that the remaining restoration requirements are minor.[10,2,11]

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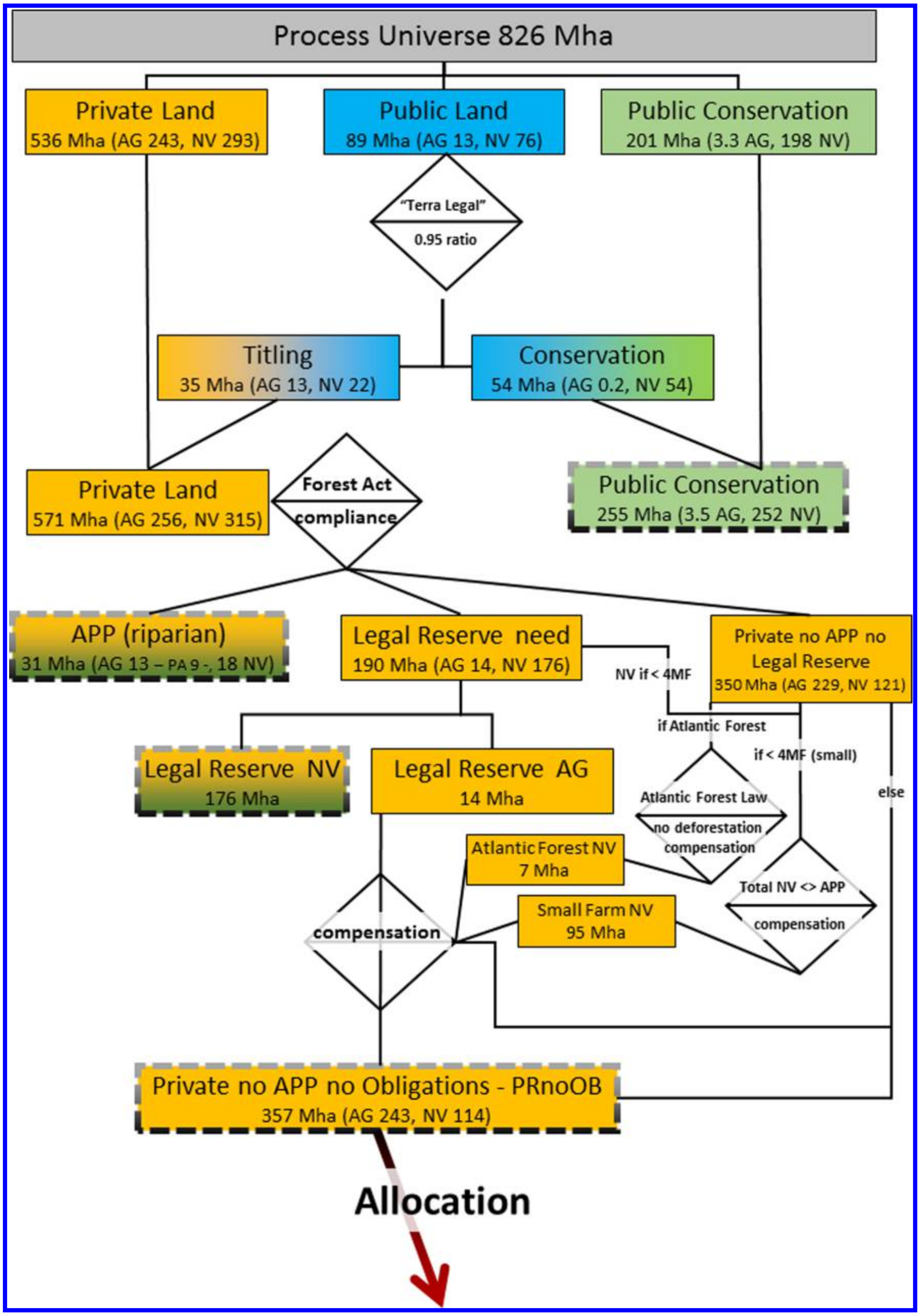

Figure 1. Structural description of process to identify land legally available for agriculture, with national area totals.

Improving land-use predictions and explanatory models still poses important challenges, for comprehensiveness and for the need to account for the complex interrelations of stakeholder choices, the physical environment, and the complementary effects of public and private governance.[13,14] The consequences of the FA revision for nature conservation and agricultural production will depend on how other public and private governance systems address aspects that are given less weight in

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the revised FA (see, e.g., refs 15−17, which discuss governance in the deforestation context). Important public governance systems in this regard include the Atlantic Forest Law (AFL)[18] and the Amazonian land titling initiative "Terra Legal" coordinated by the Ministry of Agrarian Development.[19]

We used a spatially explicit land-use model to analyze the influence of public and private environmental protection on nature conservation and agricultural production in Brazil for three scenarios that differ with regard as to how they prioritize agricultural production and environmental protection objectives (further described in Section 2.2.2). The aim was to advance the understanding of (i) how public and private governance systems addressing nature conservation and agricultural production may influence Brazilian land use, and (ii) how the outcome depends on the relative priority of nature conservation and agricultural production objectives. The applied narrative and spatially explicit modeling approach may complement economic equilibrium modeling, which takes a coarser approach to land use/land cover, legislation, and other aspects influencing land use decisions. The approach is grounded in empirical data and scientific analysis of nature conservation and agricultural production in Brazil, thus well-suited for showing development pathways that deviate from historic experiences that provide the calibration foundation in economic equilibrium modeling.

2. EXPERIMENTAL SECTION

As described in more detail below, a previously developed spatially explicit land use model[20] was extended and updated to include relevant legislative changes from recent years. The model analysis is done in two steps: *first*, parts of private and public lands are reserved for nature conservation and environmental protection, so as to comply with legal command and control (C&C) frameworks; *second*, unreserved lands are allocated to specific land uses based on (i) agricultural land suitability and available technology and management options and (ii) the possible influence of additional local and market-driven land use regulations, e.g., agroecological zoning and voluntary commitments to standardization or certification schemes. For the second step, three scenarios are developed, one prioritizing conservation objectives, one prioritizing production objectives, and one that is neutral between those objectives.

2.1. Trends and Conditions Considered in the Model. *2.1.1. Legal Compliance and Increased Standardization of Agricultural Production.* The trend in Brazilian agricultural production is toward greater legal compliance and standardization. The approval in 2012 and current implementation of the revised FA changed the rules to facilitate legal compliance by reducing the requirements for land set-asides and/or NV restoration on productively used farmland. The revised FA also includes a comprehensive Environmental Rural Registry that facilitates monitoring and surveillance by government and civil society.[10,2] Amazonian deforestation rates have drastically declined since 2004 and are currently at the lowest recorded levels. Explanations for this decline include effective surveillance and articulated networking of civil society and governmental agencies, as well as actions among important stakeholders in the agriculture sector recognizing that businesses are negatively impacted by association with environmental degradation, especially in the Amazon (e.g., the soy moratoria).[16,17,21] Consumer demand for certified agricultural products is increasing, and Brazilian agriculture is a leader in adopting certification schemes.[22] Global corporations are increasing their share of agricultural business; these corporations are more sensitive to public image issues than individual farmers are, and they are also less permissive with respect to legal nonconformity.[23] Commitments in the land use sectors have become more ambitious: to substantially reduce or even reach zero (net or gross) deforestation, with 2020 as a common target year. Examples of important stakeholders and initiatives include Brazilian and State of Pará legislatures, trade or producer groups such as Consumer Goods Forum, Nestlé, and organizations such as Greenpeace and World Wildlife Fund.[24]

These trends toward increased compliance and adoption of voluntary control standards reflect underlying and long-term external and endogenous drivers. Land use allocation rules were therefore developed in the model with these trends as fixed conditions, so as to guarantee long-term full compliance with the legal C&C frameworks that are considered in the model (Section 2.2.1).

2.1.2. Agricultural Expansion and Intensification. One premise for the modeling is that demand for agricultural products will grow substantially. Global demand is driven by population growth, wealth increase, and distribution in populated poor regions,[29,30] dietary shifts to higher consumption of meat and dairy products,[31] and promotion of bioenergy products.[32−34] There is also a growing Brazilian demand for agricultural products.[35]

Another premise is that Brazilian agricultural production can increase to meet the rising demand while also meeting high environmental standards and avoiding extensive deforestation. Factors favoring the decoupling of agricultural growth from deforestation and negative environmental impacts include (a) substantial room for increased productivity on large areas already used for pasture production, with some of this pastureland available for intensive cropping;[36,37] (b) current low yields for several crops due to low adoption of existing technologies;[38] (c) favorable conditions for large-scale farming operations, attracting corporate investments that promote intensification while attempting to avoid or mitigate negative impacts; and (d) relatively good production infrastructure and supply of institutional research and development, improving likelihood of responsible cultivation practices.

2.2. Model Components and Steps. The model includes two principal land allocation steps, as described below.

2.2.1. Reservation of Land for Compliance with Legal Provisions for Nature Conservation (Step 1). In the first step, parts of private and public lands are reserved for nature conservation and environmental protection, so as to comply with C&C governance (Figure 1). This first step defines areas protected under C&C rules, which are linked with different institutional arrangements for enforcement, monitoring, and surveillance. Besides the FA, AFL, and expected outcomes of the "Terra Legal", this includes public conservation land consisting of national, state, municipal, and private conservation parks under the National Framework for Conservation Units policy - SNUC,[39] arrangements for Indian Reservations managed by the National Indian Foundation (Fundação Nacional do Índio − FUNAI), and land use restrictions in military areas.[40]

Land is allocated as follows: (A) the Brazilian land base of 826 million hectares (Mha) is allocated to (A.i) private land complying with the rules of the revised FA and AFL; (A.ii) public land under the rules of the "Terra Legal"; and (A.iii)

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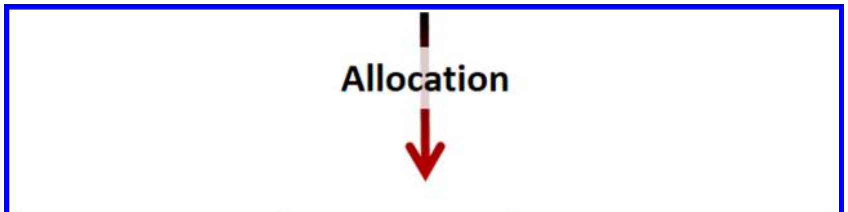

Current Land Use / Land Cover		Suitability for agriculture		Scenario		
Type	10^9 ha (Mha)	Class	Mha	Conservation	Neutral	Production
Natural Vegetation (NV)	114	Very High	9,4	CR+	CR+	CR+
		High	18,8	NV	PA+	CR+
		Medium	23,8	NV	PA+	PA+
		Low	31,0	NV	NV	PA+
		Very Low	30,7	NV	NV	NV
Pasture (PA)	166	Very High	38,4	CR+	CR+	CR+
		High	35,3	PA+	CR+	CR+
		Medium	28,4	PA+	PA+	CR+
		Low	30,4	PA	PA	PA+
		Very Low	33,2	NV	NV	PA
Crop (CR)	77	Very High	30,2	CR+	CR+	CR+
		High	19,0	CR	CR+	CR+
		Medium	9,6	CR	CR	CR+
		Low	9,1	CR	CR	CR
		Very Low	9,2	NV	CR	CR

Figure 2. Land allocation on PRnoOB lands for the three Cases (NV = Natural Vegetation, PA = Pasture, CR = Crop, + = great potential for increasing current productivity).

public conservation land consisting of national, state, municipal, and private conservation parks under the SNUC Indian reservations and military areas. (B) The public land under the rules of the "Terra Legal" is reclassified as either public conservation land or private land depending on the occurrence of NV. If the occurrence of NV in the process polygon is greater than 95%, the land in this polygon is reclassified as a public conservation area; otherwise it is reclassified as private land and further processed for conservation requirements of the FA and AFL. The threshold value of 0.95 was selected based on the analysis shown in Figure S1. (C) Compliance rules are processed for the private land to account for the FA requirement that riparian buffers be established (*Áreas de Preservação Permanente* − APP) and that a certain share of the private farmland be protected as Legal Reserve (*Reserva Legal* − LR). (D) The restrictions of the AFL and the LR compensation rules of the FA are processed on the remaining private land.

The above steps generate a land category that consists of private lands outside APP that have no obligations under the FA or AFL. These private lands are designated Private no Obligations (PRnoOB) lands. In all biomes, the LR deficit on private farmland can be addressed through a compensation mechanism or other legal adjustment. The LR deficits were therefore considered PRnoOB areas in the modeling, i.e., FA-LR C&C is assumed not to be the basis for any NV restoration on agricultural land. The PRnoOB area does not include the areas under agricultural use in APP because of the FA-imposed management restrictions, but it should be noted that the outcome of the state-level regulations during the still ongoing implementation phase will determine whether agricultural use will be allowed permanently, which in turn determines NV restoration needs in APP areas.

Figure 1 provides a graphical description of the process along with the total area for each category. The aggregated area values for political states, regions, and biomes are shown in Supporting Information (SI) Table S1. Note that in this first step not all agricultural practices are forbidden on all the lands associated with some type of restriction on agricultural land use: a few low impact options are permitted on LR and APP lands, traditional production systems are allowed on Indian reservations, and smallholder farming is allowed in the Atlantic forest biome.

2.2.2. Land Use Allocation on PRnoOB Lands Depending on the Relative Priority of Agricultural Production and Environmental Protection Objectives (Step 2). In the second step, the PRnoOB lands are either kept under current use/vegetation cover or shifted to new uses/cover. Land use decisions on PRnoOB lands are considerably less regulated by C&C. Existing restrictions are associated with market-based certification schemes, imposed by state level zoning, or licensing as in the case of NV conversion and establishment of associated capital and infrastructure (e.g., a sugar cane or pulp and paper mills). The land allocation rules applied in step 2 reflect this less restrictive governance by markets, regulations, incentives, and licenses.

Three scenarios are constructed that include land allocation principles aligning with the incentive- or regulatory-based private governance. The scenarios serve as proxies for different approaches to voluntarily adopted conservation and/or production promoting actions. They allocate land-use changes (LUC) according to criteria usually considered in agro-ecological and economic zoning, which are frequently used to fulfill legal demands and meet requirements set by the National Ministry of Environment[25] at the state level, e.g., investment agencies such as the Brazilian Development Bank for sugar cane investments,[26,27] governmental agencies in policy design, and certification schemes (e.g., High Conservation Value assessments). The criteria influence agricultural expansion patterns by promoting or restricting specific activities and are additional to the legal C&C frameworks such as FA, AFL, and "Terra Legal". Site-specific 'go/no go' decisions (e.g., to allow or not allow a certain land use activity in a specific location or land type), as determined based on these criteria, can guide institutional efforts and investments to promote changes in initial phases of development,[28] such as in the implementation

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of the revised FA. The scenarios include distinctly different sets of land allocation rules, representing differences in the relative importance assigned to agricultural production and environmental protection objectives. The land allocation rules consider land use/cover type (NV, Pasture − PA, or Cropland − CR) and land suitability class (Very High, High, Medium, Low, or Very Low).

In the **Conservation** scenario, nature protection is a high priority. Most of the NV on PRnoOB land is preserved, and NV is also restored on part of PA and CR located in the Very Low land suitability classes. Intensification of cropland or pasture management (CR+ or PA+) and conversion of PA to CR+ were restricted to the Very High land suitability classes, which are associated with the lowest risk of environmental impacts. The Very High land suitability classes are less sensitive to soil erosion, fertilizer leaching, and pesticide pollution. Thus, **Conservation** goes far beyond legal requirements concerning NV protection by promoting NV conservation and restoration on low quality cropland and pastureland and allowing only environmentally sensible intensification options. Considering that C&C regulation is minor and LUC consequently is the outcome of voluntary commitments, realization of **Conservation** would likely require strong incentives, e.g., premium payments for certified products, payment for environmental services, REDD+, and LUC carbon prices.

In the **Production** scenario, the priority is to achieve a high level of production, and there are fewer restrictions on agronomic inputs and use of PRnoOB lands. NV conservation is restricted to the Very Low land suitability classes, and there is no NV restoration on existing agriculture lands. Crop cultivation and pasture production are intensified, except for on the Low and Very Low land suitability classes, increasing the risks for negative externalities such as soil erosion, eutrophication, and pollution (Figure 2). **Production** represents a possible future in which incentives for conservation are weaker than implied by current trends, and growth of demand for Brazilian agriculture products is very strong.

The **Neutral** scenario represents an attempt to balance agricultural production and environmental protection objectives. The land use allocation rules for each case are shown in Figure 2. The aggregated area values for political states and regions and for biomes are shown in Table S2 in the SI.

The results of the second step align with trends observed in empirical data analysis[37] accounting for the model assumptions described above. Since the LUCs were not restricted by logistic or other constraints, they should not be understood as possible near-term LUC but as indicative of possible longer-term dynamics. The model reports total and aggregated values (states and biomes) and local representations in maps *(in color scale applied to the 228,250 process polygons with average area of 3,729 ha)* showing final land use types, intermediate model steps, and LUCs.

3. RESULTS AND DISCUSSION

3.1. NV Protection on Private and Public Lands by C&C. Figure 1 shows the total areas subject to conservation, and Table S1 in the SI shows the associated land use types and changes for states, regions, and biomes. Maps 1−4 in the SI show the input data on land use and land suitability classes. Maps 5−6 in the SI show the initial tenure classes (private land, public land, or public conservation) and the outcome of "Terra Legal" polygon processing. Map 7 in the SI shows the distribution of the LR deficit in relation to LR requirements − *the greater the relative deficit, the greater the role of off-farm compensation rules in the model*. Map 8 in the SI shows the unprotected NV on private lands relative to NV on private lands outside APP − *the greater the ratio, the greater the share that can be converted to agriculture legally*. Figure 3 shows

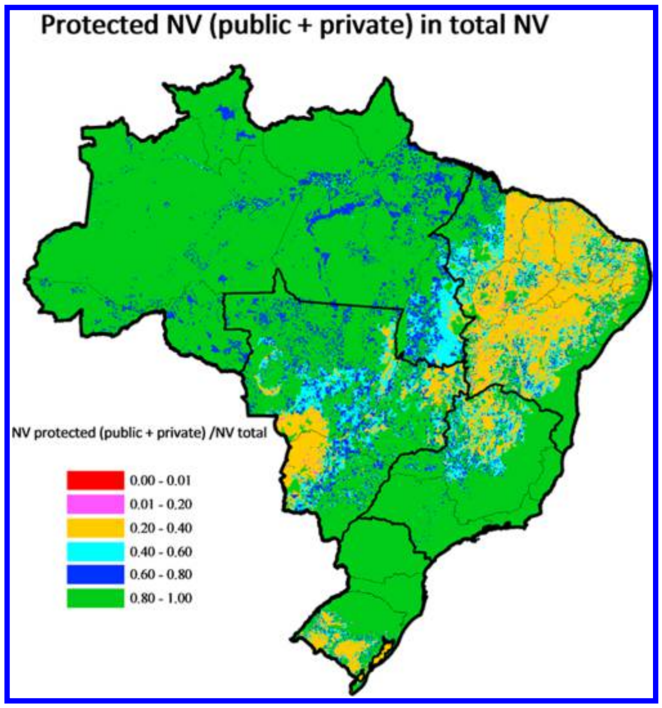

Figure 3. Ratio of protected Natural Vegetation to total Natural Vegetation.

protected NV (public and private) relative to total NV − *the greater the ratio, the greater the share of NV that is protected under legal C&C frameworks on private or public land.*

Including the possible contribution of "Terra Legal", about 80% of the existing NV in Brazil is estimated to be under either private or public C&C protection. About 250 Mha NV on public land is protected and about 200 Mha NV on private land is protected, with almost 90% and 10% protected by LR and APP requirements, respectively (Figure S1). Some 7 Mha of privately owned Atlantic Forest is protected by the AFL. Roughly one-third of NV on private land (20% of total NV) is not protected by these C&C frameworks. If we exclude the projected results of "Terra Legal", the area of protected NV on public lands is about 50 Mha less. The ongoing conservation initiative "Terra Legal" is comparable in size to the estimated outcome of the more debated FA revision but is entirely focused on the Legal Amazon region, adding roughly 28% of NV to the existing Legal Amazon public conservation network that contains 96% of the total area under public conservation.

Figure 3 shows the geographic effects of the dominating C&C protection. The sharp straight line in the state of Maranhão, dividing high protection rates to the left (green color) and lower (yellow) to the right, corresponds to the Legal Amazon region border, inside which the requirements of LR of the FA are higher. Medium protection (yellow) usually indicates surplus of NV in PRnoOB, coincident with low agricultural suitability areas of the semiarid northeast Caatinga, Pantanal and the lower half of Rio Grande do Sul Pamapas. These areas present substantial edaphic or climatic constraints on agricultural development. In the remaining consolidated

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agricultural regions, C&C protection of remaining NV is very high, mainly because all the NV that could legally be converted to agriculture is already under agricultural use.

The estimates of total areas are similar to those in recent reports on the revision of the FA[10] as well as expected changes driven by this revision[2] done before the revision passed in 2012. When less aggregated, studies produce more varied results, especially for the Amazon region. The differences are mainly due to how public land is treated. To the best of our knowledge, this study is the first to include projections for the "Terra Legal" program showing figures confirming the environmental importance of this program. The order (hierarchy) of FA rules addressing the regulation of the existing legal deficits in the Amazonian biome is also a source of uncertainty. The revised FA does not clearly define this hierarchy, so the order will be decided during the implementation phase or established later, judicially.

The approach used to designate "Terra Legal" polygons as either private land or public conservation land led to the designation of 35 Mha of land in the Legal Amazon region as private land and 54 Mha as public conservation land (See Table S1. Only 0.2 Mha of land designated public conservation land was agricultural land.). The ratio of private to public conservation lands is consistent with current "Terra Legal" outcomes; so far, 23 Mha have been mapped (out of the 89 Mha in total), and 12,000 private titles (1.5 Mha) have been issued, while 4 Mha have been designated public areas, predominately for conservation.[19] The remaining mapped areas are still waiting for final decisions. The modeled spatial and area distribution outcomes of "Terra Legal" are shown in Table S1 and Maps 5 and 6. Most titling is projected to occur in the states of Pará, Rondônia, and Tocantins, and most of the conservation is projected to occur in the states of Amazonas Acre and Roraima, around the already existing public conservation parks and Indian reservations.

The results confirm that "Terra Legal" is a key factor in consolidating the already existing Amazonian agricultural production that occurs mainly in the states of Pará and Rondônia and in restricting further expansion over mostly low suitability lands surrounding the existing network of parks in the state of Amazonas, Roraima, and Arce. The "Terra Legal" program was initiated by the Ministry of Agrarian Development for the main purpose of titling Amazonian spontaneous settlers (*posseiros*), but it has become a key environmental protection initiative complementary to the FA in the Amazon region. Despite its importance and relatively recent establishment, the "Terra Legal" program is not grounded on a specific public report or action, equivalent to the comprehensive Environmental Rural Registry of the FA, and is not prominently discussed in the environmental debates. Access to information that is essential for environmental NGOs depends on the more general national concept of free access to public information.[41]

LR deficits (14 Mha in total, see Map 7 in the SI) mirror the cropland distribution (Map 1 in the SI), and lower deficits are shown on pasturelands. Pastures more easily comply with a patchy agricultural landscape including conservation areas, as required for keeping set-aside areas as LR. The same applies for agricultural use in APP (Table S1 in the SI), where all states in the south and southeast regions (long-established and consolidated crop production), as well as the sugar cane cultivating states of the northeast (Alagoas and Sergipe), have more agricultural land use than NV in APP areas. In all other states there was more NV than agricultural land use in APP areas. The expansion of crops over pasture, which has been identified as the primary option for Brazilian crop expansion,[37,36,42] is thus favored by landscape patchiness and relative abundance of NV, reducing transaction costs and facilitating compliance with FA and the targeting of certified and environmentally sensitive markets.

3.2. Land Use on PRnoOB.

Figure 2 and Table S2 show the outcome of land use allocation on PRnoOB lands in the three scenarios, and Map 9 shows the proportion of agricultural land use (crop and pasture) on PRnoOB — *the greater the proportion, the more of the legally available land is used for agricultural production.*

3.2.1. NV on PRnoOB. Besides the 450 Mha of NV protected under C&C rules, 114 Mha of NV on PRnoOB lands rely on protection via non-C&C mechanisms and may be legally deforested. Most of this NV has limited value as agricultural land because of low physical suitability and/or remote location. However, technology shifts, increased demands for agricultural products, and logistic improvements may result in the conversion of some currently low value NV.

Another small part of the NV is located on good land in favorable locations, thus having a high likelihood of being converted to agricultural land (mainly CR+) in the near future. This part is relatively small since historic agricultural expansion has prioritized good locations and cropping conditions. Over time, most NV remnants were confined in remote and/or poor private lands or protected in C&C driven frameworks.

The spatial distribution of protected NV on PRnoOB lands is shown in Maps 10−14 in the SI, starting with the Very High and sequentially adding lower suitability classes. Most NV on Very High suitability land (9.4 Mha) is found in the Cerrado biome in the state of Bahia and north-central and northwest parts of Mato Grosso, mainly surrounding the Xingu National Park, an area that coincides with the current agricultural frontier.[37] Additional NV on High (18.8 Mha) and Medium (23.8 Mha) suitability lands is found in the Cerrado biome in the west-central and northeast regions, the upstream of the Pantanal biome, some transitions of Cerrado to the semiarid Caatinga in the northeast regions, and areas surrounding most of the public parks and Indian reservations in the Amazon biome. Further NV is found on Low (31.0 Mha) suitability lands in the northeast semiarid Caatinga and additional areas of the Amazon biome, mainly along the floodplains of large rivers. Much of the NV on lower suitability classes is found in more environmentally sensitive areas (e.g., the surroundings of the Amazonian parks, the upstream of the Pantanal) and where the risk of crop failure is relatively high (e.g., the semiarid region of the Caatinga biome). The land cover types CR and, especially, CR+ are associated with agronomic technologies that are challenging to employ on low suitability lands due to limitations such as marginal climate, steep slopes, and poor soils. The expansion of CR+ is therefore naturally limited to environmentally less sensitive locations. Most environmentally sensitive areas are naturally suited for more extensive pasture production or cultivation systems less dependent on mechanization and high-input technologies, commonly managed on smaller scales.

3.2.3. LUC Allocation in the Three Scenarios. Figure 2 shows the LUC outcome in the three scenarios. Aggregated values for states, regions, and biomes are shown in Table S2, and spatial distributions are shown on Maps 15−23 in the SI. In **Conservation**, marginal lands are set aside for NV restoration, in line with the Brazilian experience of abandonment of

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agricultural land after the consolidation period;[37] high performing cropping systems expand on NV and pastures on Very High suitability lands; and beef production increases through land productivity improvements on pastures situated on High and Medium suitability lands. Geographically (Maps 15−18 in the SI), NV prevails on PRnoOB lands in the entire Legal Amazon region, Pantanal, steep areas along the Atlantic forest biome and climatically marginal areas of the northeastern and southeast semiarid regions. The remaining pasture area occupies larger parts of the state of Rondônia and Roraima, south of Acre a larger extension of north of Tocantins, Maranhão, and Pará. In the south of Brazil, we see a more patchy distribution of pastures on the lower suitability classes associated with steep slopes. Crops dominate on PRnoOB lands in most of the Cerrado biome and northwest of Rio Grande do Sul, showing a much-aggregated geography. In total, NV on PRnoOB lands increases by about 30% and croplands increase 1.5 times, while pasturelands decrease more than 40%.

In **Production** there is no NV restoration: pasture expands on NV lands and pasture production is intensified even on lower suitability lands. NV and pastures on lower suitability lands are converted to improved croplands (Figure 2). Geographically (Maps 21−23), NV prevails on PRnoOB lands in the semiarid northeastern Caatinga biome and steep slopes or extremely poor soils of the Cerrado biome and Pampas but is replaced by pastures or croplands in the other areas, which would presumably lead to GHG emissions. Crops dominate landscapes, while pastures show a more patchy distribution occupying the lower suitability areas surrounded by crops. Agronomic intensification (i.e., large-scale mechanization, monocultures, and high fertilizer and pesticide inputs) on lower suitability lands potentially increases impacts associated with soil erosion and environmental pollution. In total, more than two-thirds of NV on PRnoOB lands is converted to agriculture; croplands increase 2.7 times, while pasturelands decrease about 30%.

In **Neutral**, NV conversion to improved croplands and pastures is partly balanced by NV restoration on pastures situated on Very Low suitable lands. Geographically (Maps 17−20), NV expands on PRnoOB lands, only excluding areas with continuous prevalence of Very High and High suitability lands in São Paulo, Mato Grosso do Sul, north of Mato Grosso, and the east margin of the São Francisco river in the state of Bahia, where crops would occupy larger portions of the rural landscape. Pastures expand over the Medium and Low suitability lands throughout Brazil, seldom dominating the landscapes but rather integrating with other land cover/land use in landscapes dominated by either croplands or NV. In total, NV on PRnoOB lands is reduced by 17%, croplands increase 2.1 times, and pasturelands decrease by about 40%, with roughly 70% of the remaining pastureland placed under intensified use.

As illustrated above, future NV protection and restoration beyond what is under C&C mechanisms depends on how incentives influence the balance between conservation and production objectives. Given the volatile situation following the gradual shift from C&C governance frameworks toward market-based intervention or voluntary certification schemes, it is highly uncertain how this balance will evolve over time.

3.3. Combined C&C and Private Voluntary Governance. The revision of the FA resulted in weaker NV protection, but 80% of the NV in Brazil is still under private or public C&C legal protection. The current trend[43] of further weakening of NV protection can be addressed through improved private sector compliance with legislation and through local actions better aligned with the global environmental policies that the Brazilian government already has ratified.[44] Promotion of relevant public institutions and monitoring/enforcement frameworks and support for civil society activism and surveillance can increase the likelihood of such changes. This promotion does not have to be prohibitively expensive but can involve organizational challenges and needs to be coordinated with ongoing societal processes influencing governance in other important areas such as poverty, economic development, health care, education, and food security. Examples of measures and activities that show promise include surveillance and transparency tools, certification and market regulation, publicity and access to public information, and actions against corruption. At the national level, the key concern is that C&C frameworks (actions and targets) are managed on several organizational levels across a wide range of institutions that are not always exclusively concerned with conservation. Further, frameworks and mechanisms promoting cooperation and efficiency are lacking.

Most of the legally unprotected NV that depends on voluntary commitments for its protection has a patchy spatial distribution pattern. C&C is not as efficient on patchy private landscapes where production and conservation occur side by side, and incentives for voluntary NV protection can be important complements. Only 10−25% of the unprotected NV is attractive from an agricultural point of view (under current technology options and logistics infrastructure). Much of the remaining NV is found in the Amazon and upstream of the ecologically important Pantanal and in the climatically marginal areas of the northeastern semiarid Caatinga biome where agricultural production would be risky. In these areas, protecting NV is important so as to avoid unnecessary NV conversion that would not make an important contribution to agricultural production in Brazil anyway. In **Conservation** and **Neutral**, cropland area increases 1.5 and 2.7 times, respectively, without using much land in these areas.

Achieving incentive-based NV protection requires far-reaching changes in the beef sector. These changes include major productivity improvements and changes in a culture that has been shaped by a long period of expanding agricultural area. The ample supply of new land in frontier regions has enabled extensive cow-calf production and fostered a culture, among producers and technology supply companies that considers management options to increase land-use efficiency of cow-calf operations less important. The ambition to decouple agricultural development from deforestation and the large investments into pasture intensification in the ABC program contribute to improve conditions for NV protection. However, complementary protection of NV is lagging, and this means that NV that is distributed in patchy patterns is still at risk of being converted to make room for extensive grazing or other activities. Thus, direct investments in conservation are strategically important for protecting NV in Brazil.[45]

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.5b01300.

Tables S1 and S2, Figure S1, and Maps 1−23 (PDF)

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