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A Comparison of Supply Chain Tracking Tools for Tropical Forest Commodities in Brazil

Author
Breanna Lujan, Policy Analyst, Climate, Environmental Defense Fund

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KEY TERMS

ABIOVE—Brazilian Association of Vegetable Oil Industries	NDC—Nationally Determined Contribution
ANEC—National Association of Cereal Exporters	NDFI—Normalized Difference Fraction Index
APP—Areas of Permanent Preservation	Pecsa— Amazon Sustainable Cattle Ranching
CAR—Rural Environmental Registry	PPCerrado—Cerrado Deforestation and Burning Prevention and Control Action Plan
CBERS—China-Brazil Earth Resources Satellite Program	PRA—Environmental Regulation Program
Cerflor—Brazilian Program for the Certification of Forests	PRODES— Program to Calculate Deforestation in the Amazon

CTF/APP—Federal Technical Registry of Potentially Polluting Activities and/or Users of Environmental Resources	RFID—Radio-frequency Identification tags
DEGRAD—System for Monitoring Forest Degradation in the Brazilian Amazon	SAD—Deforestation Alert System
DETER—Real Time System for Detection of Deforestation	SEEG—Climate and Greenhouse Gas Emission Estimating Observatory
DMC—Disaster Monitoring Constellation	SEMA—State Environmental Secretariat
DOF—Forest Origin Documents	Serpro—Federal Service for Processing Data
Embrapa—Brazilian Agricultural Research Corporation	SICAR—National Rural Environmental Registry System
ERAS—Approved Rural Establishment in Sisbov	Simex—System for Monitoring Timber Harvesting
FORMA—FORest Monitoring for Action	Sinaflor—National System for the Control of the Origin of Forest Products
FSC—Forest Stewardship Council	SISBOV—Brazilian System of Identification and Certification of Cattle Origin
GFW—Global Forest Watch	SISNAMA—National Environmental System
GTA—Animal Transport Guide	SoyM—Soy Moratorium
IBAMA—Brazilian Institute of Environment and Renewable Natural Resources	SWG—Soya Working Group
Imazon—Institute for People and Environment of Amazonia	TAC—Terms of Adjustment of Conduct
INPE—National Institute for Space Research	TEA—Timber Extraction Authorizations
Lapig—Laboratory of Image Processing and Geoprocessing	Terras—Terras App Solutions
LR—Legal Reserve	TSC—The Sustainability Consortium

MAPA—Ministry of Agriculture, Livestock, and Supply	TTA—Timber Transport Authorizations
MPF- Pará—Federal Public Prosecutor's Office in the state of Pará	

ABSTRACT

Monitoring and traceability are essential to ensuring that companies meet their commitments to reduce or eliminate deforestation from tropical forest commodity supply chains. Understanding how available supply chain tracking tools function will help companies ascertain how to most effectively and efficiently tackle the risk of deforestation in cattle, soy and timber supply chains. Gaining insight into supply chain monitoring technology will also help consumers understand what companies say about their progress toward meeting zero-deforestation supply chain goals.

EXECUTIVE SUMMARY

Robust, functional, affordable and scalable commodity supply chain tracking systems are essential to reducing deforestation resulting from the production of tropical forest commodities. In Brazil, monitoring tools are becoming increasingly important to private sector efforts aiming to reduce and eliminate the risk of deforestation from tropical forest commodity supply chains. This report provides a comprehensive comparison of supply chain tracking tools for tropical forest commodities, specifically cattle, soy and timber, currently being used in Brazil. In addition to detailing the objectives, methodologies, scope and cost[1] of each tool, the report also describes the advantages and challenges of each system, and concludes with a comprehensive comparison. This report will inform private sector entities, other supply chain actors and consumers about the various supply chain monitoring tools available to help reduce and eliminate deforestation from tropical forest commodity production, and serve as a guide to help companies identify the most suitable tools to increase supply chain transparency and traceability.

1. INTRODUCTION

Between 2004 and 2014, Brazil emerged as a world leader of deforestation reduction. Due to a combination of government policies, supply chain interventions and changes in market conditions, deforestation rates in the Amazon dropped by more than 80 percent during that period [1]. Between August 2015 and July 2016, however, deforestation rose to nearly 7,989

[1] Cost can refer to cost of access or cost of use, depending on the design of the tool.

km²—an increase of about 29 percent relative to 2015, when deforestation totaled 6,027 km² [2]. Deforestation has continued to increase. In July of 2018, the Institute for People and the Environment of Amazonia's (Imazon) Deforestation Alert System (SAD) detected 778 km² of deforestation in the Legal Amazon[2]; this represents an increase of 27 percent compared to July 2017 [3].

1.1. The link between commodity supply chains and deforestation

Tropical forest commodity supply chains are a major source of deforestation in Brazil. Between 2000 and 2012, Brazil and Indonesia together accounted for 75 percent of the global area of tropical forest estimated to have been illegally converted for commercial agriculture [4]. In Brazil, where cattle raising and soy production are the primary drivers of deforestation, at least 90 percent of deforestation is due to commercial agriculture, of which 68 to 90 percent is illegal, often in violation of the Legal Reserve (LR) forest conservation quotas established by Brazil's Forest Code[3] [4]. The impacts of the cattle and agriculture industries on deforestation in Brazil were evident in September 2017 when the number and extent of forest fires, almost exclusively due to human activity related to the expansion of cattle raising and other agricultural purposes, reached an all-time high for any single month [5]. Cattle ranching, soy production and timber harvesting all have different deforestation profiles.

Cattle: The expansion of cattle pastures continues to be the leading cause of deforestation. Between 1993 and 2013, the herd expanded 200 percent reaching nearly 60 million animals [6]. Of the deforestation caused by cattle in 2012, 73 to 90 percent was estimated to be illegal (i.e. ranchers had cleared more forest cover than legally permissible under the Forest Code) [4]. In 2014, pasturelands occupied at least 60 percent of land cleared in the Brazilian Amazon [7]. In 2016, the cattle herd in the Amazon alone totaled 85 million heads, or close to 40 percent of the national total [8].

Soy: Soy production is another major driver of deforestation. Between 2001 and 2006, soybean fields expanded by 100,000 ha in the Amazon biome [9]. In the Cerrado, the annual rate of soy expansion into native vegetation ranged from 11 to 23 percent between 2007 and 2013 [9]. In total, in 2012 about 59 to 61 percent of soy areas displaced forest, 49 to 90 percent of which was illegal; similar to previous explanations, illegality here refers to the expansion of soy crops past the LR limit [4].

Timber: Although timber harvest has played a less direct role in deforestation, it remains a principal cause of forest degradation. International rankings place Brazil as one of the highest risk countries for illegality in the timber sector [10]. Estimates suggest that between 2008 and 2012 about 68 to 90 percent of forest clearance for commercial agriculture was illegal, and that

[2] Legal Amazon is an official designation that encompasses all nine states in the Amazon basin
[3] Brazil's Forest Code mandates that landowners maintain a Legal Reserve (LR) of 80% forest cover in the Amazon biome, 35% in the Cerrado, and 20% in other areas. In the Amazon, therefore, farmers are only allowed to farm 20% of their properties.

nearly 20 percent of tropical timber exports over this period came from that source; 90 percent of those exports were illegal [11].

1.2. The role of the private sector in combatting deforestation

In light of increasing deforestation and renewed resolve to combat this trend, many companies operating in Brazil have committed to reduce or eliminate deforestation from their supply chains. Some of these supply chain interventions complement national laws and policies (e.g. Brazil's Nationally Determined Contribution (NDC) and Forest Code), multistakeholder initiatives (e.g. Novo Campo and São Felix do Xingu), and sector-wide agreements (e.g. the Soy Moratorium and Cattle Agreements). These commitments, combined with government policies and changes in market conditions, helped contribute to the significant drop in Amazon deforestation rates between 2004 and 2014 [1].

Commitments in the cattle industry

Two notable examples of supply chain interventions in the cattle industry that have helped curb deforestation are the Terms of Adjustment of Conduct (TAC) agreements and the G4 Zero-deforestation agreement, collectively known as the Cattle Agreements.

Terms of Adjustment of Conduct agreements: In 2009, the Federal Public Prosecutor's Office in the state of Pará (MPF-Pará) and NGOs pressured beef retailers, leather retailers, and meatpacking companies to reduce deforestation associated with cattle production [1]. MPF-Pará issued regulations stipulating that companies buying commodities from illegally deforested land could be held liable and sued, which prompted them to boycott slaughterhouses connected to illegal deforestation [1]. In response, individual meatpacking companies in Pará began signing legally binding TAC agreements, committing to stop purchasing from properties with illegal deforestation [1]. Companies operating in the other Amazonian states have since replicated these agreements, which now encompass two-thirds of federally inspected slaughterhouses in the Legal Amazon [1].

G4 Zero Deforestation Cattle Agreement: In October of 2009, JBS, Marfrig, Minerva and Bertin (the latter was purchased by JBS) signed the voluntary G4 Zero Deforestation Cattle Agreement with Greenpeace [1]. These meatpackers agreed to stop purchasing cattle from ranches in the Amazon where deforestation had occurred prior to and after the date of the agreement (unless the companies could prove compliance with land tenure and environmental legislation) [4]. Companies agreed to establish supply chain tracking systems to ensure suppliers had the necessary environmental permits within two years and could prove legal land titling in five years [4].

Both agreements have contributed to ensuring the legality of the cattle supply in the Legal Amazon. For example, in Pará, the state with the largest cattle herd in the Amazon biome, these agreements helped:

- Increase registration with the Rural Environmental Registry (CAR) [1]. Ranchers supplying to G4 agreement and TAC companies registered their properties with the CAR nearly two years before ranchers on surrounding non-participatory properties. By early 2010, nearly 60 percent of the slaughterhouses' monthly transactions were with registered suppliers under both agreements; by the end of 2013 that increased to 96 percent.

- Reduce deforestation rates on direct supplier properties [1]. By 2013, deforestation on direct supplier properties fell from 36 to four percent. Additionally, post-agreement suppliers had more dramatic rate reductions than pre-agreement suppliers.

- Reduce purchases from recently deforested properties [1]. Before the agreements, the probability that JBS slaughterhouses would purchase from a property was not influenced by recent deforestation, whereas after the agreements slaughterhouses actively avoided properties with deforestation. By 2013, the probability that a slaughterhouse would purchase from properties with recent deforestation was reduced by half.

Findings indicate, however, that very little forest is protected by these agreements [12]. While the agreements have led to some avoided deforestation on registered properties with transparent and publicly accessible boundaries, implementation is too narrow. More action—such as expanding monitoring to all properties in the supply chain (including to indirect suppliers)—is needed to further reduce deforestation [12].

Commitments in the soy industry

In 2006, companies linked to the soybean industry committed to reducing deforestation caused by soybean expansion in what is known as the Soy Moratorium (SoyM). Prompted by a Greenpeace campaign, the landmark voluntary zero-deforestation agreement stipulates that the Brazilian Association of the Vegetable Oil Industries (ABIOVE) and the National Association of Cereal Exporters (ANEC)—both of which include companies such as Amaggi and Cargill—will not purchase soybeans produced in areas in the Amazon biome deforested after July 2006 [13]. On account of the SoyM, deforestation resulting from soy expansion and production in the Amazon biome significantly decreased. Before the moratorium, an estimated 30 percent of soy expansion occurred through deforestation rather than on already cleared lands, whereas after the implementation of the moratorium, only about one percent of new soy expansion resulted in deforestation [14]. During this period, soy production increased by 1.3 million ha in the Amazon [9]. The successes of the SoyM are attributable in part to the participation of key corporate actors, simple compliance requirements, streamlined and transparent monitoring and enforcement systems, and the efforts of the government and civil society [9].

Commitments in the timber industry

Forest certification schemes are one approach the private sector is taking to regulate deforestation in the timber industry. Larger companies and corporations, such as Natura and Souza Cruz, are becoming interested in Forest Stewardship Council (FSC) certification [15]. A

significant proportion of Brazil's plantations is now certified by the FSC or under the Brazilian Program for the Certification of Forests (CERFLOR) [16]. At the end of 2012, about 3.5 million ha of eucalyptus plantation and 1.8 million ha of pine plantation were certified under either the FSC or CERFLOR or both [16]. Currently, 7.08 million ha of forest are certified under the FSC's forestry management scheme and 1,024 chain of custody certificates[4] have been issued, ranking Brazil seventh in the FSC's ranking system; native forest management certifications represent only a tiny fraction of trade, however [17]. Other companies have demonstrated corporate responsibility by forming the Brazilian Certified Wood Buyers' Group and committing to increasing their purchases of timber and timber products from certified sources to 50 percent of their total requirements over a five-year period [18]. Members are permitted to display the Buyers' Group logo on their products and promotions, and also encouraged to press their suppliers to purchase wood from certified sources [18]. The formation of this group has signaled greater private sector demand for certified timber and timber products.

1.3. The need to track supply chains

Despite these corporate commitments to reduce deforestation from supply chain operations, many challenges remain. Supply chain tracking tools can help address these issues and enable companies to achieve their goals of reducing and eliminating deforestation risk from their supply chains. This report provides an overview of existing tracking tools that companies are using and can use to monitor cattle, soy, and timber supply chains in Brazil. First, the report details the primary monitoring challenges particular to each commodity. The section after that delves into an analysis of national deforestation monitoring systems currently in operation. The next section compares the different commodity-specific tools in Brazil, highlighting the advantages and challenges of each. The section after that discusses global monitoring platforms that can be used to complement efforts in Brazil. Lastly, the report highlights salient considerations that supply chain actors should take into account when determining how to reduce and eliminate deforestation from their operations.

2. TRACKING COMMODITY SUPPLY CHAINS

Tools to effectively and efficiently monitor cattle, soy, and timber supply chains are essential for enabling private sector actors to uphold their commitments to reduce deforestation. By ensuring that the production of these tropical forest commodities is legal (i.e. does not result in illegal deforestation), supply chain tracking tools will help contribute to the objectives of the Forest Code and Brazil's NDC under the Paris Agreement, which explicitly aims to "enhance sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management with a view of curbing illegal and unsustainable practices" [10]. Effective and efficient monitoring systems will also ensure the environmental

[4] FSC chain of custody certification verifies that FSC-certified material has been identified and separated from non-certified, non-controlled material along the supply chain. Companies must meet Chain of Custody Certification standards to achieve chain of custody certification.

integrity of these tropical forest commodities by assuring companies and other supply chain actors that commodities are legally and responsibly produced. Lastly, powerful tracking systems will help reduce reputational risks associated with deforestation and illegal activity, bolstering the image of private sector actors in the eyes of the government and consumers [19].

2.1. The challenges of tracking supply chains

Although there are many tools available to track tropical forest commodity supply chains, the effectiveness of these systems is hindered by various factors.

Challenges in the cattle industry

In the cattle industry, the issue of leakage—or shifting deforestation from one place to another—complicates supply chain monitoring. Most systems only track transactions between direct suppliers and slaughterhouses, failing to capture sales from noncompliant, indirect suppliers that have illegally deforested. This arises from the fact that most cattle rearing ranches are not full-cycle and do not cover all production phases, meaning that a number of cattle that arrive at meatpacking plants have spent part of their lives on at least one other ranch before arriving at the fattening property [19,20]. As a result, meatpackers often acquire cattle from direct suppliers who purchased cattle from indirect suppliers that raise cattle on land where deforestation has occurred. One meatpacking company reported that about half of the direct supply ranches purchase cattle from other ranches before fattening and selling them to meatpacking plants [20]. The inability of the Cattle Agreements to impact forest cover in the regions surrounding signatory slaughterhouses in Mato Grosso and Pará in 2014, and the Brazilian meatpacker industry scandal of 2017[5]—during which employees at JBS and BRF paid federal inspectors to ignore the adulteration or expiration of processed foods, resulting in the falsification of sanitary permits and the channeling of bribes to the Brazilian Democratic Movement Party of former president Michel Temerrevealed the limitations of current supply chain tracking methodologies [21].

Challenges in the soy industry

Leakage is also an issue in the soy industry. For example, although the SoyM was effective in reducing deforestation for soy in the Amazon biome, the annual rate of soy expansion in the Cerrado biome, where the moratorium does not apply, remained sizeable [9]. This indicates that leakage may be occurring and that soy expansion continues to occur at the expense of native vegetation [9]. Additionally, systems used to monitor soy production, and other commodities, are only equipped to track forest clearing or degradation above a given threshold. Given that forest clearings of 25 ha or smaller and forest degradation are becoming more common, some deforestation may be missed [22].

[5] https://www.nytimes.com/2017/03/17/world/americas/brazil-food-companies-bribe-scandal-salmonella.html

Challenges in the timber industry

Monitoring illegality in the timber industry is impeded by a lack of transparency, poor access to information in official databases, and poorly implemented and decentralized processes between central and regional governments [11]. All of these factors have facilitated the rampant timber fraud affecting the industry.

3. ANALYSIS OF TRACKING TOOLS

By increasing transparency and promoting sustainable practices, supply chain tracking tools can help supply chain actors determine the extent to which their operations are causing deforestation, as well as the extent of deforestation risk of their operations. The first part of this section provides an overview of platforms used to assess deforestation in Brazil. The following sub-section provide a comprehensive overview of supply chain tracking tools currently available and being used in Brazil, including a description of each system's objectives, methodology, scale, cost, advantages and challenges. The last part of this section describes global platforms that can complement the systems in place in Brazil.

3.1. General deforestation monitoring tools

While the focus of this paper is supply chain tracking tools for tropical forest commodities produced in Brazil, namely cattle, soy and timber, many of these tools rely on data provided by systems used to monitor general deforestation in Brazil. It is therefore helpful to provide an overview of these systems as they are the building blocks for many supply chain tracking tools.

Program to Calculate Deforestation in the Amazon

Objective: Developed by Brazil's National Institute for Space Research (INPE), the Program to Calculate Deforestation in the Amazon (PRODES) is regarded as one of the most established forest monitoring systems in the world. The system identifies newly cleared land in the Amazon on an annual basis and provides an Amazon-wide annual deforestation rate.

Methodology: This system utilizes high-resolution data from Landsat (NASA's satellite imagery acquisition program), the China-Brazil Earth Resources Satellite program (CBERS), and the Disaster Monitoring Constellation (DMC) [23,24]. Using Landsat imagery with a spatial resolution of 30 m, PRODES detects forest clearing of areas larger than 6.25 ha, and identifies areas that have been cleared between September of the previous year and August of the current year [24,23].

Scale: Brazilian Amazon

Cost of access: Free

Advantages: PRODES sets the "gold standard" for annual deforestation estimates in the Brazilian Amazon because the system uses higher-resolution imagery and requires intensive data interpretation by experts [23]. The data gathered by PRODES has been fundamental to the success of the Cattle Agreements, as companies like JBS and Marfrig crosscheck the georeferenced information analysis their geospatial monitoring teams gather with data from PRODES to verify deforestation risk in their supply chains [25,26].

Challenges: Designed to determine where forest clearing occurs in a given year in the Amazon and how much clearing there is, PRODES measures only annual change from forest to non-forest. It cannot provide immediate results, detect forest degradation or selective logging, report on areas covered by clouds, or detect forest clearing outside of the Amazon biome [23, 24, 27].

PRODES Cerrado

Objective: To reduce deforestation and degradation of native vegetation, while maintaining ecosystem services in the Cerrado, INPE developed PRODES Cerrado [28].

Methodology: Using the same technology and approach as the original PRODES tool, PRODES Cerrado provides deforestation data in the Cerrado between 2016 and 2017. The data also helped refine the map of deforested areas between 2010 and 2015, which resulted in an update of the historical data series for 2002 to 2012, the biennial data for 2002 to 2012, and annual data for the period 2013 to 2017. The analysis encompassed all deforested polygons larger than one ha [28].

Scale: Cerrado biome

Cost of access: Free

Advantages: By generating data on the state of deforestation and vegetation degradation in the Cerrado, this mapping tool provides insight into whether efforts to reduce illegal deforestation, limit degradation, and promote sustainable development throughout the Cerrado are effective. PRODES Cerrado also integrates the Cerrado Deforestation and Burning Prevention and Control Action Plan (PPCerrado).

Challenges: Although PRODES Cerrado provides deforestation and degradation data for the Cerrado biome, the tool does not provide real-time or area specific data. The data could be made more effective when combined with the SAD and Deter systems.

Real Time System for Detection of Deforestation

Objective: The Real Time System for Detection of Deforestation (DETER), also developed by INPE, is a satellite-based system for mapping land cover in the Amazon that determines the location of recent forest clearings [24].

Methodology: Using imagery from NASA's MODIS satellite at a spatial resolution of 250 m, DETER produces real-time deforestation alerts bimonthly in three steps: 1. Generation of

algorithm-based land cover maps using data from MODIS and AWIFS-ResourceSat, 2. Inspection and adjustment of results by interpreters, 3. Visual interpretation of validated maps to identify and confirm forest clearing [23].

Scale: Brazilian Amazon

Cost of access: Free

Advantages: By providing near real-time identification of deforestation hot spots, DETER enables law enforcement officials to quickly identify and inspect new forest clearings in the Amazon and target enforcement efforts [23-24, 29]. DETER also serves as a cornerstone for assessing compliance with the Cattle Agreements. Companies crosscheck their georeferenced maps of suppliers against INPE deforestation maps from PRODES and DETER to determine whether their operations are meeting sustainability criteria [23].

Challenges: Similar to PRODES, DETER's ability to detect forest clearings is hindered by clouds [24]. Additionally, DETER is confined solely to the Brazilian Amazon [24]. DETER is also only able to detect forest clearing that occurs on a scale greater than 25 ha [30].

System for Monitoring Forest Degradation in the Brazilian Amazon

Objective: In response to indications of increased forest degradation in the Amazon reflected in the data gathered by DETER, INPE developed the System for Monitoring Forest Degradation in the Brazilian Amazon (DEGRAD) [31]. This system maps areas in the process of deforestation, or areas that are degraded and have not yet been completely deforested.

Methodology: DEGRAD uses LANDSAT and CBERS satellite images to annually map areas where forest degradation is occurring and that have a tendency to be converted into clear cut areas [31]. Like PRODES, the minimum area mapped by DEGRAD is 6.25 ha. Once the satellite images are obtained, contrasting enhancements are applied to the images in order to highlight areas of degradation. To better understand the different types of degradation, INPE developed specific techniques to process and classify the images. Forest degradation can be classified as light, moderate and high intensity.

Scale: Brazilian Amazon

Cost of access: Free

Advantages: DEGRAD is able to map areas of degradation individually and independently—regardless of data from previous years—and provide more specific insight into areas that are in the process of regeneration after having been degraded, and into areas that are experiencing recurring degradation [32]. DEGRAD is an important tool for preventing and combatting deforestation because the system detects forest that has not yet been completely cleared, permitting interventions.

Challenges: DEGRAD only detects degradation in the Amazon biome. Furthermore, DETER data on the INPE website appears to be lagging; the most recent data is for 2013 [30].

Deforestation Alert System

Objective: To monitor the impact of government policies aimed at developing and protecting the Brazilian Amazon, and to detect deforestation in the Amazon, Imazon developed the first non-governmental Deforestation Alert System (SAD) [33].

Methodology: Using MODIS imagery with a spatial resolution of 250 m, forest cover change is detected using the Normalized Difference Fraction Index (NDFI), whereby pixels that show NDFI less than 125 are classified as deforestation and those with NDFI values between 125 and 165 are categorized as forest degradation [33].

Scale: Brazilian Amazon

Cost of access: Free

Advantages: SAD has been very useful for monitoring the legality of private lands when combined with spatial analyses that incorporate property boundaries, maps of protected areas, and maps of private properties, especially in Mato Grosso [33]. This holds true for all other deforestation data collection systems previously mentioned as well.

Challenges: Like the aforementioned deforestation monitoring tools, SAD is also limited to the Brazilian Amazon, excluding other areas in jeopardy of deforestation such as the Cerrado.

TerraClass Cerrado

Objectives: TerraClass Cerrado was created in 2013 in order to systematically map land use and native vegetation coverage in the Cerrado biome [34]. TerraClass Cerrado aims to generate data that can be used to enhance the monitoring and management of the Cerrado. More specifically, TerraClass Cerrado has five objectives: 1. identify, delineate, and map natural and anthropogenic areas[6] in the Cerrado as of 2013, 2. map the use and coverage of land in anthropogenic areas in the Cerrado, 3. define a methodological protocol to systematize mapping of land use and coverage in anthropogenic areas, 4. generate maps and statistics about the use and coverage of land in the Cerrado, 5. and produce and disseminate the data and information generated [35].

Methodology: The University of Goiás, which monitors the Cerrado through the Laboratory of Image Processing and Geoprocessing (Lapig), has partnered with the Ministry of Environment, the Brazilian Agriculture Research Corporation (Embrapa), INPE, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), and the Federal University of Uberlândia to produce the data [34]. Data for TerraClass Cerrado was gathered from the Landsat 8 satellite and Operational Land Imager (OLI) information for the entire biome in 2013,

[6] Anthropogenic areas refer to areas with evidenced human influence or activity.

the baseline year; data were gathered during the dry period to limit cloud interference [36]. The images were then processed and categorized according to reflectivity and vegetation concentration in order to generate shapefiles.

Scale: Cerrado biome

Cost of access: Free

Advantages: In 2013, TerraClass Cerrado mapped more than 200 million ha of the Cerrado biome [36]. The results, which show that 54.5 percent of the Cerrado still maintains natural vegetation characteristics, have drawn attention to agricultural frontier areas that could be deforested [37]. Combined with data from the National Rural Environmental Registry System (SICAR), TerraClass Cerrado can help inform future biodiversity and natural resource management plans. The system can also help support public policies related to defining priority areas for biodiversity conservation, sustainable use, degraded area recuperation, threatened species management, soil conservation, water security and ecological zoning [35]. The maps are also very accurate, as demonstrated by the fact that the general agreement index between the maps and the validation process was 80.2 percent.[7]

Challenges: Mapping land use change and native vegetation coverage in the Cerrado is complicated by the extent of the area being mapped, heterogeneity of the native and non-native vegetation formations, and production system dynamics [35]. Additionally, coordinating the different institutions that comprise TerraClass Cerrado and reconciling their different methodologies has presented some difficulties. Furthermore, the maps provide snapshots of land use change in general, not specifically of deforestation. Lastly, TerraClass Cerrado is specific to the Cerrado biome.

MapBiomas

Objectives: MapBiomas, or the Brazilian Annual Land Use and Land Cover Mapping Project, is a multi-institutional initiative created to produce historical and annual land use change and land cover maps for the entire country [38]. Initiated by the Climate and Greenhouse Gas Emission Estimating Observatory (SEEG), MapBiomas represents a collaboration among about two dozen organizations including universities, NGOs and technology companies.

Methodology: To move from mapping tree cover change to mapping land use change more specifically, MapBiomas uses Landsat imagery (up to 30 m resolution) to create a pixel mosaic that undergoes classification to generate both a land cover and land use change, or transition, map [39]. The maps display land cover and land use change data on a country, state and municipality level, while showing indigenous territories and conservation units. MapBiomas also generates a transition matrix, which details the different land use change activities noted on the maps [38].

[7] The validation process was set up to validate the accuracy of the maps, and was conducted by a third party auditor.

Scale: Brazil

Cost of access: Free

Advantages: Using cheaper, faster and more updated methodologies, MapBiomas is able to generate land cover and land use change maps of the entirety of Brazil so as to measure agriculture productivity and identify priority restoration areas. MapBiomas has also created tools to facilitate the dissemination and adoption of the method in other countries and regions to encourage continued collaboration [38].

Challenges: While designed to be easily accessible, potential users need training in order to use the tool. Additionally, although MapBiomas can be used to improve policies and infrastructure, actual data is not precise enough for calculating deforestation rates [40].

TABLE 1

Overview of general deforestation monitoring systems in Brazil

General Deforestation Monitoring Systems in Brazil					
System	**Objectives**	**Scale**	**Access Cost**	**Advantages**	**Challenges**
Program to Calculate Deforestation in the Amazon (PRODES)	Identify newly cleared land on an annual basis; provide Amazon-wide annual deforestation rate	Brazilian Amazon	Free	Uses higher-resolution imagery; requires intensive data interpretation; frequently used to crosscheck deforestation risk data from supply chains	Unable to identify recent forest clearing, provide immediate results, detect forest degradation or selective logging, report on areas covered by clouds, or detect forest clearing outside of the Amazon

PRODES Cerrado	Provides deforestation data for the Cerrado to reduce deforestation and degradation of native vegetation, and maintain ecosystem services	Cerrado biome	Free	Provides insight into whether efforts to reduce illegal deforestation, limit degradation, and promote sustainable development are effective; integrates PPCerrado	Does not provide real-time or area specific data
Real Time System for Detection of Deforestation (DETER)	Maps land cover in the Amazon to determine the location of recent forest clearings	Brazilian Amazon	Free	Provides near real-time identification of deforestation hot spots; helps law enforcement target interventions; companies crosscheck data to determine whether their operations are meeting sustainability criteria	Unable to report on areas covered by clouds or detect forest clearing outside of the Amazon; only able to detect clearings larger than 25 ha
System for Monitoring Forest Degradation in the Brazilian Amazon (DEGRAD)	Maps areas in the process of deforestation, or areas that are degraded, where complete deforestation has not yet occurred	Brazilian Amazon	Free	Maps areas of degradation individually and independently; provides insight into areas that are in the process of regeneration and areas that are experiencing recurring degradation	Only detects degradation in the Amazon biome; data has not been updated since 2013

Deforestation Alert System (SAD)	Aims to detect forest cover change to monitor the impact of government policies to protect the Amazon	Brazilian Amazon	Free	Useful for monitoring the legality of private lands	Unable to detect forest clearing outside of the Amazon
TerraClass Cerrado	Systematically maps land use and native vegetation coverage in the Cerrado biome to enhance monitoring and management of the Cerrado	Cerrado biome	Free	Has mapped more than 200 million ha of the Cerrado biome; results have drawn attention to agricultural frontier areas that could be deforested; can help inform future biodiversity and natural resource management plans, and help define priority areas; maps are very accurate	Mapping is complicated by the extensive area, heterogeneity of vegetation, and production system dynamics; coordinating different TerraClass institutions and reconciling different methodologies is challenging; specific to the Cerrado biome
MapBiomas	Produces historical and annual land use change and land cover maps for the entire country	Brazil	Free	Uses cheaper, faster, and more updated methodologies; able to generate land cover and land use change maps to measure agricultural productivity, identify priority restoration areas, and calculate the rate of total deforestation; has	Users need to be properly trained prior to using the tool; actual data is not precise enough for calculating deforestation rates

				created tools to facilitate the dissemination and adoption of the method	

3.2. Cattle supply chain tracking tools

Effective cattle supply chain tracking tools can provide benefits for meatpackers, retailers, and manufacturers alike. Using monitoring systems to increase the transparency of transactions will help companies identify potential gaps in monitoring, reduce the potential risk of exposure, eliminate purchases from ranches with deforestation, and enhance efforts to expand monitoring to indirect suppliers [19]. Supply chain actors in the cattle industry can use a variety of tools to manage the risk of deforestation in their operations.[8]

AgroTools

Objective: AgroTools is a Brazilian Big Data firm that focuses on territorial management, risk monitoring, and consulting for tropical agribusiness [41]. With access to an extensive data bank and a series of proprietary geospatial technologies, AgroTools monitors one million properties (200 million ha) daily [42]. Companies, such as JBS, Minerva, Carrefour and others in the beef industry use AgroTools to conduct dynamic risk assessments of whether the raw materials they use are produced from sustainable sources and practices so as to protect their brands [42].

Methodology: When AgroTools receives data from a company, the data firm conducts geospatial monitoring. This process involves digitally overlaying geographical coordinates and georeferenced maps of the cattle supplier properties with criteria on deforestation in the Amazon and official deforestation maps provided by the INPE (PRODES and DETER) [25]. AgroTools provides daily updated reports, called "geomonitoring reports," which contain details about the analysis performed on monitored suppliers. Based on the results of the geospatial monitoring analysis, properties are classified as "blocked," "released" or "alert" depending on the suppliers' level of compliance with both company specific social and environmental criteria as well as with national deforestation criteria [25].

Scale: Brazilian Amazon and Cerrado Biome

Cost of use: Depends on technology utilized, data, size of the operation, level of support needed, consultation, integration process, customizations, new developments and other factors

[8] Note that not all companies utilizing the tools listed were cited.

Advantages: AgroTools offers a suite of tools, called AgroAssets, to further assist companies in the beef industry with monitoring and reducing deforestation in their supply chains.

- TerraMatrix: a geographic platform that helps agribusiness achieve compliance goals, uphold social and environmental responsibility, and increase production [43-44].

- TerraSafe: assesses compliance with pre-defined social-environmental protocol specific to each client by providing a geographic database of supplying properties [43]. By combining satellite data with information from public databases in real time, TerraSafe can help identify social and environmental risks associated with commodity production [44]. Clients simply need to enter the name of a property and click to generate a map displaying all of the criteria being analyzed, a summary of the criteria results, and a report of the analysis request and results (which is saved for five years) [45].

- GeoID: builds property-specific geographical databases, and incorporates data from the CAR to delineate property boundaries and features [46].

Companies such as Walmart, Marfrig, McDonald's, Nestle, JBS and Amaggi use the variety of services offered by AgroTools to help assess and manage deforestation risks in their supply chains. Using Google Cloud Platform, AgroTools is able to conduct more than 200,000 analyses per year on 1,151 layers of strategic information, allowing customers to increase value chain efficiency and gather competitive insights [42].

Challenges: Given that the cost depends on the complexity of the operation, the high price can be a concern.

Safe Trace

Objective: Safe Trace is a company specialized in cattle supply chain traceability. The company's methodology integrates various technologies to provide results for each step of the supply chain, from producer to consumer [47].

Methodology: Safe Trace technology electronically identifies cattle, using ear tags or chips that can be ingested by the animals and implanted in the stomach, to track each individual animal, collect DNA, and register the differences between the herd, producer, and confinement conditions [48]. Safe Trace also provides complete livestock management systems with the cooperation of Embrapa, integrates this information with the Brazilian System of Identification and Certification of Cattle Origin (or SISBOV, which will be discussed below), georeferences livestock production areas via satellite imagery, monitors the boarding, transport, and delivery to slaughterhouses, and conducts internal and external audits for operations [48]. Clients can receive alerts if anomalies or changes are detected. Additionally, Safe Trace has a centralized traceability platform that sets up blocking and recall plans, communicates these plans to all involved, and tracks progress [49]. All data gathered via the Safe Trace platform is easily accessible via the internet. Additionally, in supermarkets, consumers can scan barcodes assigned to each piece of meat to learn about the production process [50].

Scale: Brazil

Cost of use: Negotiated with retailer

Advantages: Not only does Safe Trace track meat throughout every point along the supply chain—from the pasture to the plate of consumers—but the system also makes this information readily accessible. Once cattle are slaughtered, the meat products are tagged with a barcode that, when scanned, reveals details about the entire production process to consumers, enabling them to make more informed decisions about their purchases. Furthermore, the Safe Trace system can be integrated with slaughterhouses so that 100 percent of the information about the batches of cattle purchases and meat production can be transmitted [51]. Safe Trace also developed a mechanism to ensure that rural producers do not deforest protected areas or indigenous territories. Partnering with geoprocessing companies, Safe Trace is able to point out deforestation focus areas, and use this data to prevent cattle in those areas from being sold [52].

Challenges: Similar to other systems, if companies wish to extend Safe Trace services to slaughterhouses, suppliers need to be trained to use the platform. The price can also vary, and be costly depending on the retailer and extent of the operation.

Brazilian System of Identification and Certification of Cattle Origin

Objective: The Ministry of Agriculture, Livestock, and Supply (MAPA) created the Brazilian System of Identification and Certification of Cattle Origin (SISBOV) in order to identify, register and monitor individual cattle born in or imported to Brazil [53]. SISBOV aims to ascertain the origin, health status, production and security of cattle products by regulating the traceability system throughout Brazil.

Methodology: Unlike past efforts to track cattle, which relied on identifying individual animals, SISBOV requires property certification. Certification entities accredited by MAPA consult property owners who opt to participate in the system in order to correctly identify all animals on the property according to: birth month or date the animal was brought to the property, sex, fitness, breeding and feeding system, and information referring to the animal's health [53]. This data, which details the complete history of each animal, is then entered into SISBOV's National Data Bank. In order to be approved by SISBOV and be deemed an Approved Rural Establishment in Sisbov (ERAS), properties must have the following in place: rural producer registry, property registry, basic production protocol, SISBOV term of membership, registry of inputs used, individual identification of 100 percent of cattle on the property, control of animal movement, supervision of a single certifier accredited by MAPA, and periodic visits by the certifier [53]. Although SISBOV is voluntary, property owners engaging in trade with countries that require traceability must be registered [54]. In fact, some countries in Europe only accept imports from properties that are registered, certified and audited by MAPA [54].

Scale: Brazil

Cost of use: A study conducted on the different types of identification and tracking systems permitted by SISBOV revealed that the costs for both of these activities decreases as the number

of animals monitored increases. For example, costs for using electronic chips can range from U.S. $5.50 per head for 100 animals to U.S. $3.00 for 5,000 animals [55].

Advantages: SISBOV allows for the tracking of an animal from birth to slaughter. SISBOV both guarantees the internal control of cattle information and improves and amplifies trade relations between Brazil and other countries. Additionally, the fact that SISBOV does not depend on the Federal Service for Processing Data (Serpro) to compile and process information means that the system is entirely independent.

Challenges: As the system is voluntary, not every property owner raising cattle needs to register. As of 2016, only 1,640 rural properties intending to export to the EU were registered [56]. This could enable leakage from indirect suppliers along the production chain. Furthermore, due to difficulties in implementation, SISBOV has only been used in some cases [57].

Terras App Solutions

Objective: Terras App Solutions (Terras) was created in 2014 to develop innovative applications (apps explained in the "Advantages" section below) for managing rural properties, monitoring social-environmental risks, and tracking agricultural products, including cattle [58].

Methodology: Terras uses cloud computing, digital maps and satellite imagery to connect people, rural properties and entire supply chains to increase supply chain transparency. Terras develops mobile and desktop geospatial apps to provide digital solutions for: agricultural management, risk monitoring, traceability of agricultural and forest products, and traceability of environmental services [58, 59].

Scale: Brazilian Amazon

Cost of use: The cost of using Terras depends on the app. BusCAR costs about U.S. $240 per month per slaughterhouse [60]. The cost of using Eco-Track is marginal, estimated to be about U.S. $0.62 per cow [61].

Advantages: Terras App Solutions aims to contribute to the creation of zero-deforestation zones for rural production and provision of environmental services for society by offering a suite of apps for the cattle industry. These apps enable farmers to boost agroforestry intensification, reducing the pressure to expand agriculture into forested areas [59].

- BusCAR: assesses supplying properties' compliance with specified social and environmental criteria, such as those of the TACs, by creating a comprehensive property map and a registry of transactions, audits and other production information [58]. BusCAR also assists producers with uploading their property data to CAR so that registered suppliers can crosscheck their information with the data compiled in BusCAR [60].

- CARMap: once a producer uploads his or her CAR data in BusCAR, CARMap can be used to validate the quality of the CAR registry data [60]. Properties are able to conduct an

automatic analysis of compliance with the Forest Code using satellite and mapping technologies overlaid with CAR criteria [62].

- GTA: Terras also connects CAR information with the Animal Transport Guide (GTA; for more details see the Animal Transport Guide sub-section below) to track deforestation caused by cattle raising [60]. Suppliers are required to provide GTA information for their cattle, as well as GTAs for any indirect suppliers. Terras then assesses the carrying capacity of each farm. If a rancher claims more cattle than the carrying capacity, Terras concludes that there must be indirect suppliers [60].

- Eco-Track: by tracking cattle transactions at every point along the way from ranches to slaughterhouse, Eco-Track aims to eliminate potential deforestation resulting from indirect suppliers. All purchases monitored via Eco-Track originate from farms registered in the system. These transactions can be reviewed by auditors at any time, in conjunction with accompanying GTA forms, to verify the legality of the purchases.

Currently, Terras is used by Amazon Sustainable Cattle Ranching (Pecsa) for a zero-deforestation cattle intensification initiative called Novo Campo. Pecsa applies the BusCAR tool and pairs this with PRODES deforestation maps to assess compliance with all Novo Campo protocol [60]. Arcos Dorados and JBS are currently sourcing verified zero-deforestation beef from Novo Campo.

Challenges: As of now Terras operates solely in the Amazon. Additionally, the affordability of Terras depends on the availability of big data; the more data able to be collected, the better and more affordable the apps will be. Currently, Terras does not provide data regarding transportation costs along the supply chain, reducing transport costs, connecting regions with industries, or targeting land use planning, but has intentions of doing so in the future. Additionally, Eco-Track does not track individual animals from ranches to slaughterhouses, but rather keeps track of the number of animals, which makes it difficult to link sales transactions.

Radio-frequency Identification tags

Objective: Radio-frequency identification (RFID) tags enable the unique identification and tracking of cattle.

Methodology: When a chip is implanted, an animal's location can be identified and additional information about the animal can be accessed [19]. By providing georeferenced data and biophysical information, RFID tags can be used to geo-reference the location of cattle and track movement throughout the supply chain, significantly improving both the traceability and monitoring of cattle from birth to slaughter [19].

Scale: Global

Cost of use: Varies depending on number of animals, but is generally high.

Advantages: These technologies are becoming increasingly popular in Brazil and are being used by companies, such as Carrefour, that are intent on identifying ranches that supply beef. Brazilian meatpackers are also considering using RFID tags and similar devices to ensure that cattle have not been sourced from farms on IBAMA's black list—which includes properties that have been embargoed due to deforestation violations—or from properties with deforestation [19].

Challenges: Although RFID tags could improve traceability and productivity, the high cost of this technology, which requires tags, antennas, readers and operational changes to implement the system, can be a limiting factor for some suppliers [19]. Furthermore, even if animals have been traced from source to slaughterhouse, RFID tracing stops there and the process thereafter is unclear to consumers.

BovControl

Objective: BovControl is a data collection and analysis tool aiming to reduce global hunger by helping farmers maximize meat production through improving performance on meat production, meat production and animal identification [63]. The startup is striving to create the "internet of cows" so as to connect every cow on the planet to the cloud, thereby improving data collection throughout the cattle production value chain and, as a result, improving the production and efficiency of the whole cattle industry [63].

Methodology: Farmers planning on using BovControl must first input a cow's basic data into the BovControl mobile app; this information includes birth date, medication, vaccinations and weight. Farmers can use any technology, such as ear rings, chips, smart collars and smart scales, to automatize the data collection of the animals. The app eventually starts processing the data autonomously, using artificial intelligence to make predictions about the cows. The data's level of sophistication depends on how advanced the farmer's tools are; using technology like Bluetooth-connected scales, for example, the device can sync to the app and predict when cows are large enough for slaughter [63]. The data is then displayed on the control panel dashboard, which allows farmers to follow everything that is happening.

Scale: Global

Cost of use: The cost of the app depends on the size of the farm and which package users choose to purchase. For a small to medium-sized farm, the app costs U.S. $0.15 per animal per month [63]. Other farm-wide packages include: Responsible, which applies to farms of up to 50 head and costs U.S. $15.00 per animal per month; Professional, which applies to farms of up to 330 head and costs U.S. $49.00 per animal per month; and the Scale, which applies to farms of up to 1,850 head and costs U.S. $249.00 per head per month [64].

Advantages: The mobile app continues to function and saves all information even when the user is offline. When re-connected, farmers can then upload their information to the cloud. Also, meat certifiers can use BovControl to approve meat exports more rapidly. Additionally, the livestock inventory created using the app shows the origin of products, which offers more

reliability and traceability to all destinations. Lastly, farmers can receive notifications on periodic events, such as changes to nutritional or health related issues.

Challenges: Most of the farms that use BovControl are small to medium in size. Bigger farms, however, often times have stricter processes in place so it is more difficult for them to add systems like BovControl to their operations [65]. Additionally, while growing, BovControl's operations in Brazil are quite small due to difficulty in finding qualified Brazilian candidates to work there [65]. This could complicate any potential expansion plans, and thus limit the scale at which the app is used.

Animal Transport Guide

Objective: While initially designed to eradicate foot and mouth disease in cattle, the Animal Transport Guide (GTA) is the official system used to record cattle transport in Brazil [66]. GTAs include information about origin and destination, sanitation conditions, and the purpose of transport.

Methodology: Prior to transporting cattle, farmers must fill out GTAs and indicate cattle lot information, including the number of animals being transported, age range, destination and identification of origin (which includes the municipality, name of ranch or meat processor, and Tax Payer's ID Number) [66]. The completed form accompanies the cattle until they reach their destination, at which point the government registers the data and creates a record of the whereabouts of the cattle [66].

Scale: Brazil

Cost of use: While the cost of GTAs varies depending on the issuing state, estimates from the state of Minas suggest that the cost of GTA certification per animal not destined for slaughter is U.S. $0.42, the cost per animal destined for slaughter is U.S. $0.67, and the cost of vaccinations per animal is U.S. $1.68 [67].

Advantages: Millions of cattle transactions have been archived since 2013. By providing information on where cattle have been and will go, supply chain actors can gain a comprehensive understanding of the impact cattle may have on deforestation. The GTA is used for many sustainable cattle ranching initiatives that are partnering with the private sector such as Novo Campo and São Felix do Xingu. Additionally, the GTA could support greater traceability by being linked with CAR and other databases to crosscheck data.

Challenges: GTAs do not track individual heads of cattle. This means that it is challenging to track cattle from birth to slaughter, and therefore track all potential farms animals may have passed through throughout the production period. Additionally, although electronic GTAs are implemented throughout Brazil, some states still operate with paper GTAs when errors arise in the digital system [57]. Lastly, access to GTA data is currently only possible if each producer in the supply chain provides the access code to meat processors. To be more effective, GTAs should be made more accessible.

Audsat

Objective: Audsat, which is a joint venture between Biofílica and Santiago & Cintra Consultoria, aims to offer mitigation solutions for credit risks, agricultural insurance, and environmental compliance through auditing and monitoring rural properties involved in the production of commodities, including soy and beef [68].

Methodology: Audsat develops platforms and systems to continuously monitor rural properties, considering current Brazilian legislation, best practices policies, and client commitments and insights [69]. In addition to helping register rural properties in the CAR, Audsat uses remote sensing tools such as SIG-CAR and Landscope to provide a complete assessment of the properties involved in supply chains for soy and beef, among other commodities. Key analysis is conducted on overlap with risk areas, deforestation and deforestation monitoring, and intersection with business information [69]. The analysis can be used for program development consultations alongside producers, NGOs and other partners. Audsat data can also be used to analyze property irregularities to identify where it is possible to create and restore Areas of Permanent Preservation (APPs) and Legal Reserves according to the Environmental Regulation Program (PRA in Portuguese) [70].

Scale: Brazilian Amazon

Cost of use: To prepare and support registration into the CAR, the cost totals around U.S. $325.00 [71]. It costs about U.S. $278.00 to use Audsat for a small property, and about U.S. $927.00 for a large, complex property [71].

Advantages: In addition to providing solutions for supply chains and environmental compliance, Audsat also assists with improving access to financial resources. All solutions aim to enhance transparency, traceability, efficiency and reporting consistency by integrating financial, environmental, and business data [68].

Challenges: Audsat only provides solutions for supply chains and rural properties within the Amazon. As noted above, it is substantially costlier to use Audsat on larger more complicated properties, which could serve as a barrier for potential clients.

TABLE 2

Overview of cattle supply chain tracking tools

Cattle Supply Chain Tracking Tools					
Tool	**Objective**	**Scale**	**Use Cost**	**Advantages**	**Challenges**
AgroTools	Focuses on territorial management, risk monitoring	Brazilian Amazon and	Depends on technology utilized, data, size of the operation, level	Useful for big companies to assess and manage deforestation	Given that the cost varies on the complexity of the operation, the

	and assessment; provides consulting services for tropical agribusiness	Cerrado biome	of support needed, consultation, integration process, customizations, new developments, and other factors	risks in their supply chains; able to conduct more than 200,000 analyses per year on 1,151 layers of strategic information; offers suite of tools	high price can be a concern
Safe Trace	Increases traceability of each step in the beef supply chain, from producer to consumer	Brazil	Negotiated with retailer	Information is provided for every step along the supply chain; information about entire production process is available to consumers; can help ensure that rural producers do not deforest illegally	Similar to other systems, potential users (like suppliers) need to be trained to use the system; price can be costly
SISBOV	Identify, register and monitor individual cattle born in Brazil or imported to ascertain the origin, health status, production and security of cattle products	Brazil	Depends on the number of animals; costs for using electronic chips range from U.S. $5.50 for 100 animals to U.S. $3.00 for 5,000 animals	Tracks individual animals from birth to death; guarantees internal control of cattle information; improves and amplifies trade relations between Brazil and other countries; system is	System is voluntary; leakage is a possibility; difficulties in implementation

				entirely independent	
Terras App Solutions	Provides innovative applications for managing rural properties, monitoring social-environmental risks, and tracking agricultural products	Brazilian Amazon	Depends on app; BusCAR costs U.S. $240.000 per month per slaughterhouse; Eco-Track costs about U.S. $0.62 per cow	Aims to contribute to the creation of zero-deforestation zones for rural production; currently used by Novo Campo project; apps enable farmers to boost agroforestry intensification, reducing agricultural expansion pressure; offers suite of tools	Only operates in the Brazilian Amazon; affordability of apps depends on big data; does not provide data for transportation costs along the supply chain, reducing transport costs, connecting regions with industries, or targeting land use planning; Eco-Track does not track individual animals
Radio-frequency Identification (RFID) Tags	Enable the unique identification and tracking of cattle	Global	Varies depending on number of animals, but is generally high	Facilitates identification of suppliers; helps prevent sourcing from farms on IBAMA's black list or properties with deforestation	High cost; requires support technology and operational changes; relationship between end product and animal is not maintained
BovControl	Improves performance on meat, milk and genetics production; created the "internet of	Global	Depends on the size of the farm and which package users purchase; for small-medium farms, app	Functions and saves all information when user is offline; facilitates more rapid export of	Use on bigger farms is challenging as larger farms have stricter processes in place; growing

	cows" to connect every cow to the cloud and improve data collection throughout the supply chain to improve production and efficiency of the industry		costs U.S. $0.15 per animal per month; other farm-wide packages include: Responsible, which applies to farms of up to 50 heads and costs U.S. $15.00 per month; Professional, which applies to farms of up to 330 heads and costs U.S. $49.00 per month; and the Scale, which applies to farms of up to 1,850 heads and costs U.S. $249.00 per month	meat; livestock inventory is comprehensive; farmers can receive notifications on periodic events like changes to nutrition or health	operations and increasing scale in Brazil is difficult
Animal Transport Guide (GTA)	Designed to eradicate foot and mouth disease; official system used to record cattle transport in Brazil	Brazil	Cost estimate of GTA per animal not destined for slaughter is U.S. $0.42, the cost per animal destined for slaughter is U.S. $0.67, and the cost of vaccinations per animal is U.S. $1.68	Provides comprehensive understanding of cattle transport and potential impact cattle may have on deforestation; can be paired with other databases to increase traceability	Does not track individual heads of cattle, so it is challenging to track from birth to slaughter; some paper GTAs are still used; GTAs not completely accessible

Audsat	Offers mitigation solutions for credit risks, agricultural insurances, and environmental compliance through auditing and monitoring rural properties	Brazilian Amazon	U.S. $325.00 to prepare and support registration into the CAR; U.S. $278.00 to use Audsat for a small property, about U.S. $297.00 for a large, complex property	Provides solutions for supply chains and environmental compliance; assists with improving access to financial resources; aims to enhance transparency, traceability, efficiency, and reporting consistency by integrating financial, environmental and business data	Only operates in the Amazon; use of Audsat on larger, more complex properties is costlier

3.3. Soy supply chain tracking tools

Given that soy production is one of the major drivers of deforestation in Brazil, in particular in the Cerrado region, effective and efficient tracking tools are necessary to minimize the impact of this commodity on forests. Supply chain actors in the soy industry are using various tools to increase the traceability of their operations and reduce the risk of deforestation.

Soy Moratorium Monitoring System

Objective: To effectively monitor compliance with the SoyM and ensure that traders did not market any soya growing on land in the Amazon that was deforested after 2006, the Soya Working Group (SWG)—comprised of soya traders, producers, NGOs, companies and government—developed a satellite and airborne monitoring system in collaboration with INPE [9].

Methodology: The SWG incorporates both INPE's methodology for identifying areas of deforestation and potential soy crops, incorporating PRODES satellite imagery in the SoyM's monitoring system [72]. By defining the area of soybean plantation concentration in the Amazon, using satellite images to preselect PRODES deforested polygons likely to have annual crops, and then using aerial surveys to confirm the presence of soybean, the monitoring system is able to display potential locations of soya crops grown on any land deforested after 2006 [73].

The SWG agreed to monitor deforested polygons greater than 25 ha due to the spatial resolution of the MODIS sensor [73]. If the system detects soybean growth in violation of the SoyM, then the farms or farmers responsible are identified by the trading company members of the moratorium agreement [73]. Then, the information is presented to the SWG, which ensures that contracts with farmers or farms in violation of the SoyM are cancelled [72].

Scale: Brazilian Amazon

Cost of access: Only available to signatories of moratorium

Advantages: The monitoring and compliance mechanisms established by the SoyM provide a model for expanding supply chain traceability and governance to other soy-producing regions [9]. The SWG estimates that they are monitoring 97 percent of the soybean production in the Amazon forest biome [9].

Challenges: Although the scope of the SoyM includes the Brazilian Amazon, the monitoring system is restricted to municipalities in Mato Grosso, Pará, and Rondônia with at least 5,000 ha of soybeans planted in the current or previous year, or predicted to grow in the coming year [9]. Furthermore, indigenous territories, and settlements of the National Institute of Colonization and Agrarian Reform are not included in the monitoring. Evidence suggests that soy production leakage to the Cerrado biome is occurring, indicating that to be most effective the SWG monitoring system needs to be expanded to the Cerrado biome [21].

AgroIdeal

Objective: In September of 2017, Bunge Inc. in collaboration with NGOs, global traders, banks, consultancy firms and Embrapa launched an online decision support tool to encourage sustainable expansion of soy production in the Cerrado [74]. The tool aims to help companies make decisions to evaluate the social-environmental risks associated investments in the soy sector, while aiming to determine the best economical and productivity strategies aligned with low environmental and social impacts [75-76].

Methodology: Using the database information on Brazil's Cerrado, soy supply chain actors can assess the social and environmental risks of their sourcing practices and direct sourcing, planting, or investment strategies to areas that comply with environmental pledges aimed at sustainable expansion of soybean production (which is defined by a group of specialists in the soy sector) to reduce impact while maximizing agricultural and economic potential [75]. Users can generate customized scenarios and identify regions of interest, considering distinct criteria and establishing relevance limits for each indicator [77]. To use the tool, users first select a geographic area of interest and define the weight and limit of the criteria selected [77]. The intersection of the selected indicators is then translated into a risk exposure index, which highlights economic opportunities and social-environmental risks in the region. The system also captures the information in graphs and tables, so that users can use this information to create strategies or evaluate operation risks.

Scale: Cerrado biome

Cost of use: Free

Advantages: Thus far, Bunge has been able to trace the origins of 80 percent of its purchases in key municipalities [75]. Like Bunge, companies can use AgroIdeal to model sourcing scenarios for 2018 and beyond [74]. The interface is completely open and user-friendly. AgroIdeal is more than a fixed map of risks as the tool also illustrates where the opportunities are to reduce regional risk of deforestation while upholding social-environmental commitments.

Challenges: AgroIdeal currently only has data on Brazil's Cerrado. However, the tool plans to include the Amazon region and other key production areas in South America [75].

TABLE 3

Overview of soy supply chain tracking tools

Soy Supply Chain Tracking Tools					
Tool	**Objective**	**Scale**	**Use Cost**	**Advantages**	**Challenges**
Soy Moratorium (SoyM) Monitoring system	Effectively monitors compliance with the SoyM; ensures that traders did not market any soya growing on land in the Amazon that was deforested after 2006	Brazilian Amazon	Only available to signatories of moratorium	Provides a model for expanding supply chain traceability and governance to other soy-producing regions	Limited to certain municipalities in several states; excludes indigenous territories and settlements of the National Institute of Colonization and Agrarian Reform
AgroIdeal	Encourages sustainable expansion of soy production in the Cerrado; helps companies make investments and	Cerrado biome	Free	Companies can model sourcing scenarios for 2018 and beyond; interface is completely open and user-friendly; maps risks	Operates only throughout the Cerrado

	purchasing decisions that discourage farmers from removing trees to create arable land			and illustrates opportunities to reduce regional risk of deforestation	

3.4. Timber supply chain tracking tools

Due to high rates of illegality and fraud, timber production monitoring systems need to be bolstered. In Brazil, the production of tropical timber is managed by three systems. The main system was introduced by the Brazilian Ministry of the Environment and is known as the Document of Forest of Origin. Pará and Mato Grosso (which together account for more than 70 percent of the country's timber production) adopted two state-level systems (Sisflora) [10, 78]. Each system covers all activities related to timber production, including permitting, extraction, transportation, processing and commercialization to ensure that every activity is documented [78]. The methods used to trace timber production and detect illegality range from field audits and spot checks to traceability systems, remote sensing, supply chain information platforms and big data analysis [10]. To date none of the official timber registry and monitoring systems have proved able to control large-scale fraud and illegal logging. Studies indicate that more than 70 percent of timber products from the Amazon may originate from illegal operations [10].

National System for the Control of the Origin of Forest Products

Objective: IBAMA launched the National System for the Control of the Origin of Forest Products (Sinaflor) in March 2017 to regulate and track the entire logging process and provide more transparency and security to the forestry sector, in accordance with articles 35 and 36 of the Forest Code [79-80]. By increasing the transparency and traceability of the entire timber production process, Sinaflor aims to prevent the insertion of illegally-sourced wood into the legal market [80].

Methodology: The system requires individual trees to be electronically tagged and monitored as they are cut down and make their way through the supply chain [81]. Using their cell phones and built-in satellite mapping capacities, regulators are able to check the database to verify the legality of timber against the area of licensed commercial production the product is claimed to originate from [81]. Any timber not tracked by Sinaflor will be considered illegal [79]. Sinaflor can be accessed by individuals or legal entities that are involved with, and declare, activities listed in the Federal Technical Registry of Potentially Polluting Activities and/or Users of Environmental Resources (CTF/APP), or deal regularly with IBAMA as verified by a Certificate of Regularity [82].

Scale: Sinaflor is in the process of being rolled out gradually by certain Brazilian States; Roraima was the first to adopt the system. Sinaflor is now mandatory for all states [83].

Cost of use: Free

Advantages: Thus far, it appears as if Sinaflor is an improvement from the current National Environmental System (SISNAMA), which is riddled with fraud and human error [81]. Among Sinaflor's main advantages are: transparency of both public and private activities, traceability of forestry products throughout the national timber production chain, the "forest credit" concept[9], built in integration with subsystems like the CAR to ensure that no conflicting licenses or authorizations will be granted to the same rural property, and the electronic control of the authorization processes [83].

Challenges: The efficacy of this system could be hampered by the volume of wood typically cleared. Additionally, the ability of Sinaflor to limit illegality could be hindered by the limited state presence in remote regions of the Amazon [83]. Furthermore, getting states to adhere to Sinaflor presents another challenge in that, to function properly, all states need to be regulated by SISNAMA and linked under Sinaflor [84].

System for Monitoring Timber Harvesting

Objective: Imazon developed the System for Monitoring Timber Harvesting (Simex) to detect and asses the quality of forest management plans for harvesting timber in the Amazon [85].

Methodology: The Simex process is comprised of three steps: 1. Analysis of documents available in the control systems at the State Environmental Secretariat (SEMA) of various states to identify inconsistencies, 2. Evaluation of forest management plans and overlaying their limits on satellite images that are crosschecked with Sisflora data and NDFI images, 3. Comparison of this information with forest control systems [86]. Through comparing management plans underway in the states of Pará and Mato Grosso with timber credits registered in each state's respective system, Simex is able to identify inconsistencies. For example, Simex is able to determine when the authorized area is larger than the management area, the amount of timber credit is greater than what is authorized, the number of high value species is overestimated, an area is authorized for timber harvesting within a protected area, and when an area is authorized for timber harvesting in previously exploited areas [86]. Such occurrences are signs of illegality.

Scale: Pará and Mato Grosso

Cost of use: NA

Advantages: Simex facilitates the identification of irregularities in licensing processes and the implementation of forest management plans.

[9] The 'forest credit' concept refers to a measurement of tree trunks of a given species that can be transformed into timber products.

Challenges: Despite the potential of this system, currently it has only been used in Mato Grosso and Pará. Additionally, accessing the data needed to run the analyses can be challenging.

BVRio Due Diligence and Risk Assessment System

Objective: BVRio has developed an innovative digital platform to trace the origins of wood and assess risk of illegality of the timber industry [86]. An integral part of the BVRio Responsible Timber Exchange[10], the Due Diligence and Risk Assessment System screens Brazilian timber and products for their legality status, supply chain inconsistencies, and social aspects to help buyers and traders conduct due diligence throughout the entire supply chain and assess the risk of illegality in the products they might obtain [10, 87].

Methodology: The system extracts the information it requires to conduct analyses from the Brazilian government's documentation system for the control of forest management activities, transport, and trading of timber products such as Timber Extraction Authorizations (TEA), Timber Transport Authorizations (TTA), Forest Origin Documents (DOF), and CAR registries [10]. After crosschecking information from government documents with external databases, the system generates a Due Diligence and Risk Assessment Report for each timber consignment that includes a description of the timber lot, supply chain information and loopholes, production sites in the supply chain, and a risk assessment of each production site in the chain [10]. Additionally, TEAs and TTAs are overlaid with satellite imagery to identify other irregularities detectable by spatial analyses [10]. Based on the results of the analysis, production sites are rated according to their level of compliance and risk level with "No Indication of Infringements, Irregularities, or Non-Compliance" on one end of the spectrum and "High Risk" on the other [10]. Users can then simply scan the bar codes of timber transportation permits and receive a report on the legality of the products checked.

Scale: While originally designed to screen Brazilian timber, with support from the U.K. government the system is already being adapted to enable the screening of responsible timber from West Africa and Peru.

Cost of use: The analysis of timber product risks is free of charge. However, if suppliers question the rating they can request a field audit, which costs around US $3,100.00-3,700.00 for 2-3 days of work [88].

Advantages: To date, the system includes all 3,500 TTAs issued in Pará and Mato Grosso since 2007, covering a sizeable proportion of timber extraction and processing sites [10]. Since its public release, the system has been used extensively by traders and government agencies, both domestically and internationally, and performs two billion crosschecks daily [10]. Products from other sources can also be found in the BV Rio Exchange.

[10] BVRio Responsible Timber Exchange is a negotiation platform to promote the trading of timber products from legal and or certified sources to create transparency, efficiency, and liquidity to the market.

Challenges: Although the tool has been lauded as a promising step towards ensuring timber legality, the system relies primarily on data that may be subject to fraud or alteration [10]. Additionally, accessing necessary data can be difficult due to a lack of transparency.

TABLE 4

Overview of timber supply chain tracking tools

Timber Supply Chain Tracking Tools					
Tool	**Objective**	**Scale**	**Use Cost**	**Advantages**	**Challenges**
National System for the Control of the Origin of Forest Products (Sinaflor)	Regulates and tracks the entire logging process to provide more transparency and security to the forestry sector	Brazil	Free	Transparency of public and private activities; traceability of forestry products throughout national timber production chain; "forest credit" concept; integration with subsystems like CAR; electronic control of authorization processes	Could be hindered by volume of wood typically cleared and limited state presence in remote regions of the Amazon; some states not yet part of system
Simex	Detects and assesses the quality of forest management plans for harvesting timber in the Amazon	Pará and Mato Grosso	NA	Facilitates identification of irregularities in licensing processes and implementation of forest management plans	Only in use in Mato Grosso and Pará; accessing data needed to run analyses can be difficult
BVRio Due Diligence and Risk	Traces the origins of wood; limits illegality of the timber industry by	Brazil, West Africa, Peru	Analysis is free of charge; field audits cost U.S.	Includes all 3,500 TTAs issued in Mato Grosso and Pará; used	Relies primarily on data that may be subject to fraud or

Assessment System	screening Brazilian timber and products for legality status, supply chain inconsistencies, and social aspects to help buyers and traders conduct due diligence		$3,100.00-3,700.00 for 2-3 days of work	extensively by traders and government agencies domestically and internationally; performs two billion cross-checks daily; can also assess products from other sources	alteration; accessing necessary data can be difficult due to lack of transparency

3.5. Global deforestation monitoring systems

There are several global platforms designed to help companies that buy and sell major commodities better understand and trace their impact on forests.

Global Forest Watch Commodities

Objective: Building on the Global Forest Watch (GFW) platform, GFW Commodities is an online platform that enables companies to analyze and assess the impact of key commodities, such as palm oil and soy [89].

Methodology: GFW Commodities uses satellite technology and open data to provide timely and reliable information about forests from the global to municipality level. Using the map feature, users can analyze forest change, forest cover, forest use, conservation and production suitability in specific areas of interest. Additionally, users are able to conduct business-relevant analyses through tools such as the Forest Analyzer, Suitability Mapper, and RSPO assessment tools.

- Forest Analyzer: uses spatial and temporal information to allow users to investigate forest cover change, current land cover, and legal classifications in the area of his or her choice. The tool evaluates total tree cover loss and the number of active fires within selected variable and in specific areas of interest, which can include concessions, jurisdictions, provinces, districts, or any selected area [88].

- Suitability Mapper and RSPO Tools: designed to minimize the impact of palm oil production on forests.

Scale: Global

Cost of use: Free

Advantages: Compared to the GFW deforestation monitoring tool, the GFW Commodities tool provides more detailed monitoring and alerts for deforestation caused by palm and soy, and enables companies to minimize forest-related risks in their supply chains [89].

Challenges: Despite the utility of GFW and its associated tools, the Commodities features are limited to soy, palm and wood fiber.

FORest Monitoring for Action

Objective: A component of the GFW, FORest Monitoring for Action (FORMA) is a monitoring system that produces monthly forest loss alerts for the humid tropics in Asia, Latin America, and Africa [90]. FORMA, which was inspired by Brazil's DETER and SAD forest monitoring systems, is designed to assist individuals managing forests to respond more rapidly to unwanted and unanticipated forest loss [90].

Methodology: The system utilizes data on vegetation intensity and fires from NASA's MODIS sensor, precipitation from NOAA, and historical data on forest clearing [90]. Each individual pixel is assigned a history that a statistical model uses to identify meaningful signs of forest cover loss [90]. Every 16 days, this information is compiled in a map that highlights areas of concern in order to generate alerts of potential forest-clearing activities [90].

Scale: Asia, Latin America, Africa

Cost of use: Free

Advantages: Compared to DETER, FORMA identifies PRODES hotspots with overall higher accuracy, performs better in lightly cleared areas, and identifies new hotspots about half a year faster [23]. Companies could potentially use this information to more accurately and rapidly determine whether their operations are associated with deforestation in those hotspots.

Challenges: Designed to identify hotspots, FORMA alerts may require additional verification using other data, including information from people on the ground.

Trase

Objective: The sustainability platform Trase was developed to enable governments, companies, investors, and others to understand and address the social and environmental impacts linked to their supply chains more comprehensively [91].

Methodology: In order to trace the flow of globally traded commodities (soy, beef, palm oil and timber) from production landscapes to consumer countries for entire countries and commodity sectors, the platform uses subnational production data from national governments, publicly available data on the supply chain logistics of companies, and data on the subnational origin of shipped goods acquired at the port level [91]. Trase allows users to enter the name of a specific company for statistics on its links with source municipalities and consumer markets [91]. Users can also enter the name of a production municipality, state or biome for key sustainability

indicators and statistics on linked trades and consumer markets [91]. This level of analysis provides in depth insight on the extent to which deforestation is likely to be linked to a given commodity.

Scale: Global

Cost of use: Free

Advantages: By linking the amount of deforestation that occurs in jurisdictions where forest-risk commodities handled by supply chain actors are produced during a given period, Trase reveals sustainability, reputational, legal and operational risks associated with deforestation and opportunities along the supply chain [91].

Challenges: The platform currently does not provide information on the production of cattle in Brazil, only soy. While the platform identifies deforestation attributable to the production of soy, it does not specify what portion is illegal deforestation. Additionally, Trase only reaches the level of the consumer country, not the individual purchasing company, which limits the platform's ability to link products to specific consumer goods and consumers themselves. Lastly, the platform only provides data at the municipality level, and does not provide detailed information about individual suppliers or farms.

Global Forest Watch Pro

Objectives: GFW Pro is a scalable and easy to use management application created to securely manage deforestation risks in commodity supply chains [92]. The system was designed with leading commodity companies and financial institutions to inform decision-making, assist with mitigation, and eliminate reputation and operational risks for organizations working to eliminate deforestation from commodity supply chains [92].

Methodology: Companies, banks, or any institutions managing land-related assets can plot the location of thousands of farms, production facilities or municipalities. These entities can also save location data securely, access a dashboard of alerts to track environmental risks happening in these areas (such as tree cover loss and fires), identify trends in risky areas and monitor progress over time [92].

Scope: Global

Cost of use: Only available to users with a profile.

Advantages: This platform enables users to: create portfolios of their sourcing or investment locations; upload or select from GFW-provided locations; see tailored risk analyses; actively monitor forest issues; assess progress towards commitments and policies; share secure data and insights with colleagues, suppliers and customers; and prioritize locations for management actions to achieve internal policies and commitments [92].

Challenges: In order to access the tool, users must create a profile to sign in. Additionally, the information can only be viewed by users.

The Sustainability Consortium Commodity Mapping Tool

Objective: Aware that creating sustainable supply chains is dependent on transparency, The Sustainability Consortium (TSC) created the Commodity Mapping Tool to provide transparency from farm and forest to products at retail [93].

Methodology: The Commodity Mapping Tool process consists of three parts. The first involves gathering company sourcing and risk data, by selecting commodities, risks and issues to analyze [93]. The second step entails using the Commodity Mapping Tool to identify company sourcing regions and calculate the exposure to risk [93]. Lastly, the tool generates results that can then be analyzed to understand supply chain risks and how to address these using TSC key performance indicators [93]. Companies are able to customize the supply chain risk analysis by focusing on particular segments of business (e.g. purchase location, certification or individual supplier), ranking risk exposure by category to identify how risks are spread across business (e.g. by commodity type, risk type or suppliers), and weigh the risk exposure by specific metrics (e.g. volume, spend or sales) [93].

Scale: Global

Cost: Currently available to TSC members

Advantages: The TSC Commodity Mapping Tool maps over 100 commodities, including high impact crops such as beef, cocoa, coffee, corn, palm oil, paper and pulp, soybeans, sugarcane and tea [93]. The Commodity Mapping Tool also maps the major risks associated with commodities including biodiversity, child labor, deforestation, forced labor and water scarcity risks [93]. The tool enables companies to make connections between commitments and commodity supply chains on the ground, understand the extent to which their business is affected by sustainability issues, prioritize regions and suppliers for increased scrutiny, and address risks and issues using TSC key performance indicators [93].

Challenges: The Commodity Mapping Tool is currently only available to TSC members. Considering that the tool is a model based on FAO trade data that needs a lot of information about companies' supply to be most effective, there is considerable variability in how useful the tool can be.

TABLE 5

Overview of global deforestation monitoring

Global Deforestation Monitoring Systems

System	Objectives	Scale	Use Cost	Advantages	Challenges
Global Forest Watch (GFW) Commodities	Enables companies to analyze and assess the impact of key commodities, such as palm oil, beef, soy and wood pulp, on forests	Global	Free	Provides more detailed monitoring and alerts for deforestation caused by palm and soy; enables companies to minimize forest-related risks in their supply chains	Analysis is limited to soy, palm and wood fiber
FORest Monitoring for Action (FORMA)	Produces monthly forest loss alerts for the humid tropics in Asia, Latin America and Africa; assists individuals managing forests to respond more rapidly to unwanted and unanticipated forest loss	Asia, Latin America, Africa	Free	Identifies PRODES hotspots with overall higher accuracy; performs better in lightly cleared areas; identifies new hotspots about half a year faster	Findings may require additional verification using other data, including information from people on the ground
Trase	Enables governments, companies, investors, and others to understand and address the social and environmental impacts linked to their supply	Global	Free	Links amount of deforestation that occurs in jurisdictions where forest-risk commodities are produced; reveals sustainability, reputational, legal, and	No information on the production of cattle in Brazil, only soy; does not specify what portion of detected deforestation is illegal; no information on

	chains more comprehensively			operational risks associated with deforestation and opportunities along the supply chain	purchasing companies; only provides information at municipality level
Global Forest Watch Pro	Securely manages deforestation risks in commodity supply chains	Global	Available to users with a profile	Users can create portfolios of their sourcing or investment locations, see tailored risk analyses, actively monitor forest issues, assess progress towards commitments and policies, and prioritize locations for management actions to achieve internal policies and commitments	Must create a profile to access; information can only be viewed by user
TSC Commodity Mapping Tool	Helps companies create sustainable supply chains by providing transparency from farm and forest to products at retail	Global	Limited to TSC members	Maps over 100 commodities, including high impact crops; maps the major risks associated with commodities; enables companies to better understand supply chains on the ground,	Access is limited to TSC members; model is based off of FAO data; effectiveness of tool relies on quality and quantity of company data provided

				business sustainability issues, supplier regions and risks	

4. DISCUSSION

The aim of this report was to provide a comprehensive landscape of the supply chain tracking tools available to monitor deforestation from cattle, soy and timber production in Brazil. As demonstrated, there are a variety of systems currently available to, and being utilized by, companies seeking to reduce the risk of deforestation in their supply chains. Given that each system has its own advantages and challenges, it is up to companies to decide which tool is most suited to their operations and needs. In addition to being aware of what tools are available to increase the traceability of tropical commodity supply chains and reduce deforestation risk, companies might also consider the following when determining how to minimize and eliminate deforestation from their supply chains.

Tackling indirect suppliers in the cattle supply chain

As mentioned, the issue of indirect suppliers in the cattle supply chain and associated deforestation leakage risk pose a prominent challenge to tackling deforestation in supply chains. Despite the achievements of the cattle agreements, large portions of the cattle supply chain are not monitored or tracked under current implementation; recent research revealed that only 17 percent of ranches in Pará and Mato Grosso are monitored as direct suppliers of TAC slaughterhouses [94-95]. Some companies have mentioned that they are planning on addressing this problem in their policies and plans, but have not specifically described how. Whether this is because companies may be reluctant to share their strategies on account of potential competition, or because they are unsure of how to go about actually addressing the problem, companies could benefit from prioritizing the issue of indirect suppliers and being explicit about how they are intending to do so.

Creating responsive markets

Currently, many producers in the Amazon who are complying with the Forest Code are not yet seeing or experiencing positive economic impacts on their business. Although they are incurring extra costs for bringing their properties into compliance, relative to non-compliant competitors, the market has yet to respond. Companies are well-positioned to change the perception that compliance with environmental standards and regulations is costlier than illegally deforesting. By engaging in jurisdictions that are reducing deforestation across an entire landscape, companies can work alongside government, NGO and other local stakeholders to incentivize

forest protection on a jurisdictional scale, and create regions that are improving along deforestation and productivity metrics [96].

Increasing buy-in

Ranchers and producers are pivotal to tropical forest commodity supply chains. As such, minimizing and eliminating the risk of deforestation from supply chains will be virtually impossible if ranchers and producers are not on board with efforts to tackle deforestation and comply with the CAR, for example. The changes that are needed, therefore, are more social than environmental in nature. Companies need to focus on how to increase buy-in from those actors who can make changes on the ground. Corporate actors within jurisdictions can help get producers on board by working together to connect growers with financial and technical assistance to make critical improvements necessary for increasing production while reducing deforestation [96].

Ensuring control throughout chain of custody

Often times ensuring traceability throughout cattle supply chains is not a matter of cost, but of requiring that intermediaries between suppliers and slaughterhouses exercise the same control over the origin of products [97]. If large retailers start demanding this level of control from their suppliers, then slaughterhouses will have to assist their cattle suppliers (beginning with large farms or farming companies) to implement origin control mechanisms. Large retail clients could eventually establish direct relationships with the largest cattle suppliers that are capable of exercising this control, whereby the slaughterhouses would be service providers [97].

Engaging innovative sourcing solutions

Following the recent Cerrado Manifesto—which calls for companies and investors to take immediate action to protect native vegetation in the Cerrado—BVRio developed the Responsible Commodities Facility to promote zero-deforestation commodities in Brazil, beginning with soy in the Cerrado [98]. The approach combines innovative financial and trading tools, increased transparency and traceability, and enhanced compliance with strict guidelines to accelerate the growth of zero-deforestation commodities and promote compliance with the Forest Code while reducing emissions in the Cerrado [98]. By engaging with initiatives like the Responsible Commodities Facility, companies can be assured that they are purchasing zero-deforestation commodities and working towards meeting their zero-deforestation supply chains goals.

Engaging in first-mover jurisdictions

Although the private sector has made some headway in reducing deforestation in supply chains, the extent to which these individual efforts can have a broad impact may be limited due to leakage, transparency and traceability issues [21]. To achieve deforestation reduction across entire landscapes, companies, local governments, NGOs, suppliers, communities and other stakeholders should engage in jurisdictional approaches. Companies can: publicly commit to use jurisdictional approaches as a way to meet corporate deforestation targets; work with a collective of actors to encourage governments to create and enforce strong forest laws, catalyze improved productivity, and incentivize forest protection; and monitor and track individual performance using tools like those discussed above [96].

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