

Brazil's cattle supply chain is contaminated with deforestation on indirect and unlisted suppliers

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Abstract

Most major meatpackers in the Brazilian Amazon have signed zero-illegal-deforestation cattle agreements (CA), but implementation gaps undermine tangible forest conservation outcomes. To quantify these gaps and better understand cattle supply chains, we created a database that links property maps with records of cattle movements across Mato Grosso and Pará states from 2013-2018. We found that slaughterhouses with CA have a far reach into Brazil's cattle sector and were linked to 88% of the 94,000 properties we assessed. We compared the deforestation on the direct suppliers, which are monitored by slaughterhouses, to the large network of unlisted and indirect supplying farms that were associated with cattle supply chains but were not monitored. Our results show that 81% of deforestation within CA supply chains occurred on these unmonitored properties. Nearly twice as much deforestation enters the CA supply chain from indirect suppliers as from direct suppliers. This deforestation enters the cattle supply chain regardless of how well companies avoid deforestation on direct suppliers. We estimate that a typical direct supplier purchased from 6 indirect suppliers each year and a high-volume direct supplier purchased from more than 20 indirect suppliers. This mixing of cattle purchased from multiple properties more than tripled the number of direct suppliers, and quintupled the head of cattle, that were linked to deforestation at the time of sale to a CA slaughterhouse. This high level of supply chain contamination highlights the urgent need to expand monitoring to include indirect and unlisted suppliers, and the potential for animal-level traceability.

Key Words: Deforestation, Amazon, Zero-deforestation, Cattle, Brazil, supply chain

Highlights

- We linked data on cattle sales to property maps to track the full supply chain
- Company monitoring systems miss 81% of deforestation linked to their supply chain
- Nearly twice as much deforestation enters the CA supply chain from indirect suppliers as from direct suppliers who sell cattle to the slaughterhouses.
- The mixing of cattle from multiple properties more than quintupled the head of cattle that were linked to deforestation at the time of sale to a CA slaughterhouse.
- This high level of supply chain contamination highlights the urgent need to expand monitoring to include indirect and unlisted suppliers, and the potential for animal-level traceability.

1. Introduction

Deforestation continues to contaminate Brazil's cattle supply chains, despite concerted efforts by federal prosecutors and ambitious commitments made by meatpacking companies (Rajão et al. 2020, Skidmore et al. 2021, West et al. 2022, Candino et al. 2024, Zu Ermgassen et al. 2022). At the same time, international markets are increasingly subject to regulations that seek to address deforestation linked to commodity imports as well as calls for more stringent implementation of existing regulations and for more data transparency (Reis et al. 2021, Bager et al. 2021). The recent EU adoption of a Deforestation Regulation (EUDR), which bans the import of forest risk commodities linked to deforestation on direct or indirect suppliers (European Commission 2023) has elevated attention to traceability gaps by companies and exporting countries. Other stakeholders are also pledging collective action, including the Consumer Goods' Forum's Forest Positive Coalition, which has developed guidance for retailers, brands and commodity processors to accelerate efforts to remove commodity-driven deforestation from their supply chains (Consumer Goods Forum 2024) along with 34 global financial institutions (Finance Sector Deforestation Action (FSDA) 2024).

Cattle ranching is the dominant land use in the Brazilian Amazon, where pastures cover up to 80% of deforested land (Mapbiomas 2023), and has been difficult to govern for both the public and private sectors. The most prominent efforts have fallen under what have been known as Brazil's Cattle Agreements (CA). The CA emerged following a series of public campaigns and legal actions that threatened sales of Brazilian beef due to links to deforestation (Barreto &

Gibbs, 2015; Gibbs et al., 2015; Walker et al. 2013). The CA consist of two primary interventions: (1) the voluntary Public Livestock Commitment (PLC; also known as the “G4”) made by the four largest cattle meatpacking companies in 2009 (Marfrig, Minerva, JBS, and Bertin¹) following international supply chain pressure from Greenpeace and other environmental organizations (Greenpeace, 2009), and (2) the Beef TAC (Terms of Adjustment of Conduct) which are legally binding zero-illegal-deforestation agreements that individual meatpacking companies signed with the federal public prosecutors (Ministério Público Federal; hereafter MPF) in response to threats of lawsuits and of boycotts from domestic retailers. The Beef TACs were first signed in 2009 and continued to expand to additional slaughterhouses today (MPF 2020). Both commitments prohibit direct and indirect purchase from properties connected to deforestation after 2008², located on protected areas or indigenous territories, linked to forced labor, or those lacking property registration (Beef on Track 2024; MPF 2024). However, to date, slaughterhouses only routinely monitor the properties that they purchase from directly (direct suppliers), and only these purchases from direct suppliers are subject to annual audits mandated by the MPF.

However, cattle supply chains in the Brazilian Amazon are complex, with some properties specializing in breeding, rearing, and fattening (single cycle) while others are responsible for a combination of these phases (partial cycle), or all these phases (full cycle) (Walker et al., 2013, Skidmore et al., 2021). Throughout its life, the average animal will travel through three farms prior to slaughter. Consequently, two important groups of properties are generally excluded from monitoring: 1) properties that sell cattle to direct suppliers rather than directly to slaughterhouses (indirect suppliers); 2) additional properties owned by direct and indirect suppliers that may have cattle but are not officially listed on cattle transactions (auxiliary or unlisted properties; hereafter unlisted). Even full-cycle properties, which engage in all three primary phases of production, typically purchase at least some cattle from other properties for herd management or other reasons.

For over a decade, companies assessed only their direct suppliers, despite the CAs including the requirement to also monitor their indirect suppliers where their cattle are raised but that do not sell to them directly (Alix-Garcia & Gibbs, 2017; Gibbs et al., 2015; Klingler et al.,

¹ JBS bought Bertin in 2009 and Minerva bought Marfrig’s slaughterhouses located in the Amazon biome in 2024

² The PLC prohibits any deforestation while the Beef TAC prohibits only illegal deforestation.

2018). Consequently, deforestation and other forms of non-compliance on unlisted and indirect supplying farms continue to reach meatpackers and flow to downstream companies and consumers (Skidmore et al. 2021, Brandão et al. 2020, West et al. 2022, Zu Ermgassen et al. 2022, Candino et al. 2024). Each time a property acquires an animal, there is a chance that it is linked to a property with deforestation. Compliance with the CA is decided at the property level in part because the movements of animals between properties establishes commercial links, which create legal liabilities under Brazilian law, and because it is not yet possible to track the supply chain at the animal-level.

Therefore, even if a property acquires many cattle from properties without deforestation, the acquisition of any animals from properties with deforestation may be considered to have “contaminated” the entire herd of the destination property because it is not currently possible to distinguish between cattle coming from deforesting vs non-deforesting indirect sellers once they have mixed on a buyer’s property. The supply chain contamination from unmonitored indirect suppliers is particularly problematic for the relatively small number of high-volume direct suppliers, which supply most cattle for slaughter, because they may buy from dozens of indirect suppliers each year— whose cattle then mix on their property prior to sale to slaughterhouses (Carvalho et al., 2020, Skidmore et al 2024).

An additional monitoring challenge comes from property portfolios or arrangements, which are often complex. For example, large-scale producers can raise animals on rural establishments that contain multiple properties or parcels within the environmental cadaster but only report sales of animals from a single property (Rausch & Gibbs, 2016; Skidmore et al., 2021). This allows for laundering of cattle produced on unlisted, or “auxiliary properties”, that could be non-compliant with the CA.

Nearly 75% of the slaughterhouses in the Amazon with the federal inspection (SIF) needed for export are part of the CA. Despite this broad uptake and evidence that slaughterhouses have indeed blocked purchases from properties with deforestation (Gibbs et al, 2016), this has not yet resulted in significant quantifiable avoided deforestation resulting from the CA (Alix-Garcia and Gibbs, 2017, Moffette et al. 2021) outside of modest amounts in regions with high-market share of PLC companies (Levy et al 2023). In fact, by 2022, deforestation rates in the Legal Amazon had doubled compared to their lowest point in 2012 (rates have since decreased in 2023 and 2024). This trend, in addition to the proliferation of

media coverage of laundering scandals associated with beef and leather products (Mongabay, 2024; The Washington Post, 2022; Unearthed, 2022; Vox, 2022, Andreoni et al., 2021; INPE, 2021; Krauss et al., 2019) along with growing international demands (European Commission 2023) and ambitious domestic climate policy goals (Brazilian Government, 2024), have amplified the need to fully implement the CA by expanding supply chain monitoring.

In this paper, we used data science techniques, including machine learning, to map the cattle supply chain to better understand the flow of cattle across properties and its links to deforestation across the Amazonian states of Mato Grosso and Pará. We then used our maps of supply chains to track the flow of deforestation through CA supply chains in the eight years following their implementation by the major meatpackers in Brazil and to help identify and address implementation gaps.

To accomplish this, we downloaded public records of more than four million cattle transactions from the 2013-2018 Guide to Animal Transport (GTA) records (ADEPARÁ, 2019; INDEA, 2019). We then linked them to public databases of property boundaries in the Amazon biome portions of Mato Grosso (MT) and Pará (PA) (INCRA, 2019; Ministério do Desenvolvimento, 2019; Sistema Nacional de Cadastro Ambiental Rural, 2019), which are the two largest cattle-producing states in the Brazilian Amazon. Finally, we identified deforestation on monitored direct suppliers, unmonitored indirect suppliers, and the unmonitored unlisted properties associated with these direct and indirect suppliers (Figure 1). This data enabled us to determine the proportion of cattle reaching CA meatpackers that were produced on ranches that are out of compliance with the CA.

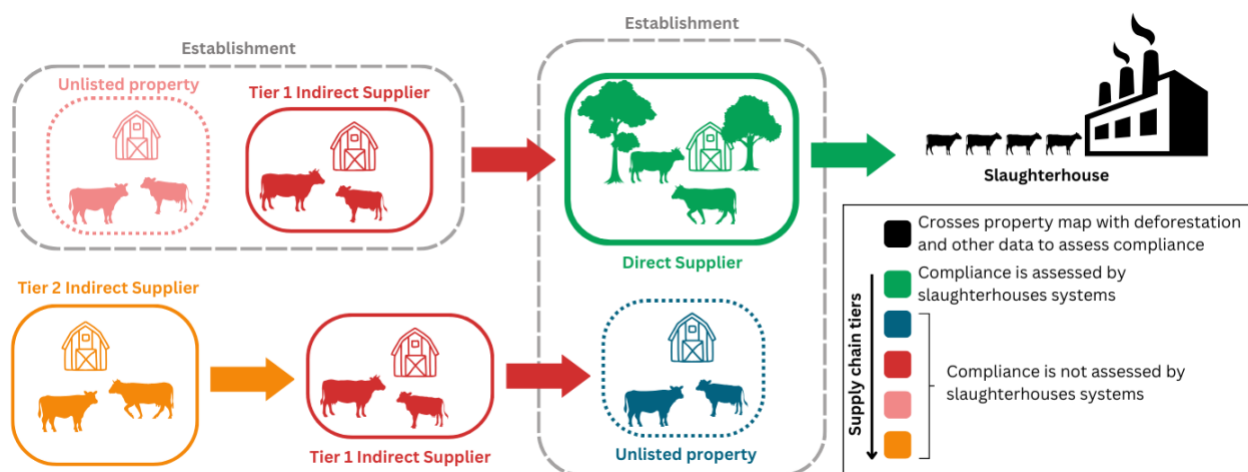


Figure 1. Illustration of gaps in meatpacking company monitoring systems. Only direct suppliers (green) providing GTA (Animal Transit Guide) and CAR (Environmental Rural Registry) data to slaughterhouses are currently being monitored. Tier 1 (red) and Tier 2 (orange) indirect suppliers that sell to other properties, and unlisted properties that are part of direct (blue) and indirect (pink) establishments are not mandated to disclose GTA and CAR data to slaughterhouses and are therefore excluded from monitoring systems.

We found that the CA supply chain was linked to most properties listed in the GTA, but that the company monitoring systems missed more than 80% of the deforestation linked to their supply chains during our study period. Nearly twice as much deforestation occurred on the unmonitored indirect suppliers than on the monitored direct suppliers. Moreover, the unmonitored unlisted properties that were part of direct suppliers' establishments had more deforestation than direct supplying properties listed in the GTA records. By quantifying the size of these monitoring gaps, our work has direct implications for efforts to improve the effectiveness of monitoring systems and reduce deforestation on properties with cattle. This work builds on previous work that discussed the role of indirect suppliers in deforestation (Alix-Garcia & Gibbs, 2017; Gibbs et al., 2015; Rajão et al., 2020; Skidmore et al., 2020, 2024, Carvalho et al. 2021, West et al, 2022, Candino et al 2024) to provide the first comprehensive characterization and assessment of deforestation across the CA supply chain.

2. Methods

2.1 Study region

We focus on the Amazon biome regions of Mato Grosso and Pará, which are the two largest cattle-producing states in the Amazon, representing 57% of cattle herd in this biome as of 2023 (IBGE, 2024) and accounting for 63% of its cumulative deforestation through 2023, due in large part to the expansion of pasture (PRODES, 2024, Mapbiomas 2024). These regions also have the highest uptake of the CA; 85% of the large federally inspected slaughterhouses for export (known as “SIFs”) in these states have signed the CA.

2.2 Mapping and classification of properties

We created a database that maps cattle production and assesses CA performance by using entity matching approaches to link GTA transactions with property boundary databases available from the federal and state governments following Skidmore et al. 2021 and West et al. 2022 (supplement). We downloaded and standardized four million GTA public records for cattle transactions from the Mato Grosso and Pará state sanitation agencies' open websites. We considered the years 2013-2018 because this is the most recent period with data available for Mato Grosso (ADEPARÁ, 2019; INDEA, 2019). The GTA is the official data that tracks movement of animals between farms and slaughterhouses and includes the primary purpose of the transaction (e.g., slaughter, fattening, or calving), the number, sex, and age of the cattle, and the property of origin and destination. The Brazilian Ministry of Agriculture, Food, and Livestock (MAPA) uses the GTA to ensure animal health standards and track animal vaccination records, in part to satisfy international trading partners who want to guarantee the health of animals and sanitary standards, and to enable traceability and containment in the event of a disease outbreak (Bowman et al., 2012). Federal law requires that ranchers register GTA information prior to moving animals between establishments or to slaughter (Law 12.097 and Decree 7.623) and the data are generally considered reliable for measuring cattle flows (General, 2011; Klingler et al., 2018).

We identified 254,624 properties in the GTA (99,987 in Mato Gross and 154,637 in Pará) by their unique combination of municipality, farm name, and owner identification number (CPF or CNPJ). These properties represent nearly 100% of the GTA properties that sold cattle, 2013-2018, from municipalities located at least partially in the Amazon Biome in Mato Grosso or Pará. Approximately 0.05% of GTA transactions were excluded because they were missing basic information required to identify a selling property. While efforts were made to “clean” and standardize the data to address common variations in attribute values, remaining variation likely resulted in some transaction records being identified as a unique property instead of reconciled to other related records, leading to an overestimation of the number of unique properties within the dataset. For example, table 6910 of the 2017 Agricultural Census reports 67,909 establishments with cattle in MT-Amazon and 97,769 in PA. The higher count of properties in our dataset compared to the Agricultural Census suggests that we are over-counting the number of unique

properties in the GTA dataset. The definition of establishments in the census may also diverge from our definition of properties.

We were able to link 94,571 GTA properties to a mapped property boundary, which were responsible for 65% of transactions and 66% of heads sold in our sample of the GTA and comprise our sample dataset; 84,620 of these (89%) had at least 10 ha of pasture based on MapBiomass land cover maps. In comparison, we identified 215,625 properties in the study region that had at least 10 ha of pasture based on MapBiomass, meaning that the mapped study properties accounted for fewer than half (44%) of the MapBiomass pasture properties in the region. The pasture properties excluded from our study likely includes those operating outside of the GTA as well as those GTA properties that could not be matched to the CAR due to typos and alternative spellings in the documentation, properties not registered in the CAR, properties that are rented or where different individuals (staff or family members with meaningfully different names) have their names on the GTA and the CAR.

To identify which transactions were with CA slaughterhouses, we created a lookup table of tax identification numbers along with the year that each slaughterhouse signed a CA agreement. The slaughterhouse lookup table was joined to GTA transaction data using the buyer tax identification number listed on GTA slaughtering transactions. Transactions were coded as “CA” if the year that the slaughterhouse signed the CA was earlier than the transaction year.

Using our coding of CA slaughter transactions, we defined direct suppliers annually as properties that sell any quantity of cattle to CA slaughterhouses for the purpose of slaughter, as listed in the GTA. Tier-1 indirect suppliers (hereafter indirect suppliers) were defined as properties that sell to a direct supplier for a purpose other than slaughter within the two years prior to that direct supplier selling to a CA slaughterhouse. This approach maximizes the likelihood that the animals from the indirect sale were ultimately those sold to a CA slaughterhouse because most animals that are sold for fattening spend less than two years on the fattening property (Skidmore et al., 2021). All other properties that sold cattle but were not identified as CA direct or tier-1 indirect suppliers in a given year were labeled as other GTA properties. While properties may play multiple roles in the supply chain, we never consider a property to be a direct and indirect supplier at the same time in our analysis; if they sold directly to a slaughterhouse they were labeled as direct suppliers even if they were also selling indirectly

at the same time. Thus, a property that sold directly is eligible to be labeled an indirect supplier in our analysis only after their final direct sale to the CA. In our sample, 11,328 direct suppliers (38% of direct suppliers) stopped selling directly to the CA before the end of the period and were thus considered indirect suppliers later in the period.

Overall, of the 94,571 seller properties that we mapped, 29,753 (31%) sold as a direct supplier to a CA slaughterhouse at some point during our study period; 53,498 (57%) never sold as direct suppliers to a CA slaughterhouse but did take part in their supply chain as a tier-1 indirect supplier to a CA slaughterhouse at some point during our study period; the remaining 11,320 (12%) never sold as a direct or tier-1 indirect to a CA slaughterhouse. We were able to match 64% of direct suppliers and 38% of indirect suppliers in the full GTA dataset to a property map. For the 12% of properties in our sample that never sold directly or as a tier-1 supplier to a CA slaughterhouse, we were unable to label their role due to uncertainty in the supply chain links. These ranchers may have sold as tier-2 or tier-3 indirect suppliers (selling to other indirect suppliers) to CA slaughterhouses.

We also identified properties that share an owner and municipality and treated these sets of co-owned property maps as an approximation of the “establishments” described in the regulations governing the GTA as a herd of cattle maintained in rural properties which may include one or more properties, registered under either an individual (CPF) or a legal entity (CNPJ) (Decree 7.623). Within an establishment, we refer to the properties that do not appear in the GTA as “unlisted properties” (aka auxiliary properties). We refer to the union of our sample and their unlisted properties as our establishment sample; this establishment sample covers 58% of MapBiomass pasture in the region.

2.3 Estimation of deforestation through the CA supply chain

We used annual deforestation data from Brazil’s official deforestation monitoring program, PRODES, from 2009-2017 (Instituto Nacional de Pesquisas Espaciais, 2020). We defined deforestation within a cattle supplier as any deforestation polygon larger than 6.25 ha, detected in 2009 or later, and occurring up to one year prior to the GTA transaction year. The Beef TAC is currently assessed against deforestation from July 22, 2008 onward, and the PLC prohibits the purchase of cattle from properties with deforestation from October of 2009 and

onward. While legal deforestation as defined by the Forest Code is permitted under the Beef TAC, only 6% of properties in our sample had more than 80% of their primary forest remaining as of 2008 which is the minimum percentage of legal forest reserve required on most farms in the Amazon biome to be able to clear forest legally. We present aggregated results for Pará and the Amazon-biome portion of Mato Grosso and for the PLC and Beef TAC (“CA” includes both PLC and Beef TAC) in the main text and present full details by state and by commitment type in the supplement (supp Tables 2, 3 and 4, sections S4 and S5).

We estimate the total deforestation area that occurred on direct and indirect suppliers under between 2009 and the year prior to final transaction year and the number of heads sold by properties with deforestation.³ While we mainly consider the prevalence of deforestation as a percent of all properties in our sample, we also present separate estimates for the properties that had the potential to deforest during the period, which were those properties with 6.25 ha or more of forest remaining in 2009 (55% of direct suppliers and 49% of indirect suppliers). We estimate the average deforested area per property with deforestation and use these estimates to compare post-agreement deforestation to pre-agreement deforestation from 2004 – 2008.

Next, we quantify deforestation on establishments. We estimate total deforestation in an establishment during the period in which the direct or indirect supplier was selling to the CA. In cases where an establishment contains both a direct and indirect supplying property, we consider the auxiliary properties in the establishment to be associated with the direct supplier. To better understand the role of establishments, we compare the likelihood that a property in our sample has deforestation with the likelihood there was deforestation on any of its auxiliary properties; we also compare the total deforestation on the property with the total deforestation in the establishment.

We then count direct suppliers that either have deforestation on their own property or are linked to deforestation through at least one noncompliant indirect supplier. We also count the number of heads these direct suppliers sell to CA slaughterhouses.

3. Results

³ In the case of properties that switched from selling directly to indirectly during the period, we only include the total ha of deforestation once, according to their status at the time of deforestation. However, we consider them to be an indirect supplier “with deforestation” even if the deforestation occurred before they became an indirect supplier.

3.1 Most GTA properties were linked to CA slaughterhouses

The 71 CA slaughterhouses that were active at some point during the 2013-2018 study period in Pará and Mato Grosso played a central role in cattle supply chains and reached most cattle properties in these states. We found that 88% (83,251) of cattle ranching properties in our sample were connected to CA slaughterhouses as direct or indirect suppliers. These CA direct and indirect suppliers accounted for 66% of all the head sold in the study region between 2013-2018, and 74% of all head sold for slaughter. Direct suppliers accounted for 36% (29,753) of properties linked to the CA.⁴ The remaining 64% (53,498) of the properties were linked to CA slaughterhouses only through indirect sales to the direct suppliers.

3.2 Indirect suppliers had two times more deforestation than direct suppliers

Nearly twice as much deforestation entered the CA supply chain from indirect suppliers as from direct suppliers between 2009-2017 (315,222 ha vs 176,512 ha; Figure 2). This discrepancy occurred despite indirect suppliers holding less than half the total area and less than half the pasture area of direct suppliers. There were three times more indirect suppliers than direct suppliers with deforestation (12,826 indirect suppliers vs 4,675 direct suppliers). This is partly because there are twice as many indirect than direct suppliers in our sample, but also because indirect suppliers were also more likely to have deforestation than direct ones (20% of indirect suppliers vs 16% of direct suppliers).

Deforestation rates were higher in Pará than in Mato Grosso from 2009 to 2017 (26% of CA direct and tier-1 suppliers in Pará compared to 9% of CA direct and tier-1 suppliers in Mato Grosso). In Pará, 27% of indirect and 22% of direct suppliers had deforestation, compared to 10% and 9% in Mato Grosso (supp Tables 2 and 3). For properties with remaining forest in 2009, 45% of indirect and 36% of direct suppliers in Pará had deforestation, versus 27% and 18% in Mato Grosso.

The concentration of deforestation on indirect suppliers increased after the CA. Prior to the CA, from 2005 to 2009, 33% of indirect suppliers had deforestation compared to 36% of direct suppliers (supp Table 1). After the CA, indirect suppliers with remaining forests in 2009 were 42% more likely to deforest than direct suppliers (40% vs. 28%).

⁴ Of these, 11,328 stopped selling directly later in the period and were subsequently considered indirect suppliers.

Our findings underestimate the total deforestation area on CA suppliers, particularly for indirect suppliers, because not all suppliers could be matched to a property map. Our match rate to connect direct suppliers to property boundaries was higher than it was for indirect suppliers; therefore, the real disparity in deforestation between the two groups is likely larger than our results show.



Figure 2: Distribution of area (ha) on GTA properties and their holdings: CA direct supplier, CA direct supplier unlisted property, CA indirect supplier, CA indirect supplier unlisted property, other GTA properties. Deforestation data from Prodes and land use data from Mapbiomas.

3.3 Unlisted properties had more deforestation than those listed in the GTA

Monitoring all properties owned by ranchers would reveal more deforestation than just monitoring GTA-listed ones. Direct and indirect unlisted properties comprised 20% of the total land area in establishments but had 40% of deforestation (Figure 2). Direct suppliers were more likely to have unlisted properties (36% vs. 26% for indirect suppliers). Among direct suppliers with unlisted properties, 24% had deforestation on unlisted properties and 16% on the GTA-listed property. For indirect suppliers that had unlisted properties, 23% had deforestation on unlisted properties, and 21% on the GTA-listed property. Among the direct suppliers that had deforestation on an unlisted property, only 27% also had deforestation on the GTA-listed property. Among the indirect suppliers that had deforestation on an unlisted property, only 33% also had deforestation on the GTA-listed property.

We found 204,670 ha of deforestation on direct supplier unlisted properties and 224,556 ha on indirect supplier unlisted properties, (Figure 2). Accounting for all deforestation including on unlisted properties, we find that CA slaughterhouses in Mato Grosso and Pará were linked to more than 920,000 ha of deforestation from 2009 – 2017.

3.4 Deforestation on indirect suppliers contaminates 66% of slaughtered CA cattle

Direct suppliers with deforestation or linked to indirect suppliers with deforestation sold 21,588,116 head to CA slaughterhouses, or 80% of the CA total slaughter during the study period. Of the 80% of CA slaughter that was linked to deforestation, 14% (3,791,722 heads) was due to direct suppliers that had deforestation on their own properties. (supp Table 3). The remaining 66% (17,796,394) of CA slaughter that was linked to deforestation came from direct suppliers that did not have deforestation but that purchased from at least one indirect supplier with deforestation (Figure 3). Yet, indirect suppliers with deforestation only sold 3,564,025 heads to direct suppliers without deforestation, far less than the 17,796,394 heads sold by direct suppliers that purchased from at least one indirect with deforestation. This discrepancy is caused by the mixing of cattle on direct supplying properties that originated from deforesting and deforestation-free indirect suppliers. The majority of CA slaughter volume was contaminated due to the mixing of animals on the farms of direct suppliers without their own deforestation.

Indeed, relatively few direct or indirect suppliers deforested – fewer than 16,000 properties (18% of the total) – but their impact on the supply chain was magnified by the interconnected nature of Brazil’s cattle supplier networks. For example, if a direct supplier purchases cattle from five different indirect suppliers, and one of the indirects has deforestation, then all cattle sold by the direct supplier are contaminated, even if most of them come from deforestation-free indirect suppliers. Using the GTA or any batch-level traceability system, it is not possible to track the origin of individual animals. Thus, a single indirect supplier with deforestation can taint all cattle sold by a direct supplier.

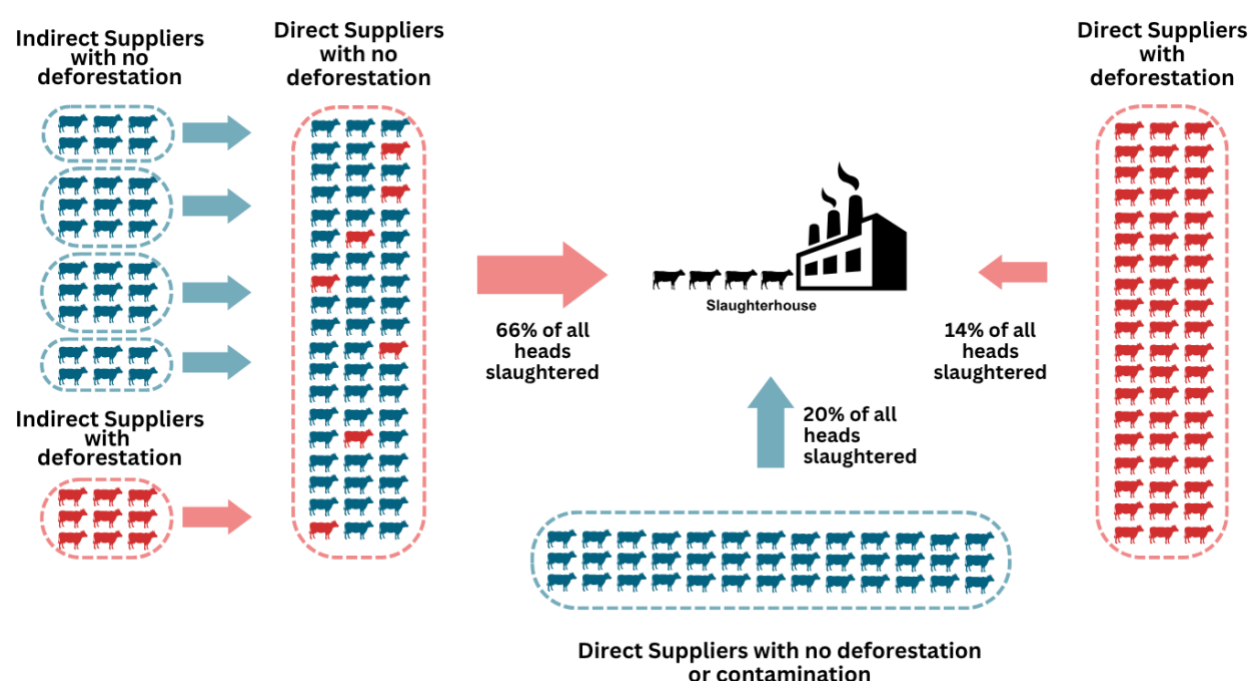


Figure 3: Most supply chain contamination of CA slaughterhouses is due to the mixing of cattle on direct suppliers that did not have deforestation but that purchased from at least one indirect supplier with deforestation.

Overall, this mixing of cattle on properties, and purchases from indirects with deforestation, more than tripled the number of direct suppliers—and more than quintupled the head of cattle—that were linked to deforestation at the time of sale to a CA slaughterhouse (Figure 3). More than half of direct suppliers (56%) were linked to deforestation, whether on their property listed in the GTA or because they purchased from an indirect supplier with

deforestation, or both. Most of these direct suppliers had multiple links to deforestation via indirect suppliers; 60% of suppliers that purchased from any indirect suppliers with deforestation purchased from more than one with deforestation (mean: 4.6 indirect suppliers with deforestation).

Indeed, GTA records show that Brazil's cattle supply chain is highly interconnected and commingling of animals between multiple properties prior to final sale increases the potential for deforestation to enter CA supply chains, even if current monitoring, which is limited to direct suppliers, suggests that they are deforestation free. Nearly all direct suppliers (89%) purchased cattle from more than one property in the six years we observe cattle transactions (2013 to 2018) (Skidmore et al. 2024). On average, direct suppliers purchased from 6 indirect suppliers per year and 24 total during the study period. Indirect suppliers sold to an average of 3 direct suppliers per year and 4 total during the study period. One-off transactions between direct and indirect suppliers were common (Skidmore et al., 2024).

3.5 High-volume suppliers amplified the impact of indirect suppliers with deforestation

We labeled the direct suppliers that sold the most heads to CA slaughterhouses as “high-volume suppliers”. We identified these high-volume suppliers by analyzing all transactions to CA slaughterhouses over the entire 2013-2018 study period. High-volume suppliers were defined as the 5% of direct suppliers that sold the most heads to CA slaughterhouses between 2013-2018. High-volume suppliers are a critical node in CA supply chains (Carvalho et al. 2020). These 1,488 suppliers sold nearly 60% of the cattle slaughtered by CA slaughterhouses; due to quantify of indirect suppliers they bought from, nearly all the cattle they sold (92%) were linked to deforestation. The average high-volume supplier purchased from 26 indirect suppliers per year and 111 over the study period. Although 85% of high-volume suppliers did not have deforestation, 86% of them (1078) bought from at least one indirect supplier with deforestation.

Notably, high-volume suppliers tend to be very large in size on average but accounted for only 7% of the total deforested area by all direct suppliers (13,094 ha), despite having five times as much total area per property on average (3,707 ha compared to 698 among all direct suppliers). They were similarly likely to clear forests as the full set of direct suppliers (15% vs. 16%), but cleared a smaller area when deforestation occurred.

3.6 Distribution of pasture area within CA supply chains

Using MapBiomas land cover data, we calculated the distribution of pasture area within CA supply chains (Figure 2), as well as other GTA properties. Among GTA suppliers and their unlisted auxiliary properties, most pasture area was located on CA direct supplying properties (56%), and 80% of pasture area was located on either direct or tier-1 indirect supplying properties. The remaining 20% of pasture area associated with GTA properties was located on either GTA properties outside of CA supply chains or on unlisted properties associated with GTA properties.

4. Discussion/Conclusion

Our study reveals that meatpacking companies with zero-deforestation commitments play a crucial role in Brazil's cattle supply chain in terms of their links to most suppliers. However, company supply chains continue to be contaminated with deforestation either from the properties involved in raising the slaughtered cattle or due to supply chain contamination from the comingling of animals coming from multiple properties where only some have deforestation.

Between 2009 and 2017, CA slaughterhouses in Mato Grosso and Pará were linked to over 920,000 hectares of deforestation. Most of this deforestation (81%) came from indirect suppliers and unlisted properties not monitored by slaughterhouses, while 19% came from direct suppliers that should have been excluded under current monitoring. High deforestation rates outside monitoring systems suggest that ranchers may exploit these gaps by shifting supply chain roles or altering property listings. This evasive behavior explains continued deforestation despite efforts to reduce it, corroborating previous studies on the shortcomings of current agreements (Gibbs et al. 2015, Alix-Garcia and Gibbs 2017, Moffette et al. 2021, Pereira et al. 2021, Klinger et al. 2018, Rajao et al. 2022, West et al. 2022, Candino et al 2024).

Further, in Brazil's complex cattle supply chain, indirect suppliers and the comingling of cattle make it challenging to discern how deforestation is associated with the animals and suppliers. The provenance of and pathways travelled by individual animals are typically not known because the animal transit records are based on lots or batches of animals and deforestation monitoring and assessment systems operate at the farm level. Thus, we consider

deforestation on one property to have “contaminated” the properties that buy cattle from it, as these cattle bring their exposure to deforestation with them to their next farm. A typical direct supplier buys from six indirect suppliers each year, which increases the chance that they buy cattle from another property with deforestation even if they do not clear their own property. Once the animals from the farms with deforestation arrive on the next farm, they can mix with animals from other farms, and, thus, there is no way to ensure that any animals subsequently purchased from this destination farm did not come from the farm with deforestation.

Supply chain contamination due to the mixing of cattle suggests the need for animal-level traceability programs in Brazil to enable control of the entire supply chain while maintaining market access for otherwise compliant cattle. Indeed, in response to a perceived threat of potential embargoes from external markets over environmental noncompliance in cattle supply chains (Mendonça, 2022), in 2023, Pará’s state government pledged to trace all cattle in the state by 2026 as part of its Cattle Integrity and Development Program, announced at COP28. More recently, the federal government has announced their plans for a national animal level traceability, though under a much longer timeline (MAPA 2024). This could also help reduce the clandestine cattle production occurring outside the GTA and the CAR.

Regardless of ear tagging efforts, property-level enforcement of environmental regulations and consideration of legal responsibility for crimes based on commercial relationships, such as is called for under the TAC, will continue to be important even with eventual, fully implemented animal level traceability. Given our results that show 20% of indirect suppliers and 16% of direct suppliers had deforestation on their farms during our study period, it will be important to avoid segregating the separate supply chains based on compliance levels but rather ensure that deforestation is disincentivized throughout Brazil’s cattle supply chain.

Our results help pave a path forward to strengthen outcomes from Brazil’s CA. First, monitoring needs to be expanded to include indirect suppliers and all properties owned by a producer, including unlisted properties. The TAC monitoring protocol was updated to include these unlisted or auxiliary properties (CITE), but application of the criterion was suspended until a working group could develop solutions to reduce fraud and triangulation. Second, easily

accessible and accurately linked GTA and CAR data is needed for meatpackers to achieve these monitoring advancements and to ensure that third-party audits can demonstrate the reliability and transparency of traceability and monitoring systems. Technical solutions based on the GTA to address deforestation on unlisted and indirect supplying properties, such as Selo Verde and Visipec, could help expand monitoring to these indirect suppliers, but efforts to do so have been hampered by reduced data transparency in Brazil since 2018 (Brazilian General Data Protection Law; LGPD Law no. 13,583). Thus, coordinated and sustained private and public actions in support of data transparency will be necessary for the cattle sector to be able to identify and address deforestation on suppliers. In addition, as shown here, linking the GTA and CAR is challenging and means that some properties will remain unaccounted. Although some states, such as Pará, have issued decrees mandating the inclusion of the CAR number in GTAs, implementation remains limited. ADEPARA reported that only 20% of GTAs currently include a linked CAR (AdT, 2024).

Finally, to effectively eliminate deforestation in the beef supply chain, it will be imperative to implement or introduce new incentives or pressures that can drive large-scale cooperation between private and public sectors. For example, starting in 2025, the Brazilian Federation of Banks' (Febraban) will require slaughterhouses to implement traceability and monitoring of direct and indirect suppliers to obtain credit (Febraban, 2023). If implemented effectively, this commitment could become the crucial lever that shifts the balance toward a more sustainable and transparent cattle supply chain in the country. Only through coordinated efforts and robust policy measures can we achieve sustainable and deforestation-free agricultural practices.

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Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

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