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REVIEW

Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains

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The recent 70% decline in deforestation in the Brazilian Amazon suggests that it is possible to manage the advance of a vast agricultural frontier. Enforcement of laws, interventions in soy and beef supply chains, restrictions on access to credit, and expansion of protected areas appear to have contributed to this decline, as did a decline in the demand for new deforestation. The supply chain interventions that fed into this deceleration are precariously dependent on corporate risk management, and public policies have relied excessively on punitive measures. Systems for delivering positive incentives for farmers to forgo deforestation have been designed but not fully implemented. Territorial approaches to deforestation have been effective and could consolidate progress in slowing deforestation while providing a framework for addressing other important dimensions of sustainable development.

The prospect of ending Amazon deforestation with most of the forest still standing while agricultural production continues to grow (*1*) has improved in Brazil. Deforestation—the clear-cutting of mature forest—declined from a 10-year average of 19,500 km^2 $year^{-1}$ through 2005 to 5843 km^2 in 2013, a 70% reduction. Soy production, the most profitable Amazon land use, continued to grow (Fig. 1). The deceleration of deforestation has avoided the emissions of 3.2 Gt CO_2 to the atmosphere [see the supplementary materials (SM)] and has made Brazil the global leader in climate change mitigation. The decline in deforestation may have triggered a cascade of positive impacts, including reduced risk of regional rainfall inhibition, fewer changes in river discharge and sedimentation, and increased biodiversity conservation (*2*–*4*).

Several studies have analyzed aspects of the decline in deforestation in the Brazilian Amazon (summarized in fig. S1), but we provide a much-needed critical review of the full range of policy interventions and commodity market effects, including "supply chain" interventions involving producers, processors, and/or buyers of soy or beef, the two main historical drivers of Amazon deforestation.

Hypotheses

The deceleration of deforestation in the Brazilian Amazon is the aggregate effect of thousands of landholders and land speculators who chose to clear less forest since 2004. We examine eight hypothetical causes of this decline (table S1). Hypothesis 1 (H1): Landholders came to associate deforestation with higher risks of reduced access to markets and finance or (H2) fines, embargos on their products (SM), and even prison sentences. H3: Landholders began to realize benefits through payment for ecosystem services, price premiums from certification, and access to new credit lines by foregoing deforestation. H4: Land speculators cleared less forest because the expansion of protected areas reduced the supply of undesignated or loosely claimed forestland, and (H5) stalled highway paving projects meant that potential new supplies of such forestland were not accessible. H6: The demand for new crop- and pastureland declined when the profitability of soy production fell, (H7) when beef intensification elevated production on existing cleared lands, and (H8) when the regional cattle herd was reduced in size.

Three Phases of Deforestation

Three phases in Brazil's decline in Amazon deforestation can be distinguished as we interpret its possible causes (Fig. 2). Descriptions of the public policy and supply chain interventions and international pledges (i.e., Norway) referred to in this section are summarized in fig. S1, table S2, and accompanying supplementary text.

Phase 1: Agro-Industrial Expansion

From the late 1990s through 2004, Amazon deforestation became far more sensitive to global influences as commodity market conditions and technological advances favored the first large-scale expansion of soy and other mechanized crops into the region (*5*). During the final years of this phase, soy prices and deforestation spiked (Fig. 1A and fig. S2); more than half of this forest clearing took place in the southeastern Amazon state of Mato Grosso, Brazil's largest agricultural producer (fig. S3). Cattle production intensified, with yields increasing fivefold (Fig. 1B) (*6*–*9*).

The Brazilian Forest Code (FC) was the most important legal restriction on forest clearing on private lands. It establishes a minimum portion of each property that must be managed as a forest reserve (*reserva legal*). In the Amazon region, the *reserva legal* was increased from 50 to 80% in 1996, making compliance virtually unattainable (*10*), reducing the law's credibility (SM); enforcement was also encumbered by the lack of a rural property cadastral database. The Rural Property Environmental Licensing System (SLPR) was launched in Mato Grosso (*11*) to address this deficiency. In this phase, protected areas and indigenous reserves were established at a slow rate, far from the active agricultural frontier (*12*).

Phase 2: Frontier Governance

From 2005 through 2006, the profitability of Brazilian soy production plummeted, driving a retraction in the area of soy planted in the Brazilian Amazon (*1*, *7*) (figs. S1, S2, and S4). Law enforcement capacity increased with the launch in 2004 of the Detection of Deforestation in Real Time (DETER) system for detecting and responding to deforestation events (table S2). The "Plan for the Protection and Control of Deforestation in the Amazon" (PPCDAm) (table S2) was also created, elevating the issue of Amazon deforestation to the president's office and, facilitating coordination and collaboration across several ministries, including the federal police and the powerful public prosecutor's office (Ministério Público). In 2006, a Greenpeace-led attack on the Brazilian Amazon soy industry led to a "Soy Moratorium" that was joined by most of the buyers of Amazon soybeans (SM). Through the moratorium, farmers who grew soy on land cleared after 26 July 2006 were no longer able to sell to participating buyers (Fig. 1 and fig. S1) (*13*).

Regional planning processes organized to prepare for highway paving projects (Fig. 3A), strong political leadership, and a national commitment to expand protected areas (Amazon Region Protected Areas Program,) (table S2) resulted in rapid expansion of the protected area and indigenous territory network (*14*, *15*). From 2004 through 2012, protected areas and indigenous territories grew 68% to encompass 47% of the entire Brazilian Amazon region, with many of these areas

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created in active agricultural frontiers (*15*) (Figs 1 and 3) (SM).

Phase 3: Territorial Performance

During this phase, the profitability of soy production began to increase, and the intensity of cattle production continued to grow (Fig. 1B and fig. S2) (*8*, *9*). A territorial performance approach to deforestation was adopted in which the geographical unit of intervention was the county (*município*) instead of the individual farm. Through a collaboration between the Central Bank and Environment Ministry, the Critical Counties program was launched, suspending access to agricultural credit for those farms and ranches located in the 36 counties with the highest deforestation rates (fig. S1 and table S2). The program stimulated collective action to reduce deforestation, mimicking some of the lessons of Brazil's successful program to eradicate foot-and-mouth disease (*5*); 11 counties succeeded in drastically reducing deforestation (*16*) (fig. S5). In response to this program, the state of Pará has launched a Green County program to help blacklisted counties reduce their deforestation rates and reestablish access to credit (table S2).

This phase also includes the first programs to create positive incentives for landholders who are making the transition to low-deforestation sustainable production systems. The National Climate Change Policy (NCCP) established the goal of an 80% reduction in Amazon deforestation by 2020 and launched a new line of farm-level low-carbon credits to help achieve this decline (SM). The Amazon Fund was created with a US$1B performance-based pledge from Norway that has been partially disbursed as deforestation has declined. Reducing Emissions from Deforestation and Forest Degradation (REDD) programs, intended to attract payments as compensation for state-wide reductions in deforestation and associated carbon emissions, were designed by the governments of most Amazon states (*1*, *17*), and some attracted investments (SM).

Property-level law enforcement capacity was also improved in 2009 through the Rural Environmental Registry [Cadastro Ambiental Rural (CAR)] in Mato Grosso and Pará. It requires landholders to submit their property boundaries to the state environmental regulatory agency (SM).

Pressured by the growing capacity of the government to enforce the FC and market demands for legal compliance (SM), a powerful faction of the agribusiness lobby sought revisions in the code. In the case of the Amazon, the 1996 increase in the *reserva legal* requirement had made compliance unattainable for most producers because it imposed more than US$2B in opportunity costs (*10*) (SM). A New Forest Code (NFC) was signed into law in 2012 (fig. S1 and table S2). Although the legal reserve requirement did not change, the NFC provided amnesty for landholders with 29 million hectares of illegal deforestation

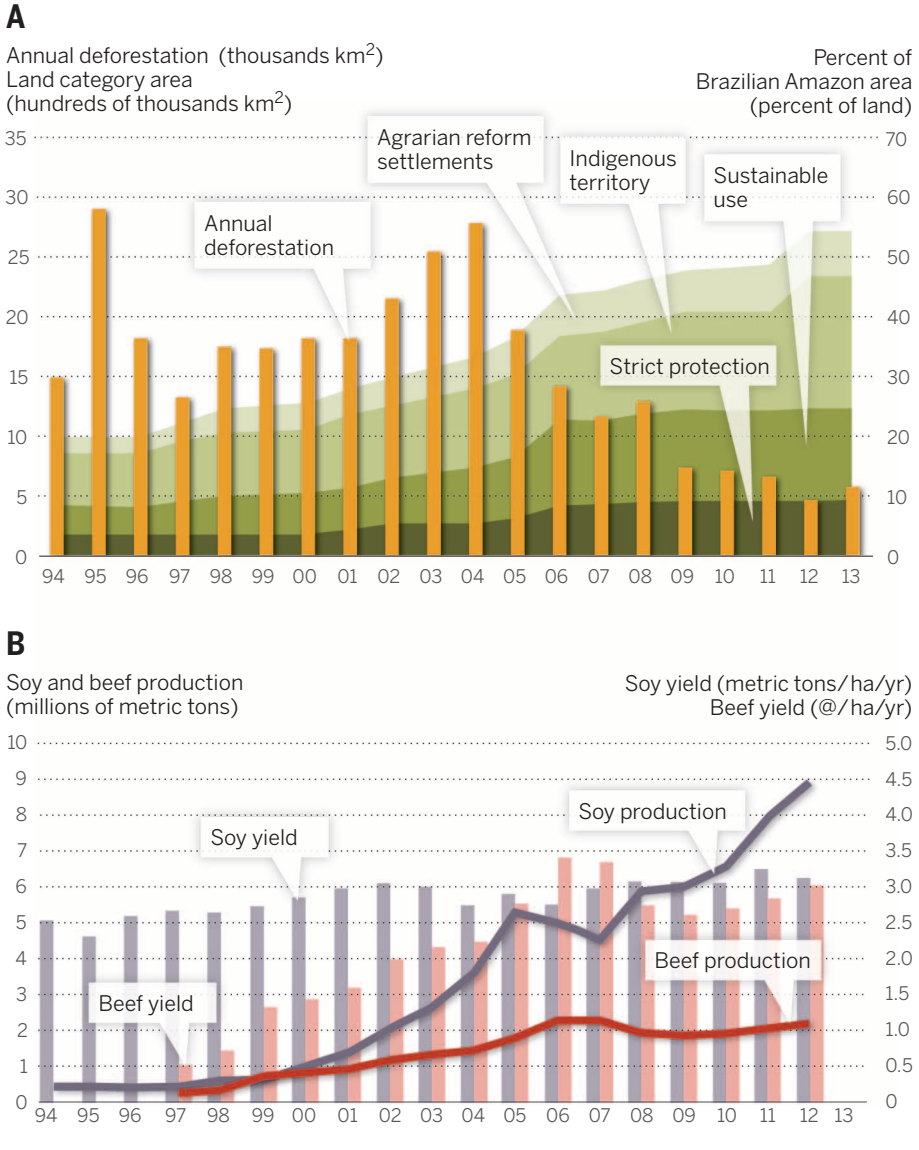

Fig. 1. Deforestation, area of land use categories, and production (beef and soy) trends in the Brazilian Amazon. (**A**) Annual deforestation and the area of indigenous territories, sustainable development reserves (e.g., extractive reserves), strict protection reserves, and agrarian reform settlements. (**B**) Soy and beef production and yields (for beef yields, @ = 15 kg of carcass weight) in the Brazilian Amazon. Annual deforestation data are from Instituto Nacional de Pesquisas Espaciais (INPE) (*26*). Indigenous territories, sustainable development reserves, and strict protection reserves are updated from Castello *et al*. (*24*), Instituto Socioambiental (ISA) (*27*), Nepstad *et al*. (*28*), and World Database on Protected Areas (WDPA) (*29*). Settlements area is from Instituto Nacional de Colonização e Reforma Agrária (INCRA) (*30*). Cattle herd and soy production data are from Instituto Brasileiro de Geografia e Estatística (IBGE) (*31*) and Nassar *et al*. (*9*).

that had taken place before July 2008 (*18*). It also introduced new measures for creating positive incentives for legal compliance (*10*). With the NFC, the farm and livestock sectors suddenly had a pathway to full legal compliance with the Amazon region's most important environmental regulation.

In 2009, a new Greenpeace campaign aimed at the Brazilian beef-processing company, Bertin—and subsequent legal proceedings against irregular slaughterhouses carried out by the Public Prosecutor's office—led to a "Cattle Agreement" in which the region's largest beef processing companies agreed to exclude from their supply chain those livestock producers who deforested after October 2009 (SM). Agricultural certification initiatives were launched during this period and are still at an early stage, as summarized in the SM (Fig. 3D).

Why Did Deforestation Decline?

The decline in deforestation during the "frontier governance" phase, from 2005 through 2007, was the result of several mutually reinforcing factors that decreased the demand for new deforestation, increased the risks to those engaged in deforestation, and reduced the supply of undesignated or loosely claimed forestland that is the target of land speculators. The demand for new deforestation declined through both a retraction in the area of soy production (supporting H6) (fig. S4), rapidly rising beef yields (H7) (Fig. 1B) and a sharp reduction in the size of the Amazon cattle herd (H8) (*9*). Deforestation became riskier through improved law enforcement, fines and embargos imposed on those associated with illegal deforestation (H2), and market rejection of deforesters through the Soy Moratorium (H3). The supply of undesignated forestland was limited through both a rapid expansion of protected areas in active agricultural frontier zones (*7*, *12*) (Fig. 1A) (H4) and delays in highway paving (H5) (SM).

The initial test of the measures implemented to slow deforestation came during the Territorial Performance phase, when soy profitability rose again and soy production increased (Fig. 1B and fig. S2). Demand for new deforestation did not come directly from the soy sector, however. The 50% expansion in soy production through 2013 took place entirely on land cleared before 2006 (fig. S6). During this period, beef production remained flat as the herd was rebuilt, gradually increasing demand for new pasture. In addition to the measures already in place, the risks associated with deforestation were further elevated through the Critical County program and the Cattle Agreement of 2009 (SM).

The contribution of each of these factors to the decline in deforestation is extremely difficult to measure because of the temporal and spatial overlap of the policy and supply chain interventions that were made. Spatial simulation modeling has found an important role of new protected areas in slowing deforestation (*12*). Econometric studies (*19*, *20*) have concluded that the rural credit restrictions implemented through the Critical Counties program contributed significantly to

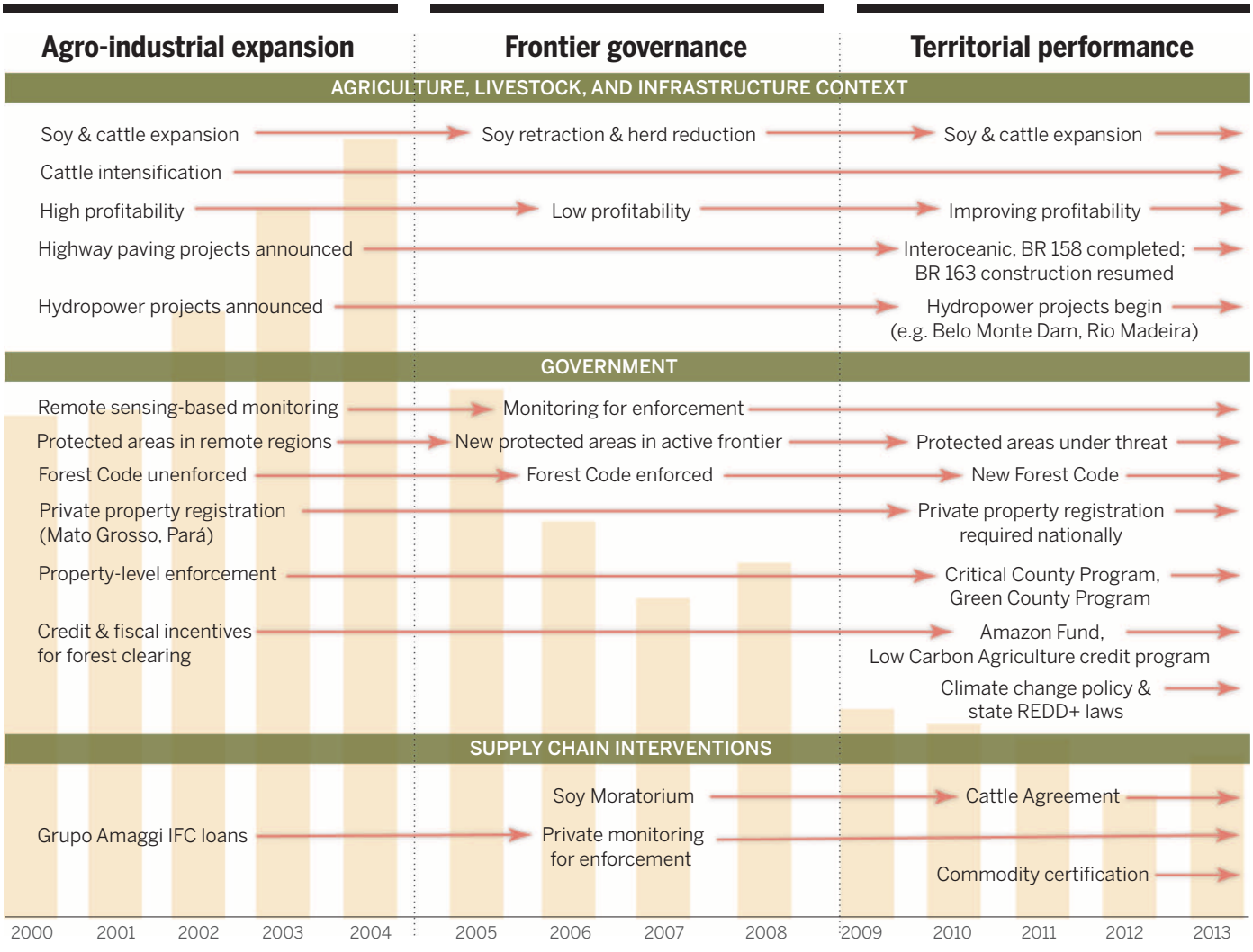

Fig. 2. Phases in the evolution of public policies and supply chain initiatives to control Amazon deforestation: 2000 to 2013. The underlying bar graph is the annual deforestation trend as shown in Fig. 1A. Sources for policy interventions are in table S2.

the decline in deforestation during this phase (table S1) (SM).

Discussion

Is the decline in deforestation sustainable, with 80% of the forest still standing? The long-term trend in deforestation will depend, in part, on continuing increases in livestock yields on existing cleared land. Cattle pasture is the main use of cleared land, and beef production has the greatest potential for yield increases compared with cropping systems (*6*). Amazon deforestation is not "decoupled" from expansion in crop and beef production, as Macedo *et al.* have concluded, unless beef yields climb fast enough to open up pastureland for soy expansion, which is a plausible scenario through 2020 (*7*, *9*). Eventually, cleared land that is suitable for soy production—the most profitable use of cleared land—will become scarce. As this scarcity sets in, the 120,000 km^2 of forests that could be profitably converted to soy in the Brazilian Amazon and that lie outside of protected areas (*4*) will become the target of deforestation pressure. Alternatively, expansion of crop and beef production could shift more heavily to the Cerrado biome to the south of the Amazon, where deforestation rates have been climbing since 2010 (*18*).

Future trends in Amazon deforestation will also depend on a continued perception of risk associated with deforestation. An important source of market access risk for soy producers is the Soy Moratorium, which is scheduled to end in 2014 because of the large number of legal soy producers who have been cut off from the market (SM). The government's command-and-control measures to fine and embargo illegal deforesters, and cut entire counties off from public agricultural credit, is precariously dependent upon the political will of government to impose these measures, which may be weakening in the face of a stagnant national economy (*21*). One early sign of a shift in political will is the reduction in size of some protected areas (*22*).

As demand for new deforestation increases, as supply chain interventions to discourage deforestation weaken, and if deforestation policies and programs lose political will, positive incentives for farmers, counties, and states that are forgoing or reducing deforestation will grow in importance. Systems for delivering these incentives are

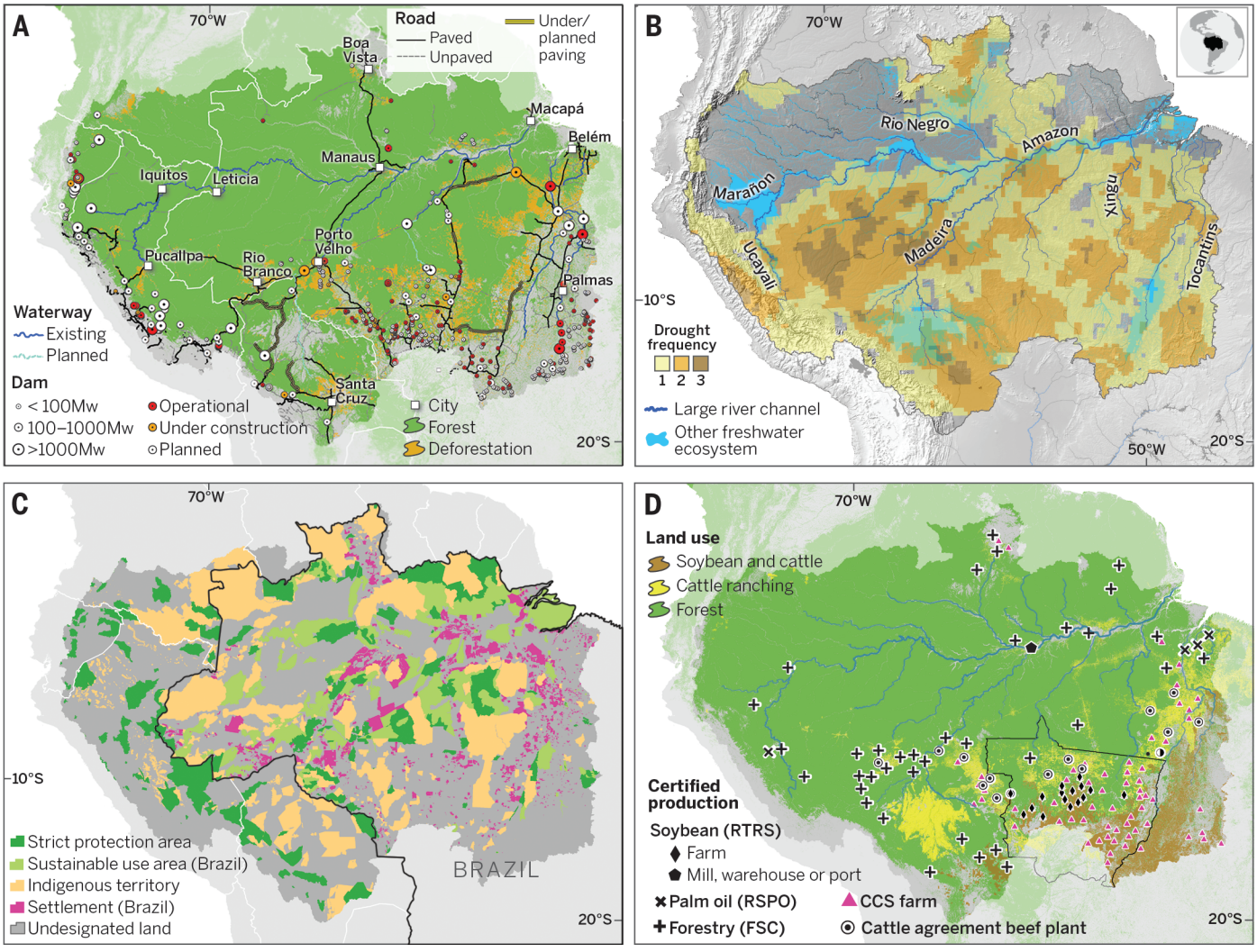

Fig. 3. The status of the Amazon region. (**A**) Infrastructure and forest loss since 2000. Highways (paved, unpaved, and planned paving), waterways (current and planned), and hydropower plants (current, under construction, and planned, with output scaled by size). Forest loss is of all forest types from 2000 through 2012 (*32*). Infrastructure updated from Soares-Filho *et al*. (*33*) and Castello *et al*. (*23*). (**B**) Rivers, other wetland ecosystems (*23*), and the number of drought episodes that exceeded the threshold of rainfall deficit [updated from Lewis *et al*. (*34*)]. (**C**) Indigenous territories, sustainable development reserves, strict protection reserves [updated from Castello *et al*. (*23*), ISA (*27*), Nepstad *et al*. (*28*), and WDPA (*29*)], agrarian reform farm settlements (Brazil only) from INCRA (*30*), and undesignated land (public and private, registered or not). (**D**) Areas of cattle and soy production (IBGE) (*31*) and locations of certified soy production and processing (Roundtable on Responsible Soy) (*35*), palm oil mills (Roundtable on Sustainable Palm Oil) (*36*), timber production (Forest Stewardship Council) (*37*, *38*), beef plants in the Cattle Agreement (*39*), and farms in the Registry of Socio-Environmental Responsibility (CCS) (*40*).

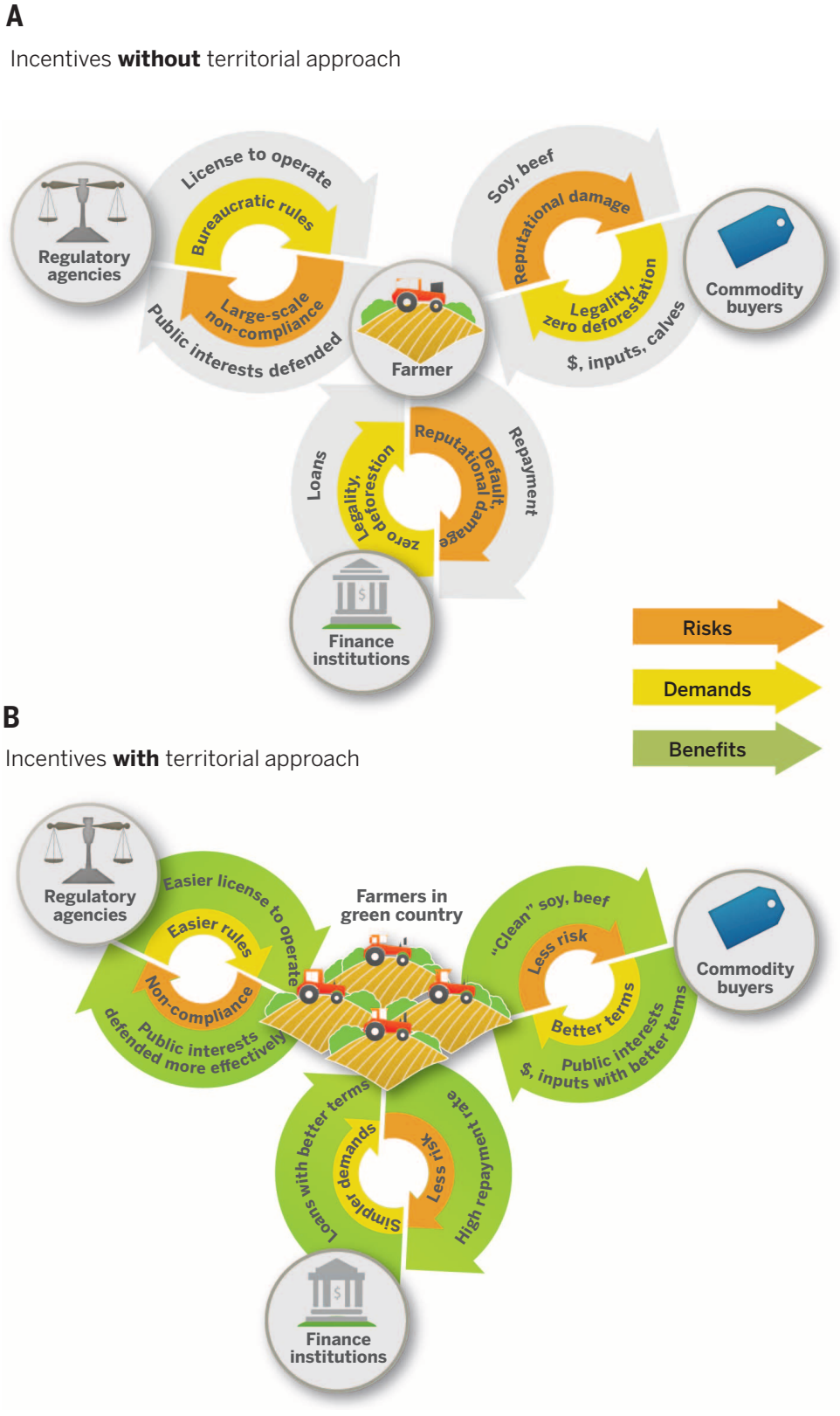

Fig. 4. Incentives for sustainable production with and without territorial performance approach. (**A**) Farmers operating in isolation are faced with many demands from regulatory agencies, commodity buyers, and financial institutions but do not receive significant positive incentives to slow deforestation. (**B**) The type of collective action to slow deforestation that is achieved in the Green County program could be reinforced through multiple incentives for territorial (county-wide) declines in deforestation. Regulatory agencies can simplify their licensing procedures, commodity suppliers can give full access to markets and better terms on preharvest loan packages, and banks can lower interest rates and improve terms (*41*).

not yet operating at scale and appear to have contributed little to the decline in deforestation (H3) even though considerable progress has been made toward establishing legal frameworks and farm-level approaches for eventually delivering these incentives (SM). Some immediate and simple positive incentives for farmers who forgo deforestation and invest in more intensive, sustainable production systems could be established without major new policies or markets for ecosystem services (Fig. 4A). Regulatory agencies could simplify their regulatory requirements or give discounts on their environmental licensing procedures, commodity suppliers could give better terms on preharvest packages, and banks could give lower interest rates or better terms on loans to legally compliant landholders. These incentives could increase for farmers in counties that have come off the Critical County black list or that are making measurable progress toward sustainable development in other ways (Fig. 4B), building on the early success of the Critical Counties program. Climate finance programs, such as the Amazon Fund, could establish innovative, competitive funding mechanisms for delivering finance to regional consortia that are ready to make the transition to low-deforestation, high-production land use systems. The new Forest Code establishes a policy framework for creating positives (*10*).

Supply chain and public policy initiatives could also become better aligned through a shared set of performance targets for further reducing deforestation that are accompanied by commitments from the relevant institutions and actors to help achieve these targets. For example, farmers; companies that produce, process, or purchase soy and beef; finance institutions; regulatory agencies; and environmental groups might agree that if counties, states, or the entire Brazilian Amazon achieve an 80% reduction in deforestation below the 10-year average, they should be considered "low deforestation" counties, conferring on the farmers in the successful territory the benefits described in Fig. 4B, including full access to markets. The target may increase to a 90% reduction in 2018. This approach could lower the costs of tracking the forest-clearing activities of millions of individual farms and ranches, which is required in the supply chain approach to deforestation. A critical issue is whether companies that have Amazon producers in their beef and soy supply chains will accept a deforestation agreement that is not absolute "zero" deforestation but that is more in line with a regional development strategy.

In the Amazon deforestation debate, little attention is paid to mechanisms for attracting investors into the Amazon region to sustainably develop its forests, fisheries, and agricultural potential. Advances in frontier governance, law enforcement, and mechanisms for punishing deforesters through restrictions on access to markets and finance succeeded in decelerating deforestation but failed to address the region's need for private investment, innovation, and enterprise. Land titling, which is fundamental to the landholder's ability to access credit, continues to progress slowly. Instead, effective campaigns by Greenpeace and others have increased the reputational risk of companies that do business in the Amazon, scaring away potential investors and market players. Consequently, the responsible agricultural and livestock companies and individuals who are needed to consolidate the progress made in reducing deforestation in the Brazilian Amazon may be driven away by the success of these campaigns.

Deforestation is only one of the threats to the Amazon region. Extensive forest fires during severe drought episodes kill mature trees, opening standing forests up to invasion by grasses and recurrent burning (Fig. 3B) (*4*, *23*). Hydropower dams, waterways (Fig. 3A), and overfishing threaten the fisheries, river ecosystems, and associated wetlands of the region, which are critical to the regional economies and to the livelihoods of indigenous and traditional communities (SM) (*24*). In addition, mining continues to degrade streams and forests through both physical disturbance and chemical pollution (*25*).

Conclusion

Brazil's remarkable decline in deforestation provides valuable lessons on the importance of public policies, monitoring systems, and supply chain interventions in slowing the advance of a vast, complex agricultural frontier. The challenge now is to build upon this progress to construct a strategy for promoting a new model of rural development in which punitive measures are complemented by positive incentives and finance at scale for landholders, indigenous communities, counties, and states to make the transition to low-deforestation, productive, sustainable rural development. Deforestation is only one dimension of the health of the Amazon Basin.

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/344/6188/1118/suppl/DC1
Supplementary Text
Figs. S1 to S4
Tables S1 and S2
References (*42*–*76*)

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