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The Role of High-Volume Ranches as Cattle Suppliers: Supply Chain Connections and Cattle Production in Mato Grosso

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Abstract: Brazil's zero-deforestation Cattle Agreements (CAs) have influenced the supply chain but their impact on deforestation has been limited in part because slaughterhouses monitor deforestation only on the properties they buy from directly. Consequently, deforestation continues to enter the supply chain indirectly from properties that are not monitored. Knowledge gaps and data limitations have made it challenging to close this loophole and achieve meaningful reductions in deforestation. Here we leverage our large property-level supply chain database that links together six years of records from the Animal Transport Guide (GTA), high-resolution satellite data, property boundaries, and land cover data to quantify different types of supply chain connections and characterize cattle production in Mato Grosso. We find that a relatively small number of high-volume suppliers—defined as the top 5% of cattle suppliers in terms of the volume of cattle sold–supplied 50–60% of the total volume purchased by major slaughterhouses. One-fourth of high-volume direct suppliers cleared forest between 2009–2018, and 90% of them also bought from indirect suppliers with deforestation, leading these high-volume direct suppliers to act as funnels for deforestation into the supply chain. Because they serve as important hubs in the supply chain, high-volume suppliers may represent a key starting point to expand the CAs to cover large numbers of indirect suppliers.

Keywords: cattle supply chain; Amazon; deforestation; high-volume cattle suppliers

1. Introduction

The expansion of ranching in the Amazon and Cerrado biomes began in the 1960s when governmental plans to occupy forested frontiers up to the North of Brazil encouraged private companies and colonizers to establish properties and raise cattle [1,2]. Since that time, expansion of ranching, spurred by prospects of land speculation, significant profits, and the low level of investment required has engulfed millions of hectares of savannas and forests, as well as sparked large numbers of social conflicts [3–6].

In the last three decades, Brazil's cattle stocks have almost doubled, and beef exports have increased from 2.8 thousand tons in the 1980s to 2.02 million tons in 2020. At the same time, the area covered by pastures expanded by 70% in the Amazon and 12% in the Cerrado [7–9]. This aggressive expansion has led to increased rates in deforestation that, after an alarming peak of 27.7 km^2 in 2004, triggered the implementation of several legal measures including the declaration of protected areas, command-and-control operations, embargoes of properties, and implementation of mandatory registration in the Rural Properties Environmental System [8,10,11].

More recently, anti-deforestation efforts have focused on commodity-specific drivers [12]. As part of this push, the Zero-Deforestation Cattle Agreements (CAs), first signed in 2009, committed major meatpackers operating in the Amazon biome to monitor supplying properties and block deforestation in their supply chain [13,14]. The Zero-Deforestation Cattle Agreements include the G4 agreement–a voluntary commitment of the industry to monitor

and block suppliers with deforestation and the TACs-the terms of adjustment of conduct–that are legal agreements under the public prosecutor offices defining obligations and sanctions to offenders. Additionally, the public prosecutor office recommended retailers to avoid purchasing from slaughterhouses supplied by properties caught deforesting [13,15]. The CAs led to some progress in terms of improving governance in the supply chain: properties that sold directly to slaughterhouses rapidly registered their property boundaries and the portion of them with deforestation declined significantly. However, deforestation has continued in the cattle supply chain due to ample opportunities for leakage and laundering [16,17]. Given the dominant role of ranching in driving Amazon deforestation, addressing the limitations of the CAs is critical as deforestation rates begin to rise again: more than doubling from the lowest recorded rate of 451.7 thousand hectares in 2012 to 1.1 million hectares in 2021 [17].

Leakage from the CAs occurs in large part due to their limited geographic scope and the complexity of cattle supply chains in the Brazil. For example, only around half of all slaughterhouses operating in the Amazon biome have signed the CAs, which allows cattle from deforested properties to easily flow into the market through non-CA plants [13,15,18]. Additionally, properties that should be under the CA can sell to slaughterhouses operating outside the Legal Amazon, which are not required to monitor their suppliers. Cattle laundering—intentionally concealing the origin of cattle, by physically or virtually moving animals from a non-compliant property to a compliant one—has also been identified as a strategy of ranchers to avoid sanctions and represents a major weakness of CAs [13]. Finally, because the monitoring systems assess only those properties that directly supply cattle to slaughterhouses, the majority of properties that participate in the supply chain as indirect suppliers are not under any scrutiny.

Identifying more efficient and effective strategies to tackle deforestation in the cattle supply chain requires increasing our understanding of its structure, or the connections and flow of cattle involving direct suppliers, their indirect suppliers, and buyers, through which deforestation enters the supply chain, and of cattle production systems and how these may support their roles as high-volume suppliers or instead indicate cattle laundering. We focus on the role of high-volume suppliers as major hubs in the cattle supply chain [18]. A relatively small group of high-volume properties, which we define as the 5% of properties supplying the highest number of heads to SIF plants, comprise a set of fewer than two thousand properties that supply between 50 and 60% of all cattle processed by SIF slaughterhouses each year. Trading millions of heads of cattle to slaughterhouses, high-volume suppliers also funnel hundreds of thousands of hectares of deforestation into the market [18].

We used a database based on six years of records from the Animal Transport Guide (GTA), satellite imagery, and land cover data to investigate the supply chain connections and cattle production of high-volume suppliers in the state of Mato Grosso. As a first step, we used the GTA data to identify high-volume suppliers by summing the volume of cattle sold to SIF slaughterhouses—both annually and throughout the entire period between 2013 and 2018—and identifying the top 5% properties that supplied the highest volumes; together, these properties accounted for 51–60% of all cattle purchased by SIF plants. We quantified the inflow (cattle purchase) and outflow (cattle sales) of these high-volume suppliers and analyzed trends over time to understand their role in the supply chain. As a second step, we used high-resolution satellite imagery, the GTA, and land cover data to characterize high-volume supplier properties by classifying cattle raising systems, estimating productivity, and quantifying deforestation. We complemented this characterization by assessing the spatial distribution of high-volume suppliers across biomes and classes of property size. As a final step, we summarize the unique role and characteristics of high-volume suppliers and provide recommendations to address the CAs' weaknesses.

2. Materials and Methods

2.1. Study Area

Spread over three different biomes (Amazon, Cerrado, and Pantanal), the state of Mato Grosso (MT) is a powerhouse of agricultural commodities in Brazil (Figure 1). With an area of more than 90.3 million ha, MT is a core region of cattle production, concentrating 14% of the national herd (30.1 million heads of cattle) [19]. Slaughterhouses with federal sanitary inspection (SIF) dominate the cattle sector in this state and slaughtered 85% of cattle between 2013 and 2018.
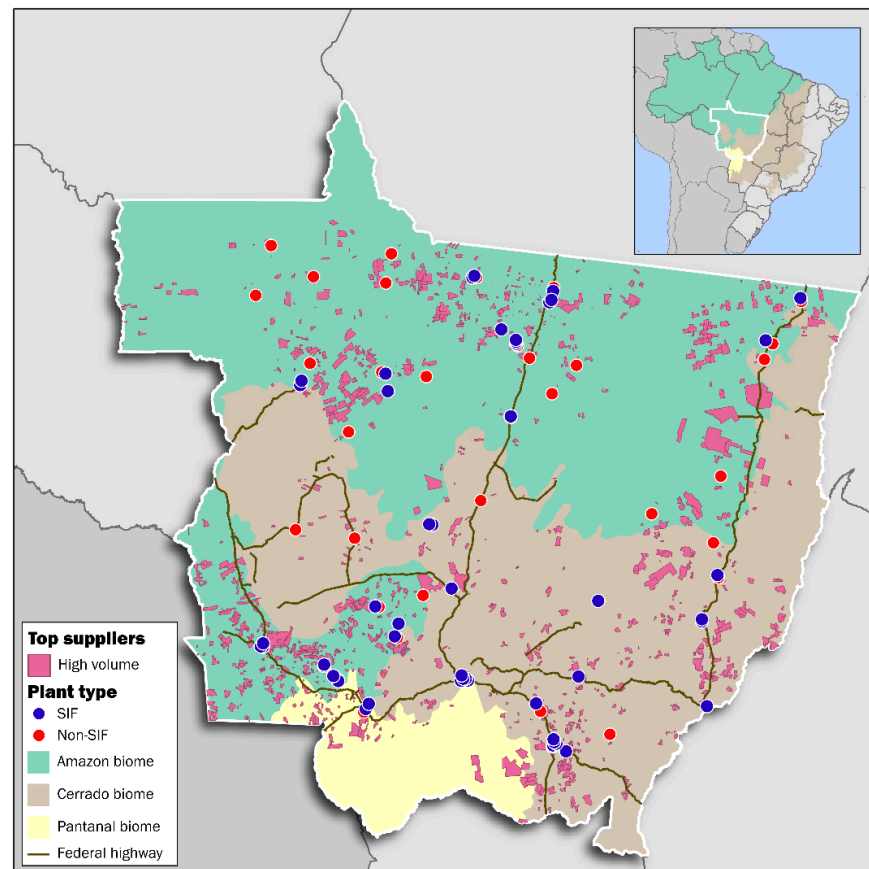

Figure 1. Study area showing the distribution of high-volume properties, and infrastructure of federally (SIF) and non-federally inspected (non-SIF) slaughterhouses and main roads.

2.2. Defining and Identifying High-Volume Suppliers Using the GTA

Among other information about the movement of cattle, the GTA provides details about the originating property, the purpose of the movement–rearing, fattening, and slaughter–and the destination of the cattle involved in the transaction. Using these data, we identified 29,649 properties that together supplied 26.7 million heads to SIF plants between January 2013 and December 2018. We identified high-volume suppliers by ranking properties according to the total number of heads supplied to SIF plants between 2013 and 2018 from highest to the lowest and then selected the top 5% of properties; together these properties supplied 60% of all volume purchased by SIF plants during the study period. When we applied this same threshold to the list of properties ranked using data for individual years, we found that over the time-period the 5% of properties corresponded between 51 to 56% of volume supplied to SIF each year.

We then used our database that links the properties registered in the GTA with property boundaries available in the datasets of the federal land cadaster system (Brazilian National Land Tenure Agency-INCRA) and federal rural environmental registry (Portuguese acronym: SiCAR) using a collection of matching rules that look for similarities

across attributes native to the datasets (e.g., farm names, "código origem" in the GTA) and property boundaries [18,20]. We were able to match property boundaries to the GTA data of 76% of high-volume suppliers, 57% of their suppliers (properties that sold cattle to them) and 56% of their buyers (properties that bought cattle from them).

2.3. Trends and Supply Chain Connections

To better understand the roles of high-volume suppliers in the cattle supply chain, we used our GTA database to track and quantify the accumulated volume of cattle sold (outflow) and purchased (inflow) based on the following transaction types (Figure 2):

1. Direct sales to SIF plants–volume of cattle directly supplied by high-volume properties to 50 SIF plants in Mato Grosso and 42 SIF plants in other states.
2. Direct sales to non-SIF plants–volume of cattle supplied by high-volume properties to 16 plants with state inspection (14 in MT and two in other states), and 164 plants with municipal inspection or uninspected (85 in MT and 79 in other states).
3. Indirect sales–volume of cattle that high-volume properties purchased from 28,554 other properties (hereafter suppliers) or cattle that high-volume suppliers sold to 12,168 other properties (hereafter buyers).
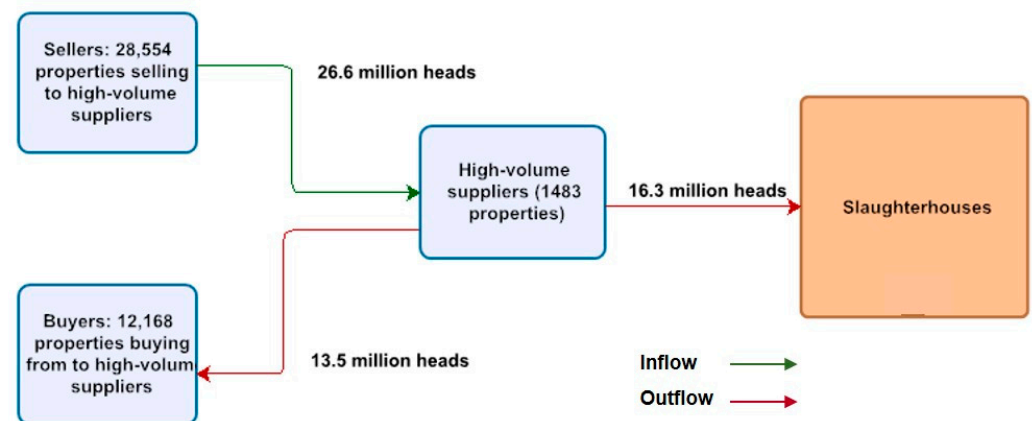

Figure 2. Structure of the cattle supply chain analyzed including the connections of high-volume suppliers.

2.4. Characterizing High-Volume Suppliers: Biomes, Cattle Production, and Deforestation

We characterized land use on the 1126 high-volume suppliers and the 30,770 properties connected to them either as buyers or suppliers that we could link to property boundaries. This expanded dataset was also used to assess the spatial distribution of high-volume suppliers, their buyers and suppliers across biomes.

2.4.1. Cattle Production in High-Volume Suppliers

We used images with a resolution of three meters from Planet [21], dated between 31 January 2020 to February 2021, to classify cattle production systems in high-volume suppliers. Because the resolution of Planet imagery makes it difficult to discern specific structures or land covers using the Planet imagery, we used Google Earth images as an additional resource. To keep the classification consistent though we used both platforms to classify all properties and compared the results. When the classifications differed, we gave preference to the classification using Google Earth, if images covered the whole property and were dated after January 2017. Three properties were excluded from our analyses because there were no images available on Planet or Google Earth that fit the criteria mentioned above.

All properties were classified by one technician who inspected images and classified systems observing the following cattle production systems:

1. Cattle confinement–Properties where structures such as corrals, silage, and warehouses indicate that cattle can be confined.
2. Extensive–Properties where no structures indicating cattle confinement were visible. The existence of pastures as the only land-cover indicates that cattle production is based exclusively on grazing.
3. Integrated crop-livestock system–Properties where a combination of pastures and crops was detected indicating that an integrated system of crop-livestock production was in place.
4. Mixed–Properties where a combination of characteristics of the above-described systems was detected. Usually, pastures and crops combined with structures to confine cattle best describe this class.
5. Non-cattle systems–Properties covered by forests with no structures or land-cover indicating cattle production has ever taken place.

To characterize cattle productivity in high-volume suppliers, we estimated the cattle outflow per ha per year (hereafter cattle level outflow) and the extent of pasture degradation. In these estimates, we used the area of properties, the cattle stocks provided by the GTA data, and the area covered by degraded pastures from the Atlas of Brazilian Pastures for 2017 (Lapig/UFG) [22]. We calculated the cattle outflow level using the accumulated volume supplied by high-volume properties in all operations i.e., directly supplied to SIF and non-SIF, and indirectly supplied to other properties per area of property per year. To estimate the extent of pasture degradation, we quantified the percent of pastures classified by Lapig as degraded relative to the total area of pasture in high-volume supplier properties.

2.4.2. Deforestation

To quantify deforestation on high-volume properties and their suppliers, we used INPE's PRODES-Legal Amazon and PRODES-Cerrado annual deforestation maps for 2009–2018. PRODES-Legal Amazon has partial coverage of the Cerrado biome portion of Mato Grosso, and to fill in the areas not covered by these data, we used PRODES-Cerrado. Deforestation was quantified considering all deforested polygons larger than 6.25 hectares with more than 50% of its area located within the property's boundary. The 1514 properties (high-volume suppliers, their suppliers, and buyers) located in the Pantanal biome were excluded from this analysis.

2.4.3. Size of Properties

We analyzed the size of high-volume suppliers and assessed characteristics across different property size classes. We structured the data based on the Brazilian land tenure legislation that identifies properties as small, medium, and large according to the number of fiscal modules. The fiscal module is defined for municipalities; in Mato Grosso 82.3% of municipalities have fiscal modules between 80 and 100 hectares (83.62 ± 14.11). Accordingly, we adopted 100 hectares as the standard fiscal module in Mato Grosso and classified properties as small ($\leq$400 hectares), medium (>400 and $\leq$1500 hectares), and large (>1500 hectares).

3. Results

3.1. Trends and Supply Chain Connections of High-Volume Suppliers

High volume suppliers sold a disproportionate amount of cattle for slaughter but the number of cattle sold by these properties each year varied widely. Properties supplying more than 20 thousand heads per year were also few (less than 13 in a given year) but particularly important in the supply chain, supplying between 5–9% of the overall volume to SIF plants each year. Most high-volume suppliers were in the Amazon biome portion of Mato Grosso (61% of high-volume suppliers) and together they sold 53% of cattle supplied by high-volume suppliers to SIF plants. Nearly one-third of high-volume suppliers were

located in the Cerrado biome and these sold 37% of cattle supplied by high-volume suppliers to SIFs (Figure 3).
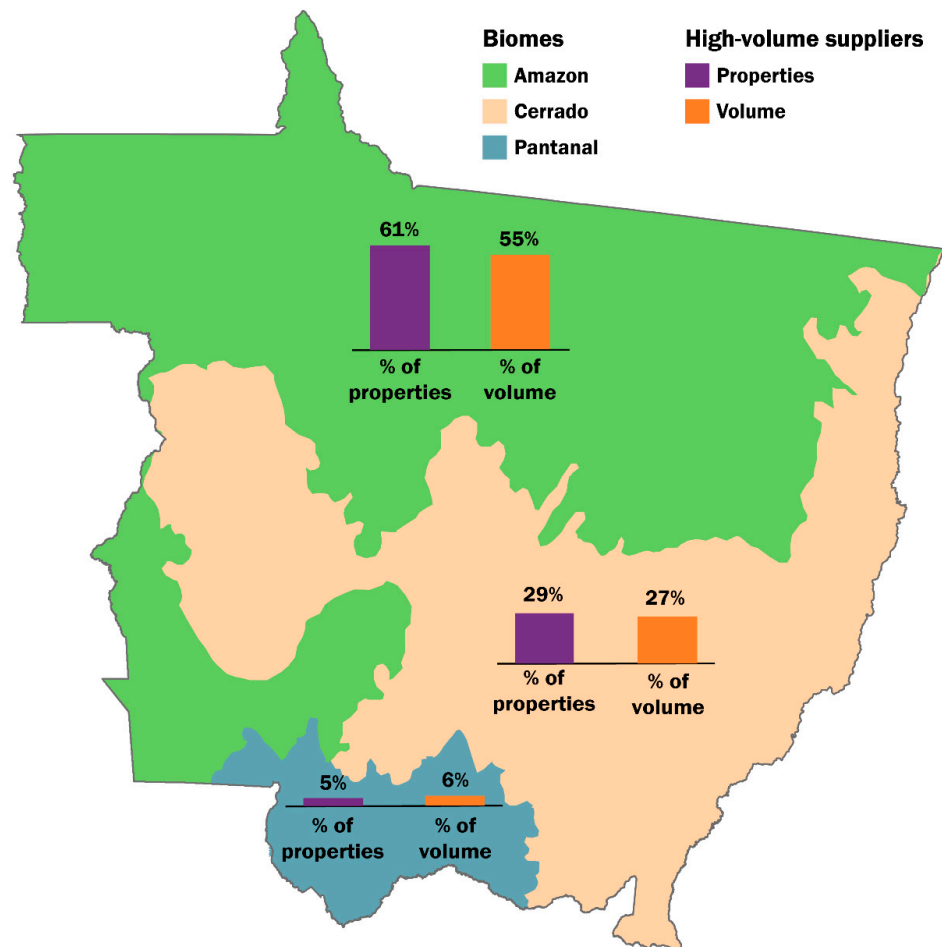

Figure 3. Distribution of high-volume suppliers and their suppliers and buyers across the three different biomes of Mato Grosso State in percent of number of total properties and area.

More than half of high-volume suppliers sold cattle to a SIF plant in only 1–2 years during the 6-year study period, meaning that these high-volume suppliers are not responsible for constantly providing the slaughterhouses access to cattle. Another 17% of the properties sold to SIF slaughterhouses in all six years (Figure 4a); these properties may be particularly important for maintaining the supply of cattle to major slaughterhouses—they were also the largest contributors to SIF slaughterhouses in terms of volume (11% of total volume supplied) (Figure 4b).

Most high-volume suppliers (50% or 742 properties) sold directly to SIF and non-SIF slaughterhouses as well as to other properties. Only 1.5% of all high-volume suppliers (22 properties) directly supplied SIF plants exclusively, and less than 0.5% (5 properties) supplied both SIF and non-SIF plants but did not ever sell to other properties. High volume suppliers in the Amazon were particularly prolific suppliers of cattle to all market connections; relative to those in the Cerrado, high-volume suppliers located in the Amazon supplied 30% more cattle to SIF plants, 60% more to non-SIF plants, and 42% more as indirect suppliers to other properties (Table S1). All SIF plants supplied by high-volume suppliers participated in CAs but less than half (40.6%) of high-volume suppliers sold to CA plants exclusively.
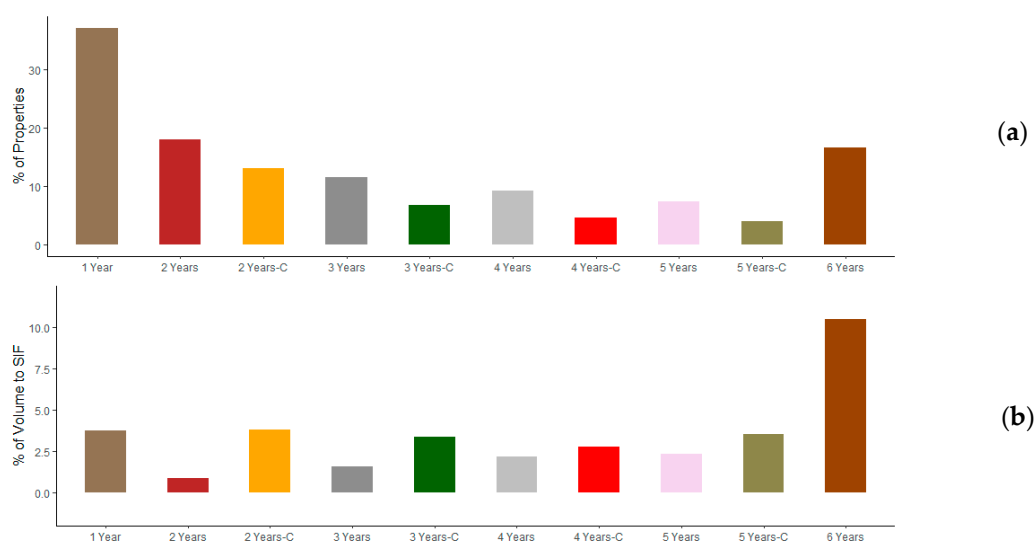
Figure 4. Categories of high-volume properties according to the number of years supplying to SIF plants in (**a**) Percent of properties; (**b**) Percent of volume supplied. C-consecutive years.

High-volume suppliers also purchased large numbers of cattle from many different properties. During our study period, Mato Grosso's high-volume properties (based on the total volume supplied to SIF in six years) had 15.1 ± 21.8 suppliers per year and purchased 24.6 million heads (twice the volume supplied to SIF plants) in the period. Most high-volume suppliers (69%) purchased from between 1 and 20 other properties each year; almost one-fourth were supplied by 20 or more other properties and fewer than 3% had one or no suppliers per year.

Similar trends were seen in annual sets of high-volume suppliers that were supplied by, on average, 18–21 other properties and took in from 2.5–2.8 million heads/year. More than half of all annual high-volume suppliers had between 1 and 20 indirect suppliers, and the percentage of properties being supplied by one or zero other properties did not exceed 7% in any year. Both indirect suppliers and annual high-volume suppliers were concentrated in the Amazon biome

3.2. Cattle Production in High-Volume Suppliers

The extensive system prevailed among high-volume suppliers and 71.3% of properties relied exclusively on pastures that covered ~3.1 million hectares across their properties. The remaining third of properties adopted intensive strategies to raise cattle that included cattle confinement, the integrated crop-livestock system (ICLS), or a combination of both (mixed system) (Figure 5). The ICLS was the intensive system most adopted (14.9% of properties) (Figure 5a), followed by cattle confinement (8.1% of properties) and the mixed system (4%) (Figure 5b,c). Fewer than 2% of properties were classified as non-cattle systems, meaning they were completely covered by forests or crops, in which case no structures indicating cattle production were identified (Figure 5d).

The highest volume of cattle per property was supplied by high-volume suppliers under the mixed system (ICLS and confinement structure) (23.4 ± 25.4 thousand heads); high-volume suppliers under the extensive system supplied the lowest volume to SIF plants ($p < 0.001$) (Table S2).

The cattle outflow level for high-volume suppliers was on average 6.62 ± 28 but ranged from less than 1 to as many as 400 heads/hectare/year. High-volume supplier properties under the extensive system and those with structures to confine cattle had the highest cattle outflow levels (7.62 ± 30.16 vs. 6.27 ± 22.5 heads/ha/year) but differences between systems were not significant (Figure 6a).
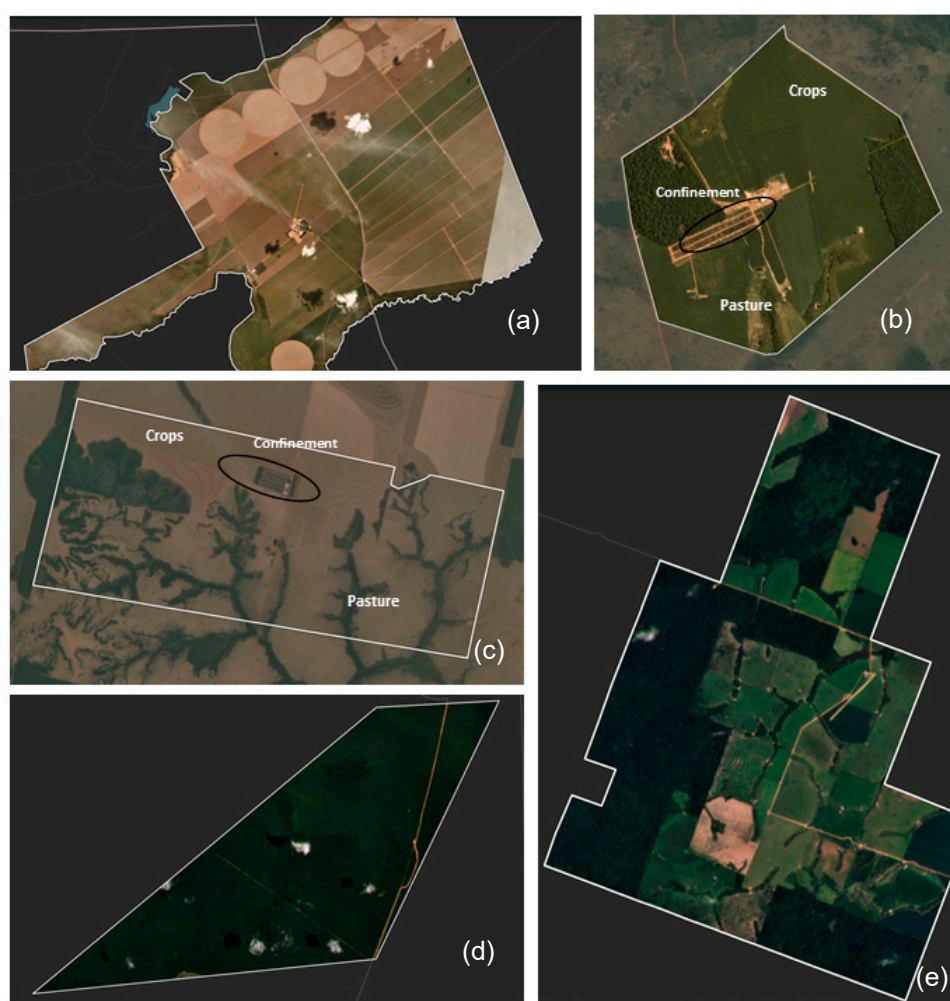
Figure 5. Cattle production systems on high-volume suppliers classified based on satellite imagery. (**a**) Integrated Crop-livestock System (ICLS); (**b**,**c**) Mixed System-ICLS and structure for cattle confinement; (**d**) Not cattle productive system; (**e**) Extensive system.
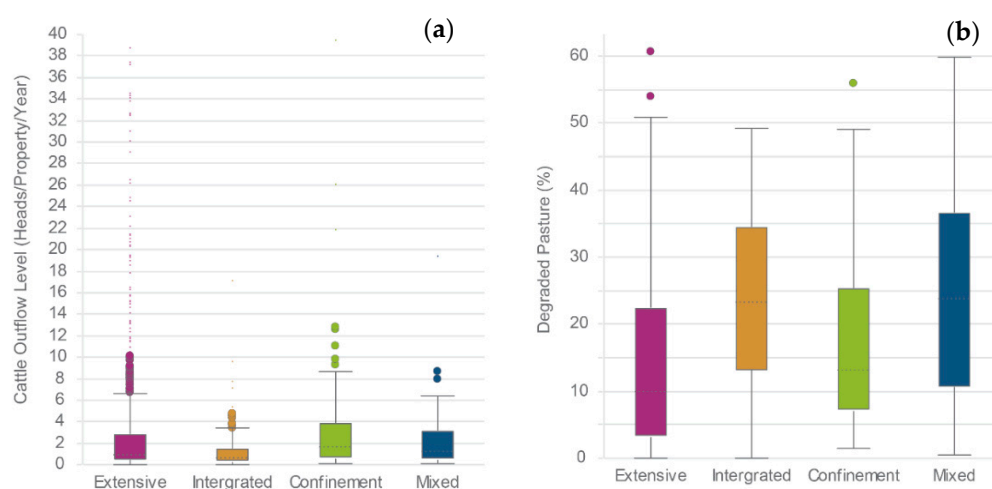

Figure 6. Complementary variables used to characterize cattle production in high-volume suppliers (**a**) cattle outflow level and (**b**) degraded pasture.

Between 14–25% of pastures on high-volume supplier properties had degraded pastures (2017) (Figure 6b). High-volume suppliers under the extensive system and those

having structures to confine cattle presented the lowest levels of pasture degradation (14–17% of total area of pasture), while properties under the mixed system were most affected (24.6 ± 15.8%); differences were significant.

3.3. Deforestation on High-Volume Suppliers and Their Suppliers

Between 2009 and 2018, deforestation on high-volume properties totaled 28.1 thousand hectares (25 ± 133.2 hectares/property). High-volume suppliers in the Cerrado cleared 60% more vegetation than those in the Amazon (19.8 versus 8.3 thousand hectares). The area deforested per property was smaller under the extensive system (17.7 ± 101.3 hectares/property) and higher in properties adopting the ICLS (62.6 ± 246.1 hectares/property) ($p < 0.0001$).

Suppliers to high-volume suppliers cleared 747.2 ± 1.5 hectares per property, totaling 320 thousand hectares, which is 10 times more deforestation than we identified on the properties of the high-volume suppliers. Suppliers of high-volume suppliers cleared 50% more vegetation in the Cerrado than in the Amazon (194.5 versus 127.8 thousand hectares), and the area cleared per property was also larger (438.2 ± 1320.5 versus 308.9 ± 604.7 hectares per property). Suppliers to high-volume suppliers that sold to both CA and non-CA plants had more deforestation than suppliers of properties that sold exclusively to CA plants (30% more in the Amazon and 75% more in the Cerrado).

3.4. High-Volume Suppliers and the Size of Properties

High-volume suppliers are predominantly large properties (47% were above 1.5 thousand hectares; the average size was 4.8 ± 9.2 thousand hectares) but the size of properties did not constrain participation in this group. Although large properties were the main SIF suppliers (47% of the total volume supplied by high volume suppliers), small and medium high-volume suppliers sold one-fourth of all volume purchased by SIF plants. One-fourth of all volume purchased by non-SIF plants came from small high-volume suppliers that, on average, supplied more cattle per property to these facilities than large high-volume suppliers (973.8 ± 4.46 thousand versus 373.6 ± 1.1 thousand heads per property). The majority of suppliers to and buyers from high-volume suppliers were small properties: almost 80% of suppliers of high-volume suppliers (104.7 ± 92.71) and 60% of high-volume suppliers' buyers (132 ± 102.1) had less than 400 hectares.

Intensification and deforestation both increased with the size of properties. Less than 12% of small high-volume suppliers had intensive systems, while 30% of medium and 42% of large properties adopted intensive strategies. Nearly all deforestation (94%) occurred on large properties (38.03 ± 167.8 hectares per property). Suppliers of high-volume suppliers smaller than 400 hectares cleared more vegetation in the Amazon compared to suppliers of high-volume suppliers in other classes of size ($p < 0.0001$) (Table S3). An important challenge with estimating the sizes of properties using our database is that ranchers typically register sales of cattle from a single registered parcel while producing the cattle across multiple parcels. Thus, we report here the size of the registered property from which the sale was reported, but the actual area used for production may vary in some cases.

4. Discussion

The central role of high-volume suppliers in the cattle supply chain points to opportunities to strengthen the CAs by focusing on these properties. For example, through their purchases that connect large numbers of other properties to slaughterhouses, high-volume suppliers funneled an additional 320 thousand hectares of deforestation into the market, beyond the 28.1 thousand hectares of deforestation that occurred on their properties during the study period. This amounts to more than 10 times the deforestation detected on their own properties. Because high-volume suppliers are few, but they frequently engage with other properties and sell large volumes of cattle to both non-CA and CA slaughterhouses. Engaging these properties directly in the CAs could expand the agreements reach and help reduce deforestation.

The plurality of roles played by most high-volume suppliers could give them the agility needed to easily evade monitoring under the CAs should they have deforestation on their own properties. More than half of high-volume suppliers sold cattle directly to both SIF and non-SIF slaughterhouses as well as to other properties. Thus, high-volume suppliers, and many other types of properties, are well-positioned to easily shift their role in the supply chain to avoid monitoring under the CAs given the established cattle laundering strategies adopted by ranchers to overcome restrictions imposed by slaughterhouses [13,15,17]. Indeed, less than half (41%) of high-volume suppliers in MT sold exclusively to CA slaughterhouses, which suggests that without additional efforts to expand the CAs to include both additional plants and more links in the supply chain, these high-volume suppliers are likely to continue to funnel large amounts of deforestation into Brazil's cattle supply chain.

Surprisingly, more than half of the volume of cattle sold by the high-volume suppliers in our study came from properties with extensive systems, showing that intensification of cattle production remains limited even among the largest cattle suppliers. The intensification that did occur among high-volume suppliers came primarily through the adoption of the integrated crop-livestock system by medium and large properties, and structures of confinements in properties of all sizes. The expansion of soy and corn has increased as adoption of Integrated Crop Livestock Systems (ICLS) has expanded in Mato Grosso: as of 2015, an estimated 500,000 hectares were managed under ICLS [23,24]. However, the implementation of ICLS requires significant investment, expertise, and technology, which could explain why this management strategy is mostly restricted to large properties. Confinements, on the other hand, were adopted by ~8% of properties, and were not concentrated on properties of any particular size. New approaches and incentives to intensify these systems will be needed given that nearly a quarter of the pasture area on high-volume suppliers was degraded.

5. Conclusions

Improving the operations of Brazil's cattle sector is a demanding task, be it by reinforcing CAs already in place or by expanding their scope. A major challenge that remains is improving the monitoring systems used by slaughterhouses to reduce opportunities for cattle laundering. The Federal Public Prosecutors and other CA stakeholders have made some progress in addressing both of these challenges, but the large footprint of Brazil's cattle sector and the number of producers involved continues to pose a challenge. Our results show that not all properties have the same importance in the cattle supply chain, suggesting that focusing on just the small number of properties that provide the largest volumes of cattle to slaughterhouses could help accelerate efforts to monitor more of the supply chain for deforestation.

However, the relationships between suppliers and slaughterhouses seem to be rather loose: most properties supplied to SIF plants in a single year out of six years. Cattle ranchers are also very diverse and versatile in their strategies of land use and trade; directly supplying to SIF slaughterhouses is just one of several trading possibilities available to these ranchers [17,25]. Thus, slaughterhouses may need new incentives to influence high volume suppliers to reduce deforestation on their own properties or to consider avoiding purchases from other properties with deforestation.

Further investigation about high-volume suppliers operating in other states of the Brazilian Amazon could be an important next step towards better understanding the cattle supply chain and strengthening environmental governance in the cattle sector. As major hubs of cattle operations this category of suppliers can provide unique insights and serve as a good starting point in terms of expanding the reach of the CAs. Policies that increase the accessibility of intensive production practices to smaller and less capitalized farms are also needed to provide alternatives to deforestation for both high volume suppliers to slaughterhouses and other properties that contribute cattle to the supply chain.

References

1. Hecht, S.B. Environment, Development and Politics: Capital Accumulation and the Livestock Sector in Eastern Amazonia. *World Dev.* **1985**, *13*, 663–684. [CrossRef]
2. Hecht, S.B. The Logic of Livestock and Deforestation in Amazonia. *BioScience* **1993**, *43*, 687–695. [CrossRef]
3. Lapola, D.M.; Martinelli, L.A.; Peres, C.A.; Ometto, J.P.H.B.; Ferreira, M.E.; Nobre, C.A.; Aguiar, A.P.D.; Bustamante, M.M.C.; Cardoso, M.F.; Costa, M.H.; et al. Pervasive Transition of the Brazilian Land-Use System. *Nat. Clim. Chang.* **2014**, *4*, 27–35. [CrossRef]
4. Bowman, M.S.; Soares-Filho, B.S.; Merry, F.D.; Nepstad, D.C.; Rodrigues, H.; Almeida, O.T. Persistence of Cattle Ranching in the Brazilian Amazon: A Spatial Analysis of the Rationale for Beef Production. *Land Use Policy* **2012**, *29*, 558–568. [CrossRef]
5. Walker, R.; Browder, J.; Arima, E.; Simmons, C.; Pereira, R.; Caldas, M.; Shirota, R.; Zen, S. de Ranching and the New Global Range: Amazônia in the 21st Century. *Geoforum* **2009**, *40*, 732–745. [CrossRef]
6. Arima, E.; Barreto, P.; Brito, M. *Pecuária Na Amazônia: Tendências e Implicações Para a Conservação Ambiental*; Imazon: Belém, Brazil, 2005.
7. Mapbiomas Brasil. Available online: https://mapbiomas.org/en (accessed on 12 September 2021).
8. Pacheco, P.; Poccard-Chapuis, R. The Complex Evolution of Cattle Ranching Development Amid Market Integration and Policy Shifts in the Brazilian Amazon. *Ann. Assoc. Am. Geogr.* **2012**, *102*, 1366–1390. [CrossRef]
9. Comex Stat. Available online: http://comexstat.mdic.gov.br/pt/home (accessed on 12 September 2021).
10. Börner, J.; Wunder, S.; Wertz-Kanounnikoff, S.; Hyman, G.; Nascimento, N. Forest Law Enforcement in the Brazilian Amazon: Costs and Income Effects. *Glob. Environ. Chang.* **2014**, *29*, 294–305. [CrossRef]
11. Börner, J.; Kis-Katos, K.; Hargrave, J.; König, K. PostCrackdown Effectiveness of FieldBased Forest Law Enforcement in the Brazilian Amazon. *PLoS ONE* **2015**, *10*, e0121544. [CrossRef] [PubMed]
12. Nepstad, D.; McGrath, D.; Stickler, C.; Alencar, A.; Azevedo, A.; Swette, B.; Bezerra, T.; DiGiano, M.; Shimada, J.; da Motta, R.S.; et al. Slowing Amazon Deforestation through Public Policy and Interventions in Beef and Soy Supply Chains. *Science* **2014**, *344*, 1118–1123. [CrossRef] [PubMed]
13. Barreto, P.; Gibbs, H. *Como Melhorar a Eficácia Dos Acordos Contra o Desmatamento Associado à Pecuária Na Amazônia?* Imazon: Belém, Brazil, 2015.
14. Gibbs, H.K.; Munger, J.; L'Roe, J.; Barreto, P.; Pereira, R.; Christie, M.; Amaral, T.; Walker, N.F. Did Ranchers and Slaughterhouses Respond to Zero-Deforestation Agreements in the Brazilian Amazon? *Conserv. Lett.* **2016**, *9*, 32–42. [CrossRef]
15. Armelin, M.J.C.; Carvalho, P.; Natália, B.; Grossi, T.B.R. *Terms of Adjustment of Conduct in Pará and the Public Commitment on Cattle Ranching the Importance of Beef Traceability in Reducing Deforestation in the Amazon*; Amigos da Terra: Porto Alegre, Brazil, 2020.

16. Alix-Garcia, J.; Gibbs, H.K. Forest Conservation Effects of Brazil's Zero Deforestation Cattle Agreements Undermined by Leakage. *Glob. Environ. Chang.* **2017**, *47*, 201–217. [CrossRef]

17. Pereira, R.; Rausch, L.L.; Carrara, A.; Gibbs, H.K. Extensive Production Practices and Incomplete Implementation Hinder Brazil's Zero-Deforestation Cattle Agreements in Pará. *Trop. Cons. Sci.* **2020**, *13*, 1940082920942014. [CrossRef]

18. Skidmore, M.E.; Moffette, F.; Rausch, L.; Christie, M.; Munger, J.; Gibbs, H.K. Cattle Ranchers and Deforestation in the Brazilian Amazon: Production, Location, and Policies. *Glob. Environ. Chang.* **2021**, *68*, 102280. [CrossRef]

19. Pesquisa Da Pecuária Municipal | IBGE. Available online: https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html?=&t=o-que-e (accessed on 21 September 2021).

20. Skidmore, M.; Moffette, F.; Rausch, L.; Gibbs, H.K. *Characterizing Compliance in Cattle Supply Chains: What Factors Encourage Deforestation-Free Production in the Brazilian Amazon?* Meridian Institute: Wahsington, DC, USA, 2020.

21. Planet | Homepage. Available online: https://www.planet.com/ (accessed on 21 September 2021).

22. Parente, L.; Mesquita, V.; Miziara, F.; Baumann, L.; Ferreira, L. Assessing the Pasturelands and Livestock Dynamics in Brazil, from 1985 to 2017: A Novel Approach Based on High Spatial Resolution Imagery and Google Earth Engine Cloud Computing. *Remote Sens. Environ.* **2019**, *232*, 111301. [CrossRef]

23. Merry, F.; Soares-Filho, B. Will Intensification of Beef Production Deliver Conservation Outcomes in the Brazilian Amazon? *Elementa* **2017**, *5*, 24. [CrossRef]

24. Gil, J.; Siebold, M.; Berger, T. Adoption and Development of Integrated Crop-Livestock-Forestry Systems in Mato Grosso, Brazil. *Agric. Ecosyst. Environ.* **2015**, *199*, 394–406. [CrossRef]

25. Carvalho, R.; de Aguiar, A.P.D.; Amaral, S. Diversity of Cattle Raising Systems and Its Effects over Forest Regrowth in a Core Region of Cattle Production in the Brazilian Amazon. *Reg. Environ. Chang.* **2020**, *20*, 44. [CrossRef]