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The risk of unintended deforestation from scaling sustainable livestock production systems

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Abstract

Silvopastoral systems (SPS)—production systems integrating trees, forages, and livestock within the same land area—are recognized as critical for reducing tropical deforestation and improving livelihoods, ecosystem services, and carbon sinks. Yet, research on how scaling SPS influences forest cover changes at large geographical scales is scant. Our study delves deeper into the interlinkages between scaling SPS and deforestation. In two surveys conducted among 144 Colombian Amazon livestock producers with traditional or SPS farms, we assessed changes in herd composition between 2016 and 2020. Results showed a change in herd composition, with fewer males and more cows/heifers, suggesting a shift toward specializing in milk production, which, with the appropriate environmental incentives and safeguards, would unlikely broaden deforestation. However, interlinkages between the dairy and beef value chains suggest that extra male cattle from SPS intensification would be moved for fattening as a source of beef to new pastures at the forest border. If SPS scaling interventions in the Colombian Amazon are to be truly deforestation-free, they need to be designed based on a clear understanding of the interlinkages between food and land systems. Therefore, policies advancing the livestock and land-use agenda must create mechanisms that support deforestation-free livestock intensification, based on biophysical and socioeconomic evaluations.

KEYWORDS

deforestation leakage, deforestation-free agriculture, environmental safeguards, scaling-out, silvopastoral systems, sustainable land use systems

1 | INTRODUCTION

The 19th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) reaffirms the importance of addressing the drivers of deforestation and forest degradation and recognizes that addressing such drivers may have implications for livelihoods (UNFCCC, 2014). In such contexts, the widespread adoption of sustainable land use systems (SLUS), such as agroforestry and silvopastoral systems (SPS), is seen as critical to reducing deforestation for both biodiversity conservation and climate change mitigation. Research has demonstrated the immense potential of SLUS to serve as important carbon sinks and deliver both livelihood improvements and ecosystem services in tropical forest environments. However, the possible unintended repercussions on forest cover from scaling SLUS warrant further examination.

We posit the need for a careful assessment of the potential effects of SLUS on forest cover, from the perspective of the deforestation drivers that each specific SLUS aims to address, before concluding that the scaling of SLUS will provide solutions toward reducing deforestation and forest degradation. To illustrate our argument, we present the findings of a study undertaken to inform strategies for scaling SPS among smallholder livestock producers in the Colombian Amazon. SPS integrate trees, forages and intensive livestock production within the same unit area of land (Calle et al., 2013). Even though SPS have proven to be economically, socially, and environmentally beneficial at the farm level, adoption remains low in Colombia and elsewhere (Tapasco, Fraçois LeCoq, Ruden, Sebastián Rivas, & Ortiz, 2019).

SPS have received growing attention in both environmental and nonenvironmental circles. Donor countries and multilateral agencies expect scaling SPS in tropical countries to reduce pressures on forests, thereby reducing deforestation and contributing toward climate-change mitigation and ecosystem conservation (Lerner, Zuluaga, Chará, Etter, & Searchinger, 2017; World Bank, 2019). This expectation is reflected in the Joint Declaration of Intent (JDI) signed in December 2019 at the COP25 climate summit in Madrid by the governments of Colombia, Germany, Norway and the United Kingdom, in which the three European countries committed result-based payments to Colombia to reduce deforestation (BMU, 2019). Despite the importance of this collaboration, potential unintended effects on forest cover from scaling of SPS in the Colombian Amazon remain empirically unexplored.

Lerner et al. (2017) highlight the capacity of SPS to drive either deforestation or forest regrowth depending on what land cover the SPS replace (traditional livestock systems vs. forests) and the conservation strategies in place to avoid undesired land use changes. Results from previous studies, usually performed at a small or pilot scale, indicate that SPS present positive farm-level results in economic and environmental terms (Chará et al., 2017; Mancera et al., 2018). Results also indicate that SPS increase production outputs, improve cow fertility and drive farm-level changes in herd composition and size (Nahed-Toral, Valdivieso-Pérez, Aguilar-Jiménez, Cámara-Cordova, & Grande-Cano, 2013; Sierra-Montoya, Barahona-Rosales, & Ruiz-Cortés, 2017). Consequently, Lerner et al. (2017) propose farm-level and larger-scale conservation strategies that can be used to avoid undesired land cover transitions due to farm-level changes in the herd size and composition, and achieve forest and biodiversity conservation goals.

Consistently, project developers are integrating conservation agreements, in which farmers commit to conserving forest remnants as a prerequisite to receiving technical and financial assistance for implementing SPS. The expectation is that such agreements will support the transition from traditional livestock systems to more efficient and productive ones, and avoid on-farm deforestation due to increases in livestock herds. However, conservation strategies and environmental safeguards to mitigate the risk of unintended deforestation at larger geographical scales have not yet been integrated into these agreements. In part, this is because greater adoption of SPS and longer-term impact studies are needed to understand how scaling these systems may influence forest-cover changes. Therefore, a theoretical and empirical understanding of the risks of unintended deforestation from investments for scaling SPS and recommendations to mitigate those risks is missing from the literature.

The present study therefore contributes to closing that gap by providing an improved understanding of how the aggregated effects of farm-level changes in herd composition from broader SPS adoption may influence forest cover changes at large geographical scales. We hypothesize that scaling SPS in the Colombian Amazon, as per the aim of the JDI, will drive farm-level changes in herd composition. This is likely to result in an increase in animal production, which in turn increases the number of lactating cows and fattening animals at a larger scale—a portion of which risk being moved to pastures at the forest frontier *to be fattened for* beef production, possibly fuelling deforestation, particularly if investments target farmers who produce milk and sell calves, males, or fattening animals for beef production, rather than beef producers (FEDEGAN, 2018). To explore this hypothesis, we surveyed 144 livestock producers with traditional or SPS farms (SPSF) in the Department of Caquetá in the Colombian Amazon, to assess changes in herd composition associated with SPS adoption. Our paper presents the interlinkages between deforestation and livestock rearing, as well as the current geographical distribution and mobility of milk and beef production in Caquetá. We also discuss the risks of unintended deforestation in the Colombian Amazon due to the aggregated effects of farm-level changes in herd composition from broader SPS adoption, and propose strategies to mitigate those risks, to make the adoption process deforestation-free.

2 | METHODS

Caquetá was chosen as a case study as it is one of the departments with the highest deforestation rates in Colombia. Our findings are based on results from surveys conducted among smallholder livestock producers from four municipalities of the Department of Caquetá: Albania, Morelia, Belén de los Andaquies, and San José del Fragua. We surveyed a total of 144 smallholder livestock producers to gather baseline data on their production systems in 2016. We surveyed them again in 2020 to identify differences in herd composition between SPS and traditional farms (TF). We classified the cattle farms into three groups: TF, SPSF, and advanced SPSF (ASPSF). TF feature traditional extensive cattle grazing techniques with either natural or improved pastures. SPSF integrate, at a minimum, assisted, or natural regeneration of trees, combined with either natural or improved pastures. ASPSF refer to SPSF that, in addition to regenerating trees, integrate other practices in the production system, such as fodder banks, trees lines, rotational grazing and livestock aqueducts. Results were obtained through univariate analysis techniques using the mean difference in key variables at different adoption levels. The statistical procedure used for this analysis was a *t* test. We used the TF as a base and compared SPSF and ASPSF with that group.

Meanwhile, municipal-level data from the Colombian Agricultural and Livestock Institute (ICA (ICA, 2019) on livestock by age and gender group (for the period 2008–2018) and livestock transport guides detailing municipal origin and destination of livestock transportation (for the period 2017–2019) were analyzed to understand the current geographical distribution of milk and beef production and current livestock mobility dynamics, respectively.

3 | RESULTS

3.1 | Farm-level changes in herd composition

Within the 4-year study period, results indicate that farmers in the SPSF group decreased the number of male cattle (1–3 years of age) in the herd (from 1 to 0.7; $p = .06$) and increased the number of lactating cows (from 0.7 to 2.5; $p = .08$), suggesting that this farming group, over time, may be aiming to specialize in milk production (Table 1). Moreover, surveyed farmers in the SPSF group ($n = 45$) increased the size of the cattle herd (from 3 to 7 heads; $p = .26$) and increased the number of calves (from 0.2 to 1.5; $p = .26$) compared with farms with "traditional" grazing SPS techniques ($n = 99$). This is consistent with previous studies reporting that integrating trees and grasses produces shade and reduces heat stress, thus reducing animal anxiety and providing higher-quality, varied diets, which in turn have positive effects on cow fertility and boost milk production levels (Broom, Galindo, & Murgueitio, 2013; Chará et al., 2017).

TABLE 1 Changes over time (2016–2020) in average herd composition by adoption group

	Average number of animals				
	TF *N* = 99	SPSF *N* = 45	*t*-Test (*p*-value) (TF)-(SPSF)	ASPSF *N* = 27	*t*-Test (*p*-value) (TF)-(ASPSF)
Cattle total	2.99 (23.8)	7.33 (20.0)	.258	10.2 (16.2)	**.070***
Dry cows (>3 years)	−0.19 (5.96)	1.02 (7.36)	.335	1.89 (7.65)	.199
Lactating cows (>3 years)	0.67 (7.33)	2.47 (4.67)	**.078***	2.59 (4.29)	**.086***
Heifers (1–3 years)	1.14 (7.19)	2.73 (11.9)	.408	3.41 (11.2)	.325
Calves (0–1 year)	0.23 (7.72)	1.53 (5.73)	.262	2.37 (3.48)	**.040****
Males (1–3 years)	1.04 (7.02)	−0.71 (3.88)	**.057***	−0.44 (3.42)	.128
Males (>3 years)	0.10 (0.75)	0.29 (0.87)	.214	0.41 (0.75)	**.066***
Cattle total/total farm Ha	0.16 (0.72)	0.16 (0.69)	.984	0.26 (0.53)	.445

Note: $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$; () *SD*.
Abbreviations: ASPSF, advanced SPS farms; SPSF, silvopastoral system farms; TF, traditional farms.

Results also showed that such differences are greater between TF and those with advanced SPS ($n = 27$) and that the latter are able to produce more on less land (Table 1; Figure S1).

3.2 | Deforestation and the dairy and beef value chains in Caquetá

Livestock production, and particularly beef production, is reported as the main driver of deforestation in both Colombia and Caquetá (Castro-Nunez, Mertz, Buritica, Sosa, & Lee, 2017; Dávalos, Holmes, Rodríguez, & Armenteras, 2014). According to IDEAM (2019), the Department of Caquetá has the highest percentage of deforestation in the country (26.29%). In 2019, Caquetá's natural forest was reduced by 29,800 ha, equivalent to 14.1 Mt of CO_2 emissions (Global Forest Watch, 2020). Of the 16 municipalities in the department, three are part of the "deforestation arc," the term used for the 13 municipalities with the highest rates of deforestation in the country. Historic data on forest cover, from Global Forest Watch (2020), and livestock herd composition at the municipality level, from the Colombian Agricultural and Livestock Institute–ICA (2019), confirm the relationship between deforestation and livestock grazing at both Colombian Amazon and Caquetá levels (Figure 1). These data sets also indicate that municipalities of the Department of Caquetá—inside the deforestation arc—have higher percentages of fattening animals (composed of male cattle aged between 1 and 3 years) than cows (heifers and cows aged above 3 years), while municipalities outside the deforestation arc have higher percentages of cows compared to fattening animals (Figure 2). Specifically, data show that on average, between 2008 and 2018, 20% of the herds in municipalities outside the deforestation arc were composed of male cattle and 23% were heifers and cows. On the contrary, municipalities inside the deforestation arc were composed of 30% male cattle aged between 1 and 3 years and 19% heifers and cows aged above 3 years.

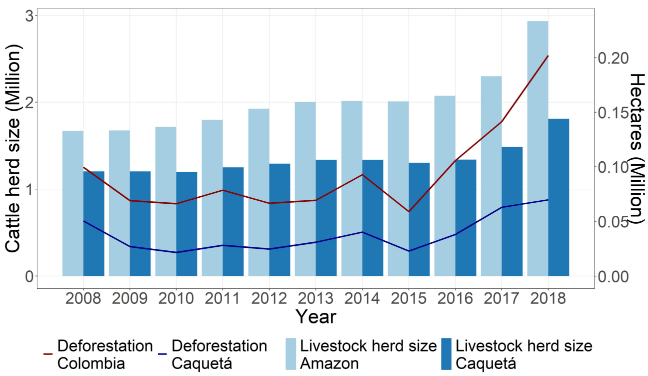

FIGURE 1 Relationship between deforestation and total livestock herd for the Colombian Amazon region and for the Department of Caquetá.
Source: (Global Forest Watch, 2020) and (ICA, 2019)

3.3 | Livestock mobility in Caquetá

According to ICA's mobility records, 381,710 fattening animals were transported from the Department of Caquetá between 2017 and 2019, corresponding to 17.29% of the total head of cattle transported in the department. In 2017, 37,982 fattening animals were transported from municipalities in the Department of Caquetá, while in 2018 and 2019, 177,325 and 166,403 fattening animals were transported, respectively. This coincides with the observed increase in deforestation in the department during the same period.

Although most of the fattening animals moved from the Department of Caquetá were transported to

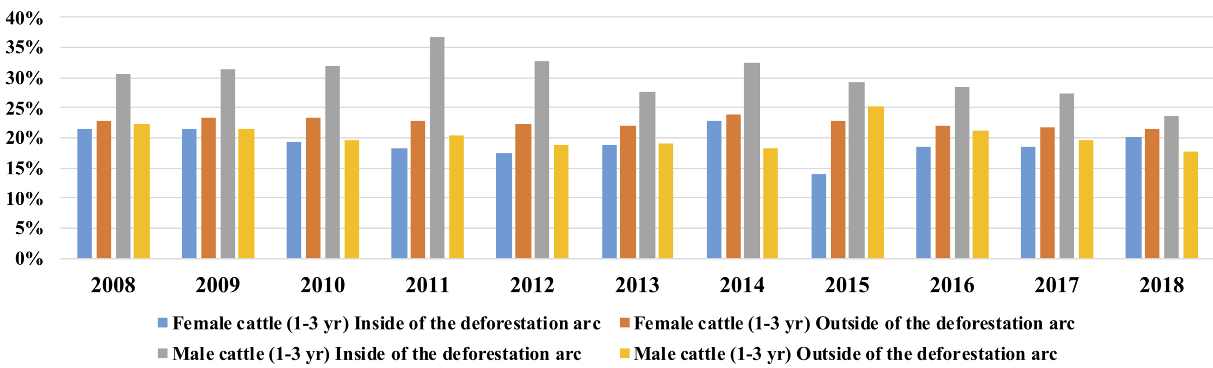

FIGURE 2 Difference in the percentage of fattening animals (males 1–3 years of age) and cows (1–3 years of age) with respect to the total livestock herd between municipalities in Caquetá inside and outside Colombia's "deforestation arc."
Source: (ICA, 2019)

municipalities outside the deforestation arc, a significant number were moved to municipalities inside the deforestation arc or moved among municipalities within the deforestation arc (Figure 3). Specifically, 50.45% of fattening animals transported from the Department of Caquetá had final destinations in 1 of the 13 municipalities inside the deforestation arc. The main destinations of fattening animals were the municipalities of San Vicente del Caguán (32.52%), Cartagena del Chairá (11.91%), and Puerto Rico (7.25%), all three of which are inside the deforestation arc. Meanwhile, most of the fattening animals transported from Caquetá originated from the municipalities of San Vicente del Caguán (41.38%), Cartagena del Chairá (11.06%), and Puerto Rico (10.91%). This may indicate that forest depletion in these three municipalities is caused by animals not originating there but that they are used as a fattening ground.

In the four municipalities where surveyed farmers were located, approximately 20,525 of 122,322 total movements corresponded to fattening animals. The municipal origins of these movements were mainly Albania (6,943); followed by Belen de los Andaquies (5,056); and Morelia (4,402). Of these movements, 3,300 corresponded to movements to one of the 13 municipalities inside the deforestation arc—mainly Puerto Guzman (30.94%), San Vicente del Caguán (29.79%), Cartagena del Chairá (14.64%), and Puerto Leguizamo (11.64%). The main destinations of fattening animals from Albania were Albania (19.78%) and Florencia (15.47%). However, they also had destination municipalities inside the deforestation arc, such as Puerto Guzmán in the Department of Putumayo (8.87%). The main destinations of fattening animals from Morelia were Florencia (28.90%), Morelia (10.95%), and San Vicente del Caguán (8.09%), with this last municipality being located inside the deforestation arc. Belen de los Andaquies moved fattening animals mainly to Florencia (18.47%), Belen de los Andaquies (16.08%), and San Jose del Fragua (6.47%). Meanwhile, San Jose del Fragua moved fattening animals to San Jose del Fragua (21.08%), Florencia (14.71%), and Albania (9.84%).

4 | DISCUSSION

Our study, involving a survey of small-scale livestock producers in the Colombian Amazon shows farm-level changes in herd composition that suggest a transition toward milk production among SPSF. These results support previous findings reporting that advanced SPS produce comparatively more on less land and in a more sustainable way than traditional livestock systems. Meanwhile, the current geographical distribution and mobility of fattening animals in Caquetá presented in this article, as well as the interlinkages between deforestation and cattle rearing, and between milk and beef value chains, suggest there is a risk that part of the extra animals resulting from current investments for scaling of SPS would be moved, as fattening animals, to new pastures at the forest frontier.

Although we found statistically significant differences using the univariate statistical test, *t* tests of means, these results do not measure causality effects. Furthermore, we caution that our results are based on descriptive analysis and not on causal inference models. We thus recommend a further examination of the risk of deforestation leakage and ways to mitigate it, to ensure that investments support a truly deforestation-free path to scaling SPS. The basis for our recommendation is consistent with previous findings reporting the risks of deforestation leakage arising from efforts to achieve zero-deforestation beef production (Gibbs et al., 2016).

Moving toward milk production is essentially a process of intensification, which generally means higher output per hectare, higher labor inputs and a more limited market. With the proper incentives and safeguards, this is unlikely to drive further deforestation at the local scale. Therefore, it could be argued that sustainable intensification of livestock production in the Colombian Amazon will reduce pressure on forests by adopters, as expected by donor countries and multilateral agencies (Nelson & Durschinger, 2015; Sotelo Cabrera et al., 2017).

However, relationships between the livestock sector and deforestation worldwide have already been widely documented (Seymour & Harris, 2019) and also exist at both Colombian Amazon and Caquetá levels (Figure 1). This article's empirical findings, therefore, raise the question of how the extra male cattle heads, between 1 and 3 years of age resulting from large-scale investment for scaling SPS, would influence forest cover changes at a larger scale as a result of systems moving toward milk production.

Our results show that the dairy and beef (cattle) production systems in the Colombian Amazon are geographically dispersed. However, they are linked through the provision of inputs (fattening animals) from one to the other (González-Quintero et al., 2020). Therefore, substantial changes to one could affect the other and possibly the entire livestock sector and their value chains. Milk- and calf-producing farms, locally known as dual-purpose farms, are common in municipalities outside Colombia's deforestation arc, which are usually areas with lower deforestation rates, good market access, and good governance conditions (Nelson & Durschinger, 2015). The livestock farmers surveyed for this study reflect these conditions because their municipalities are not in the

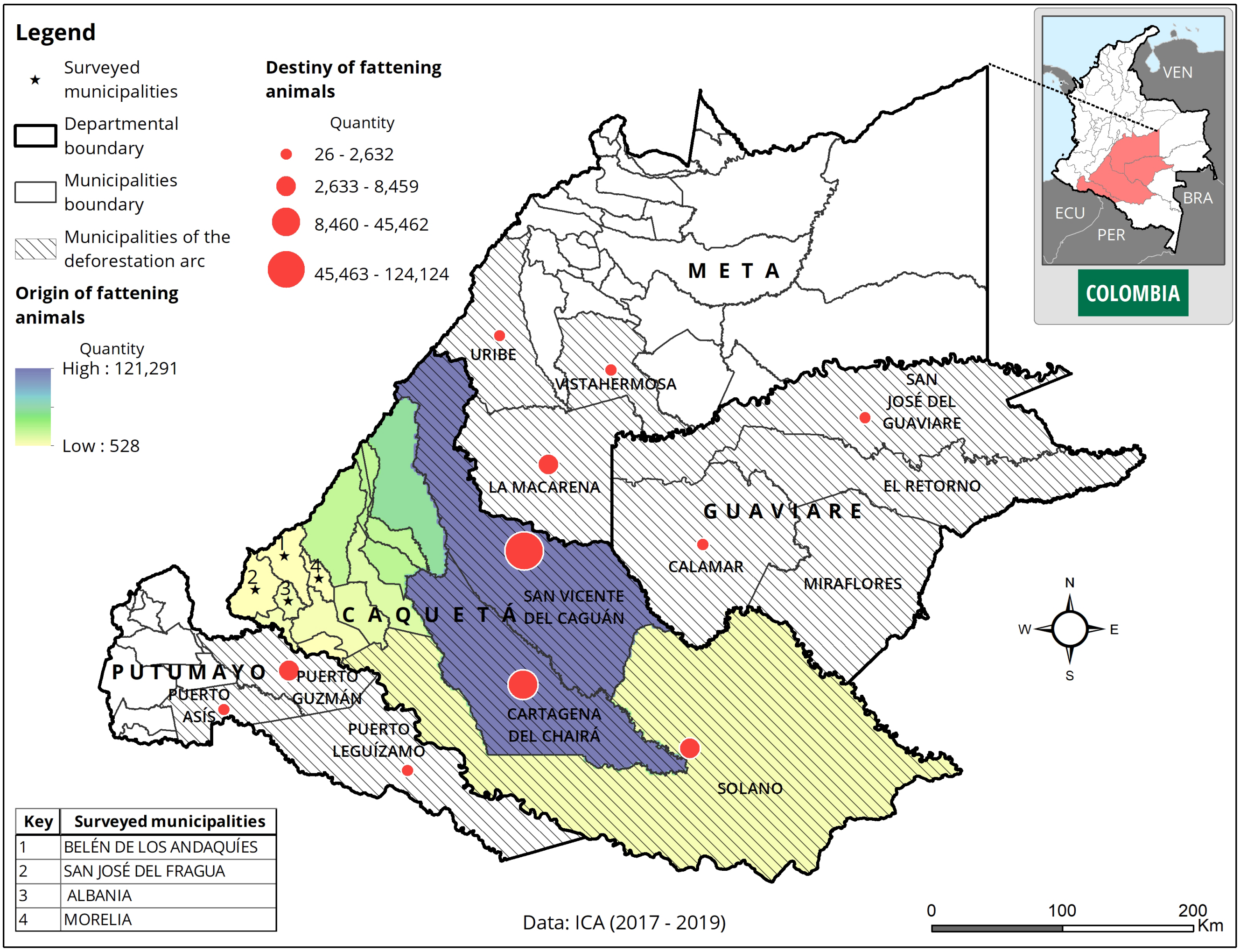

FIGURE 3 Mobility of fattening animals (male cattle aged between 1 and 3 years) originating from the municipalities of the Department of Caquetá, with destinations inside Colombia's "deforestation arc."
Source: (ICA, 2019)

deforestation arc and their main source of livelihood comes from milk and the sale of fattening animals. Consistently, municipalities in Caquetá, outside the deforestation arc, have more cows or heifers and cows aged above 3 years, than their counterparts located inside the arc. In contrast, further afield at the Amazon's receding forest frontier in the deforestation arc, where deforestation, land grabbing, and armed conflict overlap (Castro-Nunez et al., 2017), producers focus almost exclusively on beef production as suggested by the greater number of fattening animals, or male cattle aged between 1 and 3 years, in municipalities inside the deforestation arc. These production systems thrive, in part, because of limited market access, decreased governance and the higher-quality pastures that are available on recently deforested land (Castro-Nunez et al., 2017).

Although the increased supply of calves and male heads does not necessarily directly equate to more deforestation, it is better to be safe than to risk the Amazon being further deforested Thus, based on our results, we argue that all investments for scaling SPS targeting milk- and calf-producing farms in the Colombian Amazon would need to implement environmental safeguards to ensure that the environmental and economic benefits needed for widespread adoption of SPS are indeed deforestation-free. Particularly considering that Colombia's ongoing efforts to transform the livestock sector into sustainable production are mainly oriented toward farmers who produce milk and sell calves and males, or fattening animals, for beef production (FEDEGAN, 2018).

For instance, actions to reduce deforestation defined in the JDI signed at the COP25 climate summit include transforming 147,000 ha of "traditional" cattle pastures into SPS by 2022. Considering current trends, SPS scaling investments will be unlikely to target beef producers, who are mostly associated with deforestation (Nelson & Durschinger, 2015). Instead, they are likely to target dual-purpose producers (Nelson & Durschinger, 2015). Given that governance is weaker in forest frontier areas

(Baptiste et al., 2017), the risk of an unintended leakage effect is high.

Although there is a lack of both observational studies and randomized experiments aimed at estimating the impact of SPS scaling on forest cover, studies do indicate that cattle pastures form a considerable part of deforestation and land-grabbing strategies (Armenteras et al., 2019). Furthermore, recent findings indicate that economic factors or market demands do not influence beef production in deforestation frontiers; rather, land acquisition and land grabbing do (Castro-Nunez et al., 2017; Dávalos et al., 2014). This trend may be exacerbated by structural policies for land use and the expansion of the agricultural frontier (Eufemia et al., 2019). If SPS scaling interventions in the Colombian Amazon are to be truly deforestation-free, they will need to be designed based on a clear understanding of the interlinkages between food and land systems. They must be multifocused to target both milk and beef producers, strengthen the beef and dairy value chains and create mechanisms that limit the steady supply of calves and males from neighboring milk-producing municipalities located outside the deforestation arc, so as to limit the expansion of cattle pastures and the associated deforestation within the deforestation arc.

Farmers who produce milk and sell fattening animals for beef production are the most common farmers in the Colombian Amazon. Prioritizing such farmers as a means to achieving development goals, including peace-building goals, is therefore essential. However, poor governance and land tenure issues in deforestation hotspots, where beef production is predominantly located, require greater attention in order to reduce deforestation (World Bank, 2019). Lack of formal tenure, particularly among small-scale farmers, significantly restricts access to finance. Thus, expediting the process that secures land tenure can mitigate the risk of unintended deforestation (Nelson & Durschinger, 2015). Furthermore, increasing the opportunity costs of converting forests to other uses, by combining livestock production and sustainable forest management, has shown potential for mitigating deforestation risks (CEPAL, 2020). This is particularly so if producers perceive greater financial returns *from these systems* than from traditional beef production, which is only quantified by the kilos of beef produced. Argentina, for instance, presents successful cases in which exotic tree species or native forests are managed in combination with livestock systems allowing the production of trees and livestock in the same land area unit (Peri, Dube, & Varella, 2016).

Transformation of Colombia's beef production, however, requires an approach tailored to livestock fattening and should include a switch from extensive land use to sustainable intensification. Fattening is the most inefficient and land-demanding part of the beef value chain (Ledesma, Gallego, & Peláez, 2002; Vergara Vergara, 2010). This is because the predominant beef production system extensively involves deforestation for pasture production, which in turn is a tool for land grabbing (Castro-Nunez et al., 2017; Dávalos et al., 2014). Nevertheless, this system is less targeted by interventions. This highlights the need for safeguards to prevent additional fattening animals, from SPS scaling, from being moved to forest frontiers without reducing the adopters' income, which, in the case of targeted farmers, is derived from the sale of milk and fattening animals.

Complementary policies to mitigate the potential unintended effects on forest cover from scaling SPS may include financial incentives, such as conditional payments. Conditional payments are in essence similar to payments for ecosystem services, as they provide economic incentives for landowners to carry out and maintain specific actions on their farms (Alix-Garcia et al., 2018; Andersson et al., 2018; Piñeiro et al., 2020). In this context, conditional payments would aim to ensure that cattle farmers adequately and efficiently use to the calves and male cattle that will not be incorporated in the specialization of their cattle herd designated for dairy production. Such incentives must be built upon rigorous biophysical and socioeconomic evaluations and assessed by means of monitoring systems, generating alternatives for degraded farmlands and conservation of biodiversity in agricultural landscapes. Therefore, scaling and replicating SPS by means of complementary policies should focus on the socioeconomic geography of conditional payments and the spatial and temporal patterns of the value of conditional payments.

Likewise, strengthening value chains makes it possible to create incentives for farmers to adopt and maintain sustainable technologies instead of increasing the area of land where those strategies are carried out (Bold, Kaizzi, Svensson, & Yanagizawa-Drott, 2017; de Janvry & Sadoulet, 2020). These strategies could be used to mitigate the risk of deforestation leakage resulting from an increase in cattle herds under the implementation of the Colombian government's commitments to transform 147,000 ha to SPS. Based on the 0.07 increase in the number of animals found on high-intensity SPS (Table 1), an increase to over 147,000 ha of SPS would lead to approximately 10,290 additional calves after 4 years. Of these additional calves, 5,145 would be males or fattening animals assuming that the probability that calves would be male is 0.5.

5 | CONCLUSIONS

While our research results support previous findings, indicating that SPS offer ecological and economic benefits at farm level, they also urge that environmental safeguards be put in place to prevent possible deforestation leakage due to the aggregated effects of farm-level changes in herd composition from broader SPS adoption. Our results complement the growing body of research on scaling SLUS to halt global deforestation, which focuses on monitoring the benefits and identifying the factors limiting their adoption (Amadu, McNamara, & Miller, 2020). Consistently, investments in scaling SLUS focus on overcoming adoption barriers, inadequate access to finance, markets, technical assistance, and production inputs. However, they do not necessarily create the institutions and accompanying mechanisms that help to understand and mitigate the possible unintended effects on forest cover caused by their widespread adoption, mechanisms such as safeguards, tailored incentives, and the establishment of public agencies dedicated to conducting traceability of dairy and beef products to their deforestation-free origins.

In Colombia, for instance, there is a government body can trace agricultural commodities back to their origins to verify whether they present a health hazard. Yet, there is no such arm that can verify whether the production of a particular commodity contributes to forest loss. These institutional gaps exist, in part, because existing literature has yet to provide a deeper understanding of the topic. Determining any unintended effects of investments promoting SLUS thus warrants further investigation. This is significantly important considering that other forest-rich countries, nine of them in Latin America, are designing strategies to overcome factors that limit the adoption of SLUS. One such country is Peru, which aims to scale 119,000 SPS in the Amazon Region to meet sustainable development objectives, including food security, climate-change mitigation and biodiversity conservation. In the meantime, achieving a deforestation-free path through the scaling of SLUS will only be possible with a "push" or incentives that help farmers to overcome adoption barriers and that allow value chain stakeholders in both dairy and beef subsectors to complete the additional actions required to mitigate possible unintended effects on forest cover. Such a "push" would be ideally supported by complementary policies that address the socioeconomic geography of conditional payments (e.g., financial incentives) and the spatial and temporal patterns of the value of conditional payments. Alongside this, national and local regulations on SPS cross-sectoral integration and promotion of research, training, and education are also a much-needed requirement.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

Survey data that support the findings will be available on request following a 2 years embargo from the date of publication to allow the publication of additional research findings.

ETHICS STATEMENT

In undertaking our survey, we complied with applicable guidelines and regulations relating to studies with human subjects, including the regulations of the institutional review board at the International Center for Tropical Agriculture (CIAT) (Clearance Letter #2019-IRB23). We informed all survey participants of the aim of the research and obtained their prior consent to use their responses anonymously for academic purposes.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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