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Solving Brazil's land use puzzle: Increasing production and slowing Amazon deforestation

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ABSTRACT

Brazil has become an agricultural powerhouse, producing roughly 30 % of the world's soy and 15 % of its beef by 2013 – yet historically much of that growth has come at the expense of its native ecosystems. Since 1985, pastures and croplands have replaced nearly 65 Mha of forests and savannas in the legal Amazon. A growing body of work suggests that this paradigm of horizontal expansion of agriculture over ecosystems is outdated and brings negative social and environmental outcomes. Here we propose four strategies that can reduce deforestation, while increasing production and social wellbeing. First, *eliminate land grabbing and land speculation through designation of public forests*. This would clarify land tenure and limit the pool of land available for uncontrolled expansion of agriculture and ranching. Second, *reduce deforestation on private properties* by implementing existing mechanisms in Brazil's Forest Code to facilitate payments for environmental services, with support from market initiatives for sustainable sourcing of agricultural products. Third, *incentivize increased productivity on medium and large properties through targeted investments*. By stimulating adoption of proven technologies for sustainable intensification, this would help meet Brazil's production targets and growing international demand for agricultural products, without expanding into new production areas. Finally, *foster economic, environmental and social improvements through technical assistance to small farmers*. Small farmers occupy a large swath of the Amazon and often lack access to technical assistance, production technology, and markets. Providing quality technical assistance to small farmers could help them better align production practices with local opportunities; increase household income and improve livelihoods; and reduce deforestation pressure. By implementing these four strategies in a coordinated effort between public and private agents, Brazil can show the world how to reduce deforestation while increasing agricultural output, reestablishing its leadership in managing natural resources and mitigating climate change.

1. Introduction

Over the last three decades Brazil has emerged as a global agricultural powerhouse. In the 1970s it was a net importer of food commodities, with an average international trade deficit of US$1.8 billion per year (MDIC and Brasil, 2018). To address this imbalance, the Federal Government implemented a structured, long term plan including subsidies for rural credit; investments in agricultural research through the creation of Embrapa; a national plan for Amazon integration; and infrastructure projects to enable transportation of agricultural goods (Chaddad, 2015). Fifty years later, Brazil is a leading exporter of agricultural products such as soy, sugar, chicken, coffee and beef. Its agricultural sector is responsible for over 20 % of the country's GDP, producing roughly 30 % of the world's soybeans and 15 % of its beef (FAO et al., 2018).

The revolution in Brazilian agricultural production was built through strong political will, long-term planning and billions of dollars in targeted subsidies and incentives (Caldart et al., 2012). However, the expansion of Brazilian agriculture in the legal Amazon states[1] occurred at the expense of nearly 65 million hectares (Mha) of native ecosystems, which were converted to pasture or croplands from 1985 to 2018 (MapBiomas, 2019). Over the same period, annual soy production in

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[1] The legal amazon is a political definition composed of nine Brazilian states.

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the region increased from 1.7 to ~40 million tons (IBGE, 2018a), while the cattle herd increased from 15 to ~86 million animals (IBGE, 2018b). In some regions, this boom in agricultural production generated social benefits such as increased income, access to schools and better health (Richards et al., 2015). In others, the deforestation-based model of frontier expansion caused income inequality and land concentration (Sant'anna, 2017), rural violence (Dantas et al., 2017), land grabbing (Azevedo-Ramos and Moutinho, 2018), and environmental degradation (Nepstad et al., 1999).

Although it enabled the region to produce grains and meat to feed domestic and foreign markets, the associated environmental degradation has become a threat to future production (IPCC et al., 2019). The cumulative effect of this agricultural expansion has contributed to regional climate changes (Silvério et al., 2015) and has the potential to alter planetary-scale circulation (Mahmood et al., 2014; Snyder, 2010). For example, in the southern Amazon, local deforestation (by reducing water vapor flux to the atmosphere) has already delayed the onset of the rainy season and shortened the growing season (Leite-Filho et al., 2019). Mitigating such climate changes has thus become a real and growing challenge for Brazil's agricultural sector.

Between 2004 and 2017, annual deforestation in the legal Amazon states fell by > 70 % (INPE, 2018a, 2018b) while soybean and beef production increased by 130 % and 72 %, respectively (IBGE, 2019, 2018a) (Fig. 1). These reductions in deforestation have been linked to various public and private policies and the observed trends are subject to complex interactions, time lags, and teleconnections (Alix-Garcia et al., 2017; Boucher et al., 2013; Kastens et al., 2017). Even so, several studies suggest that Brazil now has an opportunity to significantly increase its agricultural production without new deforestation (Chambers and Artaxo, 2017; Garcia et al., 2017; Macedo et al., 2012; Nepstad et al., 2014). This opportunity is rooted in the fact that Brazil has a very large pool of already cleared, underutilized land (Strassburg et al., 2014), as well as capable agricultural sector that is primed for innovation.

The business case for improving environmental performance is increasingly clear. International markets are demanding deforestation-free products that meet multiple sustainability criteria (Lambin et al., 2018). In response, producers and companies (e.g. traders, meatpackers and animal feed producers) have made a series of voluntary commitments to source deforestation-free commodities. These include pledges by the Consumer Goods Forum (CGF, 2019), the Tropical Forest Alliance (TFA, 2020, 2019), the New York Declaration on Forests (NYDF, 2019), the Amsterdam Declaration Partnership (AD-Partnership, 2015) and the Soy and Beef Moratoriums, among others. Brazilian society knows that it cannot continue to sacrifice its natural environment to satisfy short-term targets for economic and agricultural growth (Pinto et al., 2017; Strassburg et al., 2014).

The model of increasing production through "frontier expansion" is outdated and increasingly out-of-step with markets and societal demands. It not only falls short of sustainability standards, but also faces increased production risks as deforestation and forest fragmentation alter regional climate (Butt et al., 2011; Spracklen et al., 2018). Many studies have pointed to sector-specific proposals to address this (Cohn et al., 2014; Gibbs et al., 2015; Nepstad et al., 2014), but Brazil still lacks a long term, integrated approach to reconcile its production goals with environmental conservation. For example, by 2030 the Brazilian Ministry of Agriculture aims to increase beef production by ~43 % and grain production by ~33 % (Brasil and Secretaria de Política Agrícola, 2017). The current strategy to achieve those targets is rooted in the old paradigm of expanding agriculture at the expense of forests (Azevedo-Ramos and Moutinho, 2018). Moreover, agricultural expansion is at odds with the goals set by the federal government's Nationally Determined Contribution (NDC), which aims to restore 12 million ha of forests and end illegal deforestation in the Amazon by 2030 (Brasil, 2017a).

Despite the lack of coherence in federal policies, producers are already testing new modes of agricultural production, including planting grains in degraded pasturelands, double cropping (Kastens et al., 2017) and integrated agriculture-forest-pasture systems (EMBRAPA, 2017). This move towards intensification has occurred with few (if any) government incentives, but new incentives and strategic investments could accelerate its widespread adoption. Mato Grosso, the largest commodity producer in Brazil, has been proactive in setting targets to increase production, while promoting forest conservation and social inclusion (Mato Grosso, 2016). At the same time, the environmental policies now being proposed by Brazil's federal government threaten to dismantle Brazil's Forest Code (Tollefson, 2018) and may have already contributed to the recent surge in land speculation and deforestation in the Amazon (Venâncio et al., 2018). This dissonance between regional and federal policies underscores the urgent need for a new, integrated

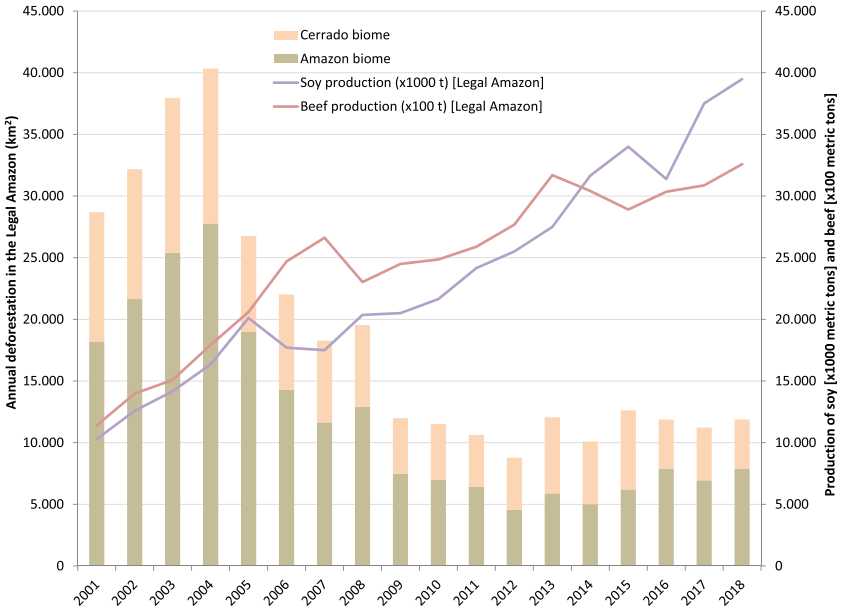

Fig. 1. Deforestation (km²/yr) in the Amazon (green bar) and Cerrado (yellow bar) biomes of the legal Amazon states in the primary Y axis and the annual production of soy (purple line) and beef (red line) in the region (Data sources: IBGE, 2019, 2018a; INPE, 2018a, 2018b).

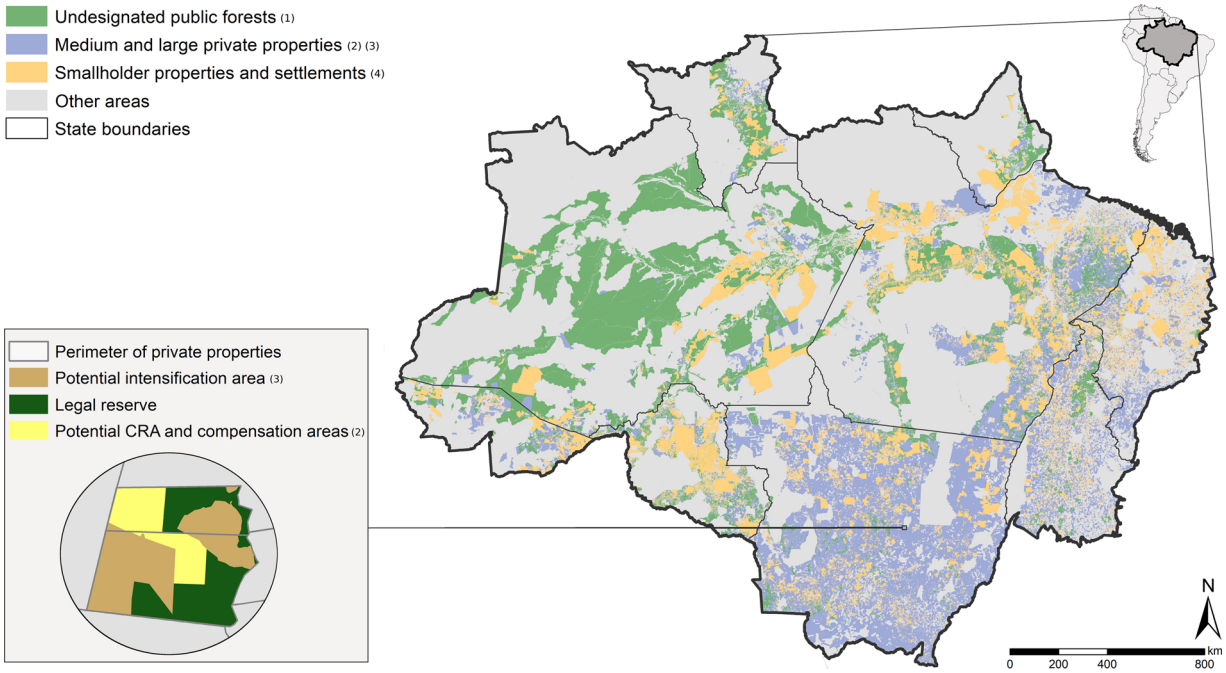

Fig. 2. Land tenure categories in the Brazilian Amazon related to our four proposed strategies to reduce deforestation in the region (see text for details). *Inset*: Representation of large private property with areas (in yellow) that can be financially compensated to avoid legal deforestation (see the text for details). CRA is a Portuguese acronym for Environmental Reserve Quotas as established by the Forest code (Brasil, 2012). The number in parenthesis indicated which strategy applies to each of the colours in the maps.

model of development that reconciles agricultural growth, forest conservation and social well-being in the Amazon.

This study explores potential pathways to foster a new development paradigm for the Brazilian Amazon (Fig. 2). We focus on four complementary strategies: (1) *eliminate land grabbing and land speculation through designation of public forests*; (2) *reduce deforestation on private properties*; (3) *incentivize increased productivity on medium and large properties through targeted investments*; and (4) *foster economic, environmental and social improvements through technical assistance to small farmers*. Given that implementing all four strategies simultaneously is unrealistic, a key issue is to prioritize implementation across strategies or regions to maximize the benefits to conservation, climate mitigation, production and social inclusion goals. Furthermore, the model proposed here assumes that existing public policies and command-and-control enforcement mechanisms are maintained and improved.

2. More food, more forests: charting a path forward

(1) Eliminate land grabbing and land speculation through designation of public forests. Brazil has over 65 Mha of undesignated public forests in the Amazon – an area the size of France never officially allocated by the government (Fig. 2). In the absence of clear land tenure, land speculators and grabbers often occupy and deforest these lands illegally, whether by forging land titles or using loopholes in existing legislation to resolve tenure issues, selling these areas at a profit and flooding the market with low opportunity cost lands (Brown et al., 2016; Sparovek et al., 2019). Recent changes to the laws governing land occupation have only encouraged this dynamic by creating confusion and the perception that environmental laws have no teeth. For example, Terra Legal (Brasil, 2009) – a government program designed to give long-time occupants a pathway to legalize their land claims – recently extended its cut-off date for filing claims (Brasil, 2017b), sending the signal that land speculation can pay off. As a result, 25 % of Amazon deforestation in 2017 (INPE, 2018a) occurred in undesignated lands.

Designating undesignated public forests as protected areas with adequate management and clear tenure could significantly reduce illegal deforestation and limit the market for illegal land grabbing and land speculation (Azevedo-Ramos and Moutinho, 2018; Moutinho et al., 2016). The cost of creating and maintaining such protected areas varies greatly (Geluda et al., 2012; da Silva et al., 2019), but could be compensated by a stronger regional forest economy and by sustainable use of the forest resources. At the same time, creating new protected areas would contribute to maintenance of ecosystem services and biodiversity (Golden Kroner et al., 2019). An important aspect of inclusion would be through sustainable use of these new protected areas, providing incentives and income generating opportunities for local communities, such as tourism or sustainable extraction of timber, rubber, "açaí", Brazil nuts, and other forest products (Medeiros and Young, 2011). The avoided deforestation could also attract green investments, including existing mechanisms for Reducing Emissions from Deforestation and Forest Degradation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC).

(2) Reduce legal deforestation on private properties. We estimate that there are 28 Mha of Amazon forests on private properties that could be legally deforested under existing legislation (Stabile, 2018) (Fig. 2). Roughly 16 Mha of this legal deforestation could be avoided through a market for environmental offsets known as Environmental Reserve Quotas (CRA, Portuguese acronym) – a mechanism proposed in the 2012 revision of the Brazilian Forest Code (Soares-Filho et al., 2016). The CRA would establish a cap-and-trade system of forests certificates, making it possible for landowners with forest surpluses (i.e. forest areas exceeding the legal requirement) to transfer their "right to deforest" and offset forest deficits elsewhere (i.e. illegally deforested land that needs to be restored). Implementation of the CRA mechanism is still pending regulation.

Avoiding legal deforestation in the remaining areas (12 Mha) would require a new mechanism and regulation for payments for environmental services (PES) to compensate farmers for the foregone profits associated with conserving forests on their property. Our preliminary calculations suggest an opportunity cost of US$77-123 $ha^{-1}yr^{-1}$ to compensate 12 Mha of forest surplus (Stabile, 2018). The Brazilian government could promote private or public compensation programs

using a PES approach (Börner et al., 2017), implementing a national cap and trade scheme (IPAM, 2014) or REDD + mechanisms (Angelsen et al., 2012). Payments for avoiding legal deforestation would generate income for farmers that could be reinvested to improve productivity. The regulation of PES mechanisms has moved forward recently with Brazilian Congress approving legislation to regulate such mechanisms.

Market initiatives that support deforestation-free supply chains could also play a crucial role in reducing legal deforestation. Examples include industry-led initiatives such as the Soy and Beef Moratoria (Gibbs et *al.*, 2015), as well as international commitments to source zero-deforestation products such as Consumer Goods Forum (CGF, 2019), Tropical Forest Alliance 2020 (TFA, 2020, 2019), New York Declaration on forests (NYDF, 2019) and the Amsterdam Declaration Partnership (AD-Partnership, 2015). These initiatives could provide additional incentives to promote intelligent land-use planning and agricultural intensification. Harnessing international financing for avoided deforestation (e.g., the Green Climate Fund and International Civil Aviation Organization) could provide additional funding and facilitate trading of forest certificates.

(3) Incentivize increased productivity on medium and large properties through targeted investments. Achieving Brazil's agricultural development targets (MAPA 2017) solely through agricultural expansion (into new areas) could require as much as 12 Mha of additional deforestation. Targeted intensification can play a substantial avoiding this deforestation by increasing production on already cleared land (Garcia et al., 2017; Martha et al., 2012; Strassburg et al., 2014). In this regard, intensification of cattle ranching on existing pastures represents particularly low-hanging fruit. Increasing beef productivity in the Amazon from 60 kg $ha^{-1}yr^{-1}$ to 150 kg $ha^{-1}yr^{-1}$ on just 21 % (11.5 Mha) of existing rangelands would free enough land (4 Mha) to meet beef production targets and allow for crop expansion in these areas (MAPA 2017) without any new deforestation. The economic benefits of intensifying beef production on medium and large ranches outweigh the needed investments (Garcia et al., 2017; Silva and Barreto, 2014; Stabile et al., 2017), but there are cultural and economic barriers to doing so. Ranchers are often risk-averse because they cannot control the price of beef or accurately predict the return on investments to increase production. Furthermore, expanding into new areas is still seen as a sign of prosperity, and purchasing new land is often cheaper than investing in productivity gains (Koch et al., 2019).

This third strategy would redirect (or reinvent) incentives to increase productivity on private properties (Fig. 2). This could involve both public and private sectors. For example, a portion of public investments through Brazil's "Plano Safra" (an existing subsidized credit program for agriculture) could be redirected to increasing agricultural productivity. Subsidies could help promote adoption of existing technologies, innovation, and sound land management. Moreover, setting environmental criteria to access credit could encourage producers to implement changes that ultimately help them meet commercial demands for deforestation-free products, comply with environmental legislation, and increase the long-term sustainability of production. For instance, a greater share of agricultural credit lines could be earmarked for "low-carbon agriculture" as proposed by Brazil's Low Carbon Agriculture (ABC) Program – which now represents only 2 % of total rural lending. At the same time, the private sector has signaled with commitments to source deforestation-free products. This demand should be accompanied by direct support to producers and supply chains to increase productivity while complying with existing legislation (Azevedo et al., 2015).

(4) Foster economic, environmental and social improvements through technical assistance to small farmers. The fourth and final strategy is to strengthen small family farming through technical assistance to improve their economic, social and environmental outcomes (Fig. 2). About two million people occupy the 77 Mha of official settlements in the Amazon (INCRA, 2017) – the same areas responsible for 30 % of all Amazon deforestation in recent years (INPE, 2018a). Historically, small family farming has been neglected in the modernization of Brazilian agriculture (de Castro and Pereira, 2017). The high rates of deforestation on these properties stem from low income; a lack of basic infrastructure and institutional support; and poor access to technical assistance, farming technology, and markets (Alencar et al., 2016). Current farming practices often lead to the depletion of soil nutrients, as farmers lack the technical assistance, know-how, or resources to implement new practices and invest in inputs (dos Santos et al., 2018). The result is low crop productivity, which generates insufficient income and encourages more deforestation to gain scale or increase production.

A recent pilot project providing technical assistance to small farmers succeeded in increasing household income and reducing deforestation (IPAM, 2017). The Sustainable Settlements Project (PAS) provided technical assistance to over 650 families in eastern Amazonia over three years. Technicians encouraged smallholders to adopt integrated management systems designed to avoid (or reverse) environmental degradation and sustain the production capacity of agricultural lands over the long term. Key components included: planning of farm interventions along with smallholders; adoption of new technology to increase productivity for beef, milk and other produce; improvements in processing infrastructure to comply with health and sanitary regulations; and increased access to markets (IPAM, 2017b). A PAS market study revealed opportunities to replace many products being imported into the region (at a great cost) with locally sourced goods. Technical assistance and extension services helped farmers become more competitive due to increased scale of production, legal compliance and competitive prices. Farmers were also engaged in new activities – e.g. production and processing of fruits, milk, meat, rice, beans and cassava – and improved supply chains, such as black pepper and açai. As a result, household income more than doubled (+121 %), raising the average annual net revenue from US$2190 to US$4831 $ha^{-1}yr^{-1}$ (assuming an exchange rate of 3.93 Brazilian Reais per US dollar, IPAM, 2017). Simultaneously, deforestation rates in these properties dropped by 79 %. This experience suggests that current technical assistance provided by government agencies (EMATER and ANATER) needs to be modernized and adapted to a new, more sustainable production model focused on increasing productivity, while minimizing dependence on expensive agriculture inputs.

3. Conclusion

The conventional narrative posits that conserving forests and reducing CO_2 emissions is simply too expensive to be practical. Here we argue that this paradigm is outdated, particularly in the Brazilian Amazon. By investing in the strategies proposed here, designating lands to protected areas will limit the market for expansion of agriculture, while enabling sustainable use of the protected areas, fostering a new forest economy. Conservation in private lands can generate income to farmers through PES and other mechanisms, while allowing for compliance with the environmental legislation and sourcing of deforestation-free products. Furthermore, through intensification of cattle ranching and agriculture (rather than expansion in medium and large properties), as well as diversification and access to markets for smallholders, Brazil can prove to the world that it is possible to curb deforestation and increase production. This assumes that Brazil will maintain or strengthen existing environmental policies, and command and control initiatives to combat illegal deforestation as required by its Paris Agreement targets. To succeed, the approach outlined here must be coordinated with efforts to limit the land available for land grabbing; targeted investments to preserve forests on private properties; and innovation to increase the productivity of farms and ranches. Implementation of the four strategies could be staged, first prioritizing locations where it is possible to maximize environmental, social and economic benefits but then expanded to the whole region.

Now is the time to set Brazil on a path to economic growth and

environmental conservation – contributing to the region's GDP in the short term, while securing its socio-environmental well-being over the long-term. Careful and targeted investments in the strategies described here could yield environmental, economic, and social gains for Brazil, while helping to mitigate the impacts of global climate change in the region. Doing so would not only generate revenue, but also have global repercussions. Given its targets to supply over 10 % of global food demand, Brazil could help feed the world while providing much-needed leadership in meeting or exceeding its targets to reduce greenhouse gases emissions and conserve functioning ecosystems. It is up to Brazilian society and its new government to chart a different path for Amazon development. Brazil has the opportunity to prove its leadership in the world by managing its land and resources for the benefit of both current and future generations.

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References

AD-Partnership, 2015. Amsterdam Declaration Partnership [WWW Document]. URL (accessed 9.17.19). https://ad-partnership.org/.

Alencar, A.A., Pereira, C., Castro, I., Cardoso, A., Lucimar, S., Costa, R., Bentes, A.J., Stella, O., Azevedo, A.A., Gomes, J., Novaes, R., 2016. Desmatamento nos Assentamentos da Amazônia: Histórico, Tendências e Oportunidades, 1st ed. IPAM, Brasilia, DF, Brasil.

Alix-Garcia, J., Rausch, L.L., L'Roe, J., Gibbs, H.K., Munger, J., 2017. Avoided deforestation linked to environmental registration of properties in the brazilian amazon: environmental registration in the Amazon. Conserv. Lett. https://doi.org/10.1111/conl.12414.

Angelsen, A., Brockhaus, M., Sunderlin, W.D., Verchot, L.V. (Eds.), 2012. Analysing REDD+: Challenges and Choices. CIFOR, Bogor, Indonesia.

Azevedo, A.A., Stabile, M.C.C., Reis, T.N.P., 2015. Commodity production in Brazil: combining zero deforestation and zero illegality. Elem. Sci. Anthr. 3, 000076. https://doi.org/10.12952/journal.elementa.000076.

Azevedo-Ramos, C., Moutinho, P., 2018. No man's land in the Brazilian Amazon: could undesignated public forests slow Amazon deforestation? Land Use Policy 73, 125–127. https://doi.org/10.1016/j.landusepol.2018.01.005.

Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U.M., Wunder, S., 2017. The effectiveness of payments for environmental services. World Dev. 96, 359–374. https://doi.org/10.1016/j.worlddev.2017.03.020.

Boucher, D., Roquemore, S., Fitzhugh, E., 2013. Brazil's success in reducing deforestation. Trop. Conserv. Sci. 6, 426–445. https://doi.org/10.1177/194008291300600308.

Brasil, 2017a. Decreto 9.073, de 05 de junho de 2017 (Promulga o Acordo de Paris sob a Convenção-Quadro das Nações Unidas sobre Mudança do Clima, celebrado em Paris, em 12 de dezembro de 2015, e firmado em Nova Iorque, em 22 de abril de 2016.).

Brasil, 2017b. Lei nº 13.465, de 11 de Julho de 2017. Dispõe sobre a regularização fundiária rural e urbana, sobre a liquidação de créditos concedidos aos assentados da reforma agrária e sobre a regularização fundiária no âmbito da Amazônia Legal; institui mecanismos para aprimorar a eficiência dos procedimentos de alienação de imóveis da União.

Brasil, 2012. Lei nº 12.651, de 25 de maio de 2012 (Dispõe sobre a proteção da vegetação nativa; altera as Leis nos 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nos 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória no 2.166-67, de 24 de agosto de 2001; e dá outras providências).

Brasil, 2009. Lei nº 11.952, de 25 de Junho de 2009: Dispõe sobre a regularização fundiária das ocupações incidentes em terras situadas em áreas da União, no âmbito da Amazônia Legal; altera as Leis nos 8.666, de 21 de junho de 1993, e 6.015, de 31 de dezembro de 1973; e dá outras providências.

Brasil, Secretaria de Política Agrícola, 2017. Projeções do Agronegócio. Brasil 2016/17 a 2026/27. Projeções de Longo Prazo. MAPA, Brasilia, DF, Brasil.

Brown, D.S., Brown, J.C., Brown, C., 2016. Land occupations and deforestation in the Brazilian Amazon. Land Use Policy 54, 331–338. https://doi.org/10.1016/j.landusepol.2016.02.003.

Butt, N., de Oliveira, P.A., Costa, M.H., 2011. Evidence that deforestation affects the onset of the rainy season in Rondonia. Brazil. J. Geophys. Res. 116, D11120. https://doi.org/10.1029/2010JD015174.

Caldart, R.S., Pereira, I.B., Alentejano, P., Frigotto, G. (Eds.), 2012. Dicionário da educação do campo. Escola Politécnica de Saúde Joaquim Venâncio/Fiocruz ; Expressão Popular, Rio de Janeiro : São Paulo.

CGF, 2019. Consumer Goods Forum: Towards zero net deforestation.

Chaddad, F., 2015. The Economics and Organization of Brazilian Agriculture: Recent Evolution and Productivity Gains. Elsevier Science.

Chambers, J.Q., Artaxo, P., 2017. Deforestation size influences rainfall. Nat. Clim. Change 7, 175–176. https://doi.org/10.1038/nclimate3238.

Cohn, A.S., Mosnier, A., Havlík, P., Valin, H., Herrero, M., Schmid, E., O'Hare, M., Obersteiner, M., 2014. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. Proc. Natl. Acad. Sci. https://doi.org/10.1073/pnas.1307163111.

Dantas, A.T., Kozioł, W., Siuda-Ambroziak, R. (Eds.), 2017. Brazil - Poland Focus on Environment. University of Warsaw : Rio de Janerio State University, Warsaw; Rio de Janeiro.

de Castro, C.N., Pereira, C.N., 2017. Agricultura familiar, assistência técnica e extensão rural e a política nacional de ATER (Texto para discussão No. 2343). IPEA, Rio de Janeiro, RJ, Brasil.

dos Santos, C.C., Souza de Lima Ferraz Junior, A., Oliveira Sá, S., Andrés Muñoz Gutiérrez, J., Braun, H., Sarrazin, M., Brossard, M., Desjardins, T., 2018. Soil carbon stock and Plinthosol fertility in smallholder land-use systems in the eastern Amazon. Brazil. Carbon Manag. 9, 655–664. https://doi.org/10.1080/17583004.2018.1530026.

EMBRAPA, 2017. ICLF in Numb3R5. EMBRAPA.

FAO, 2018. FAOSTAT. FAO, Rome, Italy.

Garcia, E., Ramos Filho, F., Mallmann, G., Fonseca, F., 2017. Costs, benefits and challenges of sustainable livestock intensification in a major deforestation frontier in the brazilian amazon. Sustainability 9, 158. https://doi.org/10.3390/su9010158.

Geluda, L., Serrão, M., Muanis, M.M., Oliveira, J., Oliveira, D., Catapan, M., Tararan, S., 2012. Quanto custa o Programa Áreas Protegidas da Amazônia?: Uma modelagem financeira para as Unidades de Conservação do Arpa. Fundo Brasileiro para a Biodiversidade - FUNBIO, Rio de Janeiro, RJ, Brasil.

Gibbs, H.K., Rausch, L., Munger, J., Schelly, I., Morton, D.C., Noojipady, P., Soares-Filho, B., Barreto, P., Micol, L., Walker, N.F., 2015. Brazil's soy moratorium. Science 347, 377–378. https://doi.org/10.1126/science.aaa0181.

Golden Kroner, R.E., Qin, S., Cook, C.N., Krithivasan, R., Pack, S.M., Bonilla, O.D., Cort-Kansinally, K.A., Coutinho, B., Feng, M., Martínez Garcia, M.I., He, Y., Kennedy, C.J., Lebreton, C., Ledezma, J.C., Lovejoy, T.E., Luther, D.A., Parmanand, Y., Ruíz-Agudelo, C.A., Yerena, E., Morón Zambrano, V., Mascia, M.B., 2019. The uncertain future of protected lands and waters. Science 364, 881–886. https://doi.org/10.1126/science.aau5525.

IBGE, 2019. Pesquisa Trimestral do Abate de Animais - Tabela 1086 - Número de informantes e Quantidade de leite cru, resfriado ou não, adquirido e industrializado, no mês e no trimestre, por tipo de inspeção (No. Tabela 1086). IBGE.

IBGE, 2018a. Produção Agrícola Municipal - Tabela 1612 - Área plantada, área colhida, quantidade produzida e valor da produção da lavoura temporária (No. Tabela 1612). IBGE.

IBGE, 2018b. Pesquisa Pecuária Municipal - Tabela 73 - Efetivo dos rebanhos por tipo de rebanho (No. Tabela 73). IBGE.

INCRA, 2017. Incra nos Estados - Informações gerais sobre os assentamentos da Reforma Agrária. Brasil, Brasilia, DF, Brasil.

INPE, 2018a. Projeto PRODES [WWW Document]. Proj. PRODES Monit. Floresta Amaz. Bras. Por Satél. URL. http://www.obt.inpe.br/prodes/.

INPE, 2018b. PRODES Cerrado [WWW Document]. PRODES - Incremento Anu. Área Desmatada No Cerrado Bras. URL. http://www.obt.inpe.br/cerrado.

IPAM, 2017. InfoPAS 10: O desafio da produção familiar de baixo carbono (No. InfoPAS 10), Informativo do Projeto Assentamentos Sutentáveis na Amazônia. IPAM, Brasilia, DF, Brasil.

IPAM, 2014. Stimulating the Demand for REDD+ Emission Reductions in Brazil: the Need for a Strategic Intervention Pre 2020: a Case Study for the Interim Forest Finance Project. Global canopy Programme, Oxford, UK.

IPCC, 2019. Climat Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems (approved Draft), IPCC Special Reports. IPCC, Geneva, Switzerland.

Kastens, J.H., Brown, J.C., Coutinho, A.C., Bishop, C.R., Esquerdo, J.C.D.M., 2017. Soy moratorium impacts on soybean and deforestation dynamics in Mato Grosso, Brazil. PLOS ONE 12, e0176168. https://doi.org/10.1371/journal.pone.0176168.

Koch, N., zu Ermgassen, E.K.H.J., Wehkamp, J., Oliveira Filho, F.J.B., Schwerhoff, G., 2019. Agricultural productivity and forest conservation: evidence from the brazilian amazon. Am. J. Agric. Econ. 101, 919–940. https://doi.org/10.1093/ajae/aay110.

Lambin, E.F., Gibbs, H.K., Heilmayr, R., Carlson, K.M., Fleck, L.C., Garrett, R.D., le Polain de Waroux, Y., McDermott, C.L., McLaughlin, D., Newton, P., Nolte, C., Pacheco, P., Rausch, L.L., Streck, C., Thorlakson, T., Walker, N.F., 2018. The role of supply-chain initiatives in reducing deforestation. Nat. Clim. Change 8, 109–116. https://doi.org/10.1038/s41558-017-0061-1.

Leite-Filho, A.T., Sousa Pontes, V.Y., Costa, M.H., 2019. Effects of deforestation on the onset of the rainy season and the duration of dry spells in Southern Amazonia. J. Geophys. Res. Atmos. 124, 5268–5281. https://doi.org/10.1029/2018JD029537.

Macedo, M.N., DeFries, R.S., Morton, D.C., Stickler, C.M., Galford, G.L., Shimabukuro, Y.E., 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proc. Natl. Acad. Sci. 109, 1341–1346. https://doi.org/10.1073/pnas.1111374109.

Mahmood, R., Pielke, R.A., Hubbard, K.G., Niyogi, D., Dirmeyer, P.A., McAlpine, C., Carleton, A.M., Hale, R., Gameda, S., Beltrán-Przekurat, A., Baker, B., McNider, R., Legates, D.R., Shepherd, M., Du, J., Blanken, P.D., Frauenfeld, O.W., Nair, U.S., Fall, S., 2014. Land cover changes and their biogeophysical effects on climate: land cover changes and their biogeophysical effects on climate. Int. J. Climatol. 34, 929–953. https://doi.org/10.1002/joc.3736.

MapBiomas, 2019. Collection 4 of Brazilian Land Cover & Use Map Series. SEEG, Brazil.

Martha, G.B., Alves, E., Contini, E., 2012. Land-saving approaches and beef production growth in Brazil. Agric. Syst. 110, 173–177. https://doi.org/10.1016/j.agsy.2012.03.001.

Mato Grosso, 2016. Decreto 468, de 31 de março de 2016 (Dispõe sobre a instituição do Comitê Estadual da Estratégia: Produzir, Conservar e Incluir - PCI, apresentada pelo

Estado de Mato Grosso na COP 21, e dá outras providências.).
MDIC, Brasil, 2018. Statistics of International Trade in the Last 200 Years. pp. 1971–1980.
Medeiros, R., Young, C.E.F., 2011. Contribuição das unidades de conservação brasileiras para a economia nacional: Relatório Final. UNEP-WCMC, Brasilia.
Moutinho, P., Guerra, R., Azevedo-Ramos, C., 2016. Achieving zero deforestation in the Brazilian Amazon: what is missing? Elem. Sci. Anthr. 4, 000125. https://doi.org/10.12952/journal.elementa.000125.
Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Seroa da Motta, R., Armijo, E., Castello, L., Brando, P., Hansen, M., McGrath-Horn, M., Carvalho, O., Hess, L., 2014. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science 344, 1118–1123. https://doi.org/10.1126/science.1248525.
Nepstad, D.C., Verssimo, A., Alencar, A., Nobre, C., Lima, E., Lefebvre, P., Schlesinger, P., Potter, C., Moutinho, P., Mendoza, E., Cochrane, M., Brooks, V., 1999. Large-scale impoverishment of Amazonian forests by logging and fire. Nature 398, 505–508. https://doi.org/10.1038/19066.
NYDF, 2019. New Yorl Declaration on Forests. Pledge: the New York Declaration on Forests Is a Partnership of Governments, Multinational Companies, Civil Society and Indigenous Peoples Who Strive to Halve Deforestation by 2020 and to End It by 2030.
Pinto, L.F., Sparovek, G., Bento, J., Faria, V., 2017. Qual o impacto do desmatamento zero no Brasil? Instituto Escolhas, São Paulo, Brasil. https://doi.org/10.13140/RG.2.2.15934.79684.
Richards, P., Pellegrina, H., VanWey, L., Spera, S., 2015. Soybean development: the impact of a decade of agricultural change on urban and economic growth in Mato Grosso, Brazil. PloS One 10, e0122510. https://doi.org/10.1371/journal.pone.0122510.
Sant'anna, A.A., 2017. Land inequality and deforestation in the Brazilian Amazon. Environ. Dev. Econ. 22, 1–25. https://doi.org/10.1017/S1355770X1600022X.
da Silva, J.M.C., da Castro Dias, T.C.A., da Cunha, A.C., Cunha, H.F.A., 2019. Public spending in federal protected areas in Brazil. Land Use Policy 86, 158–164. https://doi.org/10.1016/j.landusepol.2019.04.035.
Silva, D.S., Barreto, P., 2014. O Aumento da Produtividade e Lucratividade da Pecuária Bovina na Amazônia: O Caso do Projeto Pecuária Verde em Paragominas. IMAZON, Belém, PA, Brasil.
Silvério, D.V., Brando, P.M., Macedo, M.N., Beck, P.S.A., Bustamante, M., Coe, M.T., 2015. Agricultural expansion dominates climate changes in southeastern Amazonia: the overlooked non-GHG forcing. Environ. Res. Lett. 10, 104015. https://doi.org/10.1088/1748-9326/10/10/104015.
Snyder, P.K., 2010. The influence of tropical deforestation on the Northern Hemisphere Climate by atmospheric teleconnections. Earth Interact. 14, 1–34. https://doi.org/10.1175/2010EI280.1.
Soares-Filho, B., Rajão, R., Merry, F., Rodrigues, H., Davis, J., Lima, L., Macedo, M., Coe, M., Carneiro, A., Santiago, L., 2016. Brazil's market for trading forest certificates. PLoS One 11, e0152311. https://doi.org/10.1371/journal.pone.0152311.
Sparovek, G., Reydon, B.P., Guedes Pinto, L.F., Faria, V., de Freitas, F.L.M., Azevedo-Ramos, C., Gardner, T., Hamamura, C., Rajão, R., Cerignoni, F., Siqueira, G.P., Carvalho, T., Alencar, A., Ribeiro, V., 2019. Who owns Brazilian lands? Land Use Policy 87, 104062. https://doi.org/10.1016/j.landusepol.2019.104062.
Spracklen, D.V., Baker, J.C.A., Garcia-Carreras, L., Marsham, J.H., 2018. The effects of tropical vegetation on rainfall. Annu. Rev. Environ. Resour. 43, 193–218. https://doi.org/10.1146/annurev-environ-102017-030136.
Stabile, M.C.C., 2018. CONSERV: an innovative mechanism to protect forests through payment for performance.
Stabile, M.C.C., Woldmar, R., Azevedo, A.A., Silva, D.S., 2017. Financiando Paisagens Sustentaveis: Mato Grosso, Brasil. Relatorio Final. IPAM, Brasilia, DF, Brasil.
Strassburg, B.B.N., Latawiec, A.E., Barioni, L.G., Nobre, C.A., da Silva, V.P., Valentim, J.F., Vianna, M., Assad, E.D., 2014. When enough should be enough: improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Glob. Environ. Change 28, 84–97. https://doi.org/10.1016/j.gloenvcha.2014.06.001.
TFA, 2020. 2019. Tropical Forest Alliance 2020: Reduce Tropical Deforestation.
Tollefson, J., 2018. Brazil's lawmakers renew push to weaken environmental rules. Nature 557https://doi.org/10.1038/d41586-018-05022-2. 17–17.
Venâncio, M.D., Pope, K., Sieber, S., 2018. Brazil's new government threatens food security and biodiversity. Nature 564https://doi.org/10.1038/d41586-018-07611-7. 39–39.