SUPPLY CHAIN SUSTAINABILITY RESEARCH FUND

Improving the broader effectiveness of zero-deforestation commitments and commodity standards

INSTITUTE ON THE ENVIRONMENT
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Paul C. West, Deepak K. Ray, James S. Gerber
(Institute on the Environment, University of Minnesota)

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Executive Summary

- Non-profit organizations, foundations, and companies have invested tremendous resources, political capital, and their reputations on the theory of change that creating deforestation-free supply chains is a key strategy for reducing—and eventually eliminating—deforestation. While there have been regional successes, particularly in parts of Brazil and Indonesia, of reducing the expansion of commodities onto recently cleared forest, the broader effectiveness of market-based strategies is less clear.

- The aim of this report is to develop methods for quantifying the amount of total deforestation that can be attributed to commodity production within and across tropical biomes. We use readily available data and present preliminary results to help develop data-driven solutions. The analysis is focused on Brazil and Indonesia. Both of these countries are key hotspots of deforestation associated with commodity production, allowing us to compare our findings with previous research.

- We estimate how much deforestation can be attributed to commodity production using a simple bookkeeping model for ecoregions and sub-national administrative units. Our approach is similar to previous global analyses that use countries as the unit of analysis and assumes that the total deforestation that can be attributed to a commodity is proportional to the commodity's expansion.

- Our findings reveal that while other studies have shown successes, impact on total deforestation is much higher than direct deforestation estimates by others. For example, previous studies have shown that the Soy Moratorium reduced the amount of new soy area on recently cleared forest to less than 1%. Our estimates of the amount of total deforestation that can be attributed to soy production are much higher in all cases.

- In some cases, commodity expansion is greater than deforestation (or agricultural expansion). Where this occurs, 100% of the total deforestation is attributable to the commodity and that it is also replacing other crops and/or pastures. Such examples occur in both the Amazon and Cerrado parts of Mato Grosso in Brazil, as well as South Kalimantan in Indonesia. *This finding illustrates how all commodity production in a region can be zero-deforestation compliant, yet the commodity can still drive 100% of total deforestation across the landscape.*

- The priority next step is to determine how these methods and preliminary results can be used to refine or develop new strategies to improve the broader effectiveness of sustainable supply chain initiatives. Several organizations, companies, and governments have been leading these discussions for years. Our team's aim is to contribute to further discussions rather than assume that we can propose something better. As such, we recommend issues to consider for refining policies and identify additional research that could support science-based decisions.

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Context

Tropical deforestation is a leading cause of biodiversity loss and source of greenhouse gas emissions. Much of this habitat loss results from expanding agricultural lands for producing a handful of commodities. Fortunately, many companies have made zero-deforestation commitments and adopted sustainability standards to reduce environmental impact in their supply chains. These commitments can transform sustainability practices far faster than the pace of policy and have resulted in many local successes.

Regional supply chain initiatives demonstrate that deforestation can be drastically reduced while agricultural productivity increases. After the Soy Moratorium in the Brazilian Amazon was established, new soy production on recently deforested land decreased dramatically, with some researchers reporting less than 5%.[1–3] In Sumatra and Kalimantan, deforestation on RSPO-certified land holdings decreased by 33% between 2000-2015.[4] Many of the successes were enabled by collaborations among public and private partners working together to implement and monitor the strategies.[5]

However, the broader effectiveness of market-based strategies is less clear. Non-profit organizations, foundations, and companies have invested tremendous resources, political capital, and their reputations on the theory of change that creating deforestation-free supply chains is a key strategy for reducing—and eventually eliminating—deforestation. Between 2000 and 2015, 152 million hectares (1.52 million square km) of tropical forests were cleared, and the annual deforestation rate increased (see Figure 1). These trends illustrate that we are far from meeting the New York Declaration on Forests' 2014 goal to halve tropical deforestation by 2020. It is critical to examine the broader effectiveness of supply chain strategies so that future efforts can be adapted to build on past successes and increase their impact.

The analysis presented here is focused on soy production in Brazil and oil palm production in Indonesia, although the methods developed are applicable across the tropics. Our data sources include globally available satellite-based deforestation data and land cover data (GFC, ESA-CCI) agricultural census data, and some regional datasets. The timeframe is restricted to 2001-2015 as that is the range of most studies, allowing us to place results reported here in the context of other research.

Our aim is to assess the broader effectiveness of supply chain strategies on reducing total deforestation, providing methods and results to help develop data-driven solutions. First, we quantify how deforestation is shifting across and within biomes. These results place local "wins and losses" in the context of broader trends in deforestation. Second, we propose methods and present preliminary results for estimating the amount of total deforestation that can be attributed to specific commodities. Finally, we provide recommendations for future research and issues to improve the broader effectiveness of commodity standards and commitments.

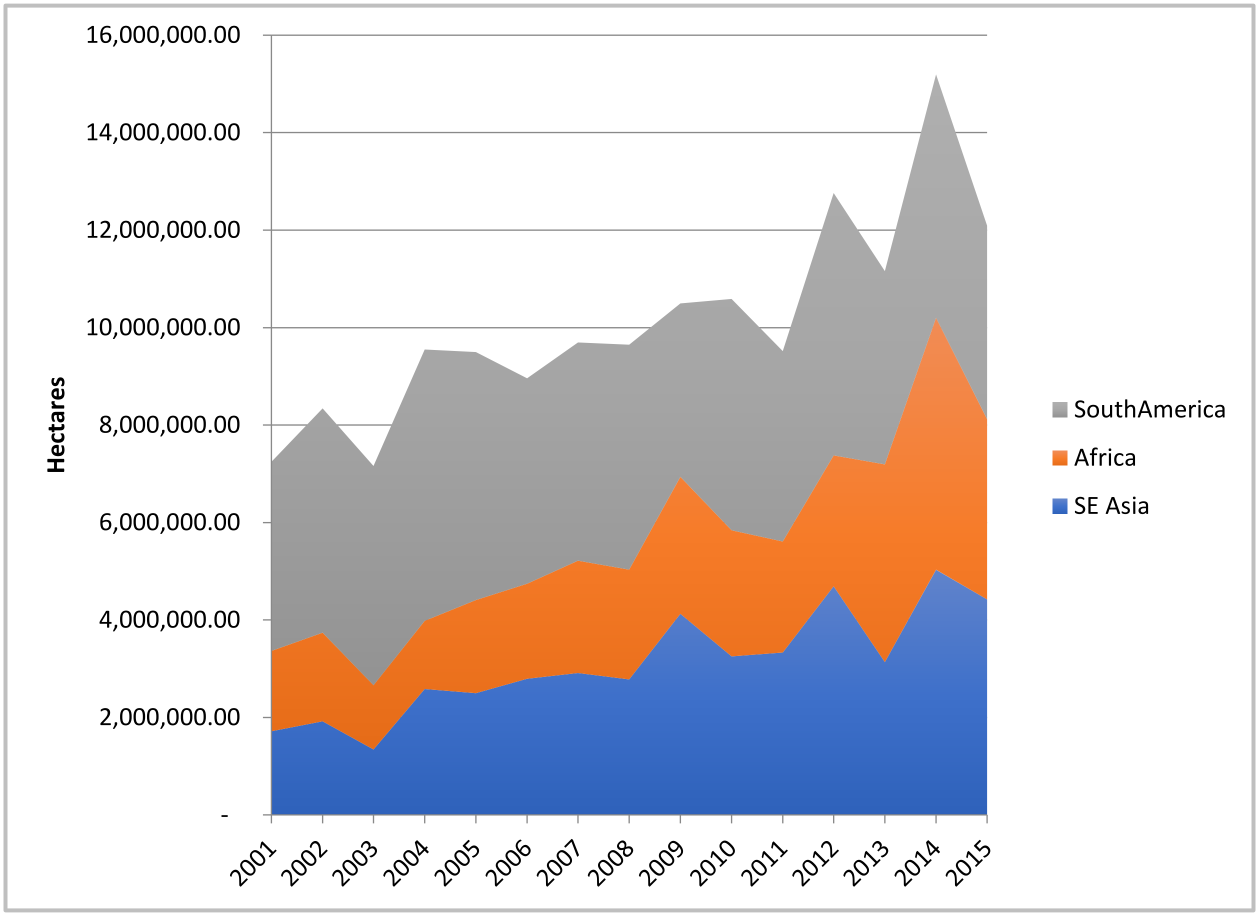

Figure 1. ***Steady deforestation in the tropics.*** *Although efforts to create sustainable supply chains have been locally effective at reducing deforestation, the current set of strategies for eliminating deforestation have not had a transformational impact on total deforestation. Between 2001 and 2015, 152 million hectares of tropical forests were cleared.*[i] *The average annual deforestation rate increased during that time—the average deforestation rate in 2008-2015 was 32% greater than 2001-2007 (average 8.6 Mha/yr (2000-2007) vs. 11.4 Mha/yr (2008-2015). Developing new, or refining current, strategies will require a science-based foundation in quantifying how deforestation shifts across the landscape and which commodities are indirectly driving that change.*

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[i] Deforestation was calculated using the Global Forest Change dataset (Hansen et al. 2013), which measures tree cover loss. As such, tree cover in savannas and other open ecosystems is included in the calculation. Analysis included all countries within South America and Sub-Saharan Africa. Southeast Asia countries included Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, and Thailand.

Quantifying shifts in deforestation

Tropical deforestation is largely driven by production of a few commodities: cattle, soybean, oil palm, and timber products.[6,7] Where, when, and how much deforestation occurs is a complex system of local and global social, economic, and environmental factors.[8]

Supply chain initiatives, such as zero-deforestation commitments and commodity standards, have successfully reduced deforestation directly caused by increased commodity production. For example, new soy production on recently deforested land decreased as part of the Soy Moratorium;[2,3,9] RSPO certification in Indonesia decreased deforestation on oil palm concessions[4]. However, these conservation restrictions can reshape where deforestation occurs[10] rather than changing total deforestation. "Wins" in the Amazon did not transfer to the neighboring Cerrado biome where the Soy Moratorium was not in place.[2] Companies are attracted to invest in regions, such as the Chaco, where there are fewer restrictions and enforcements related to deforestation.[11] In other cases, deforestation may decrease in some regions because the most suitable land for commodities is already under production,[12] which can drive agricultural expansion elsewhere. More broadly, the gains in Brazil (2001-2013) were more than offset by deforestation in other tropical countries during the same period.[13]

The Brazilian Amazon has the only biome-wide implementation of a zero-deforestation supply chain initiative.[14] Yet as the examples above illustrate, even this large scale does not limit the deforestation and commodity production expansion into the neighboring Cerrado and Chaco biomes. Further, the majority of supply chain initiatives are smaller-scale commodity certification programs.[14] These regional efforts have led to local and regional successes, but do not address the scale of the challenge. For example, much emphasis is placed on sustainable oil palm production in Indonesia, yet it is also produced in four additional countries in Southeast Asia: Malaysia, Thailand, Cambodia, and the Philippines (FAOStat), and increasingly in Latin America[15] and Africa.[16]

To assess the effectiveness of biome- and local-scale initiatives, it is critical to view these efforts in the context of how deforestation is changing within the larger region. Below, we summarize shifts in deforestation both across and within biomes/countries in South America and states within Indonesia's Kalimantan in Southeast Asia. Both of these regions are key hotspots of deforestation associated with commodity production, allowing us to compare our findings with previous research.

South America

Using the Global Forest Change (GFC) dataset,[17] we calculated annual deforestation (2000-2015) within six biomes across South America. Biome boundaries were defined by aggregating neighboring terrestrial ecoregions[18] within a major habitat type. The exception is the Amazon basin, where we defined three separate biomes to account for different land use pressures and major geologic patterns. The Southern Amazon, where most deforestation in the Amazon has occurred (and the focus of most studies that report on Mato Grosso, Pará, and Rondônia) is defined as the tropical rainforest ecoregions within the basin that are south of the Amazon River and part of the Brazilian Shield geologic formation (the Cerrado is excluded). Similarly, we defined the Northern Amazon as the tropical forest ecoregions with the basin, north of the river and located on the Guiana Shield. The Western Amazon is defined as the lowland and highland tropical forest ecoregions within the basin.

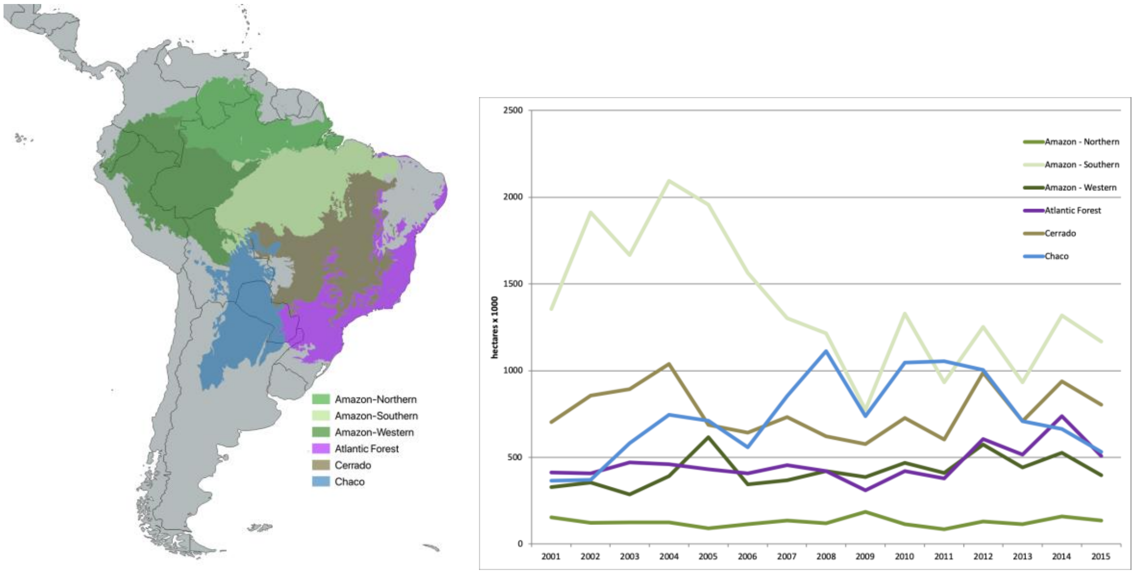


*Figure 2. **Deforestation in South American biomes.** Deforestation was analyzed based on the GFC dataset[17] for four major biomes in Brazil, with the Amazon biome analyzed as three sub-biomes. Thus, the analysis was carried out on Northern, Southern and Western Amazon, as well as the Atlantic Forest, Cerrado, and Chaco biomes.*

Key findings and discussion

- The annual deforestation rate within the Southern Amazon decreased dramatically between 2001-2010 (Figure 2). Although the annual deforestation from 2008-2015 remained lower (1.1 Mha/yr for a total loss of 8.9 Mha between 2008-2015).

- During the same 2008-2015 period, average annual deforestation in the Western and Northern Amazon biomes was 452 kha/yr and 128 kha/yr, respectively.

- The annual deforestation rate in the Chaco increased from 2001 to 2008. Between 2008-2015, the annual deforestation rate in the Chaco was ~1.0M ha, which was similar to the Southern Amazon (1.1M ha/yr), yet the Chaco biome is only 65% as large as the Southern Amazon.

- While tree cover loss also decreased in the Cerrado during the same period, this is likely an underestimate of landcover change: the GFC[17] data calculates tree cover loss for trees >5m tall and >30% forest cover and hence misses much of the native Cerrado which is open grassland, sparse shrublands, and sparse trees.

- Much increase in annual deforestation in the Atlantic Forest occurred in three ecoregions where very little native forest remained outside of protected areas (Alto Paranaíba forest, Araucaria moist forest, and Bahia interior forest). More detailed analysis would be needed to determine if the deforestation was intact or secondary forests, or plantations.

- It is important to note that while we restricted our analysis to 2000-2015 to be consistent with several other studies, deforestation spiked across several of the biomes here as a result of widespread fires in addition to cutting down forests. Further, easing of environmental regulations in Brazil in 2019 led to an additional spike in deforestation.

Shifts in deforestation among Kalimantan states

Similar to South America, we calculated annual deforestation in Kalimantan Indonesia using the Global Forest Change (GFC)[17] dataset. We used state administrative boundaries rather than ecoregions, as the climate, geology, and major habitat types are similar across Kalimantan.

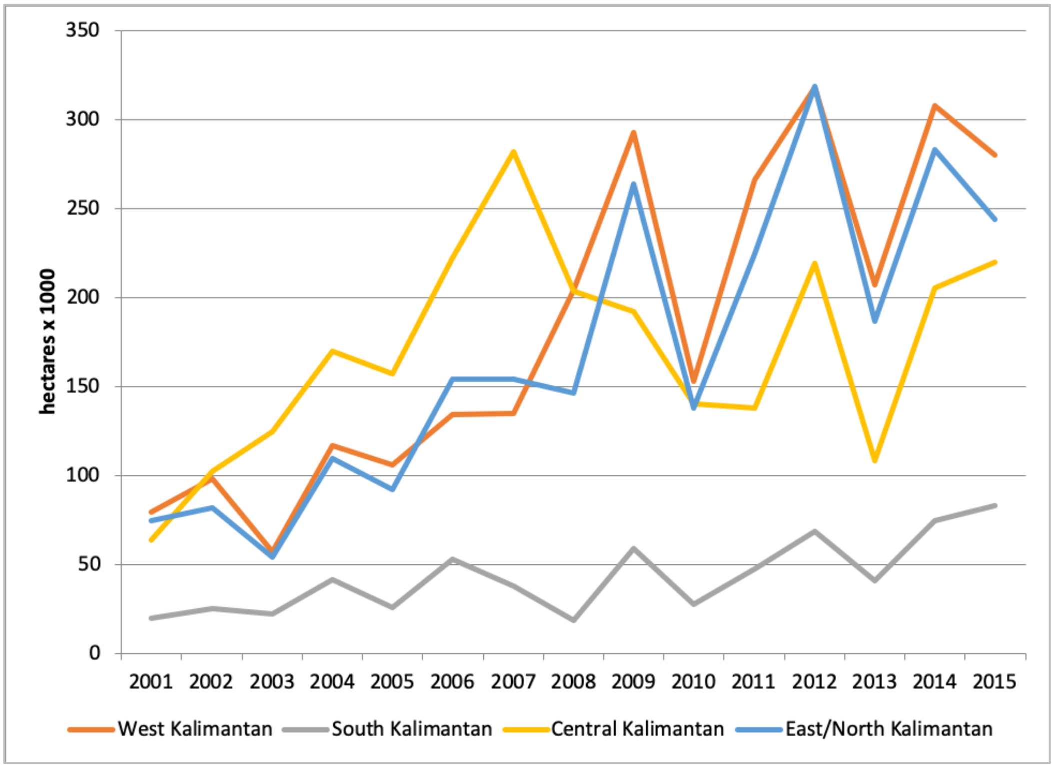


Figure 3. ***Deforestation in Kalimantan.*** *Deforestation was analyzed based on the GFC dataset (Hansen et al, 2013) for four states in Kalimantan. We follow the convention of gadm.org and combine results for East and North Kalimantan.*

Key findings and discussion

- The annual deforestation rate for all of Kalimantan generally increased from 2001 with peaks in 2009 and 2012, which is consistent with findings reported by Gaveau and colleagues.[19] At a broader scale, between 1995-2015, deforestation shifted from Sumatra to Kalimantan, and more recently parts of Papua.[20]

- We found that annual deforestation decreased in Central Kalimantan from approximately 2007 to 2015, largely due to a decrease in the eastern district of Kotawaringin Barat, where most of the deforestation was concentrated.

- There was an upward trend in deforestation in West Kalimantan, East/North Kalimantan, and South Kalimantan from 2000-2015.

- Additional findings are presented in the next section.

Attributing deforestation to individual commodities

Since a few commodities drive most of the tropical deforestation,[7,21,22] several environmental organizations work under the theory of change that developing sustainable supply chains for these commodities will reduce deforestation. Through several forums and declarations—such as the Consumer Goods Forum, New York Declaration on Forests, and the Amsterdam Declaration on Deforestation—hundreds of companies have made zero-deforestation commitments. Several of these initiatives have produced many positive outcomes, most notably in reducing deforestation on lands that are producing beef and soy in Brazil,[2,5,23] and oil palm in Indonesia.[4,24,25]

However, several studies have documented the shortcomings of these initiatives. One of the biggest limiting factors is low adoption rates.[14,26,27] Conservation benefits of initiatives can be limited if adoption is largely on properties that are already compliant,[27] or on properties where there is little forest left to conserve.[4,10] Several loopholes and limitations exist,[28,14] such as exemptions to smallholder farmers,[3,13,25] and laundering of non-compliant commodities through compliant property owners.[29,30] Further, properties can be compliant with zero-deforestation commitments despite not being compliant with national policies.[31] Even how zero-deforestation commitments are defined (zero-net, zero-gross, or zero-illegal) adds to the difficulty of implementing and certifying commodities.[32]

Previous efforts to attribute *total* deforestation to specific commodities have focused on country-scale analyses of land use trade, imports, and exports. Henders and colleagues[22] found that four commodities—beef, soy, palm oil, and timber—were responsible for 40% of the tropical deforestation across seven countries with high deforestation rates between 2000-2011 and that the fraction of the impact of these commodities was increasing over the study period. Between 2010-2014, more than 50% of greenhouse gas emissions from tropical deforestation was driven by cattle and oilseed crops.[6] These findings demonstrate that sustainable supply chains have yet to have broader scale impact on reducing tropical deforestation.

Here, we aim to assess the broader effectiveness of sustainable supply chain initiatives within biomes and countries. This scale allows us to assess beyond the properties producing the commodities, yet provides finer resolution than the global country-level assessments, that is consistent for a particular initiative enabling us to see if and where they have broader impact on reducing deforestation. Godar and colleagues[33] used a similar "middle-ground" scale for estimating resources embodied in traded commodities.

Methods for quantifying attribution

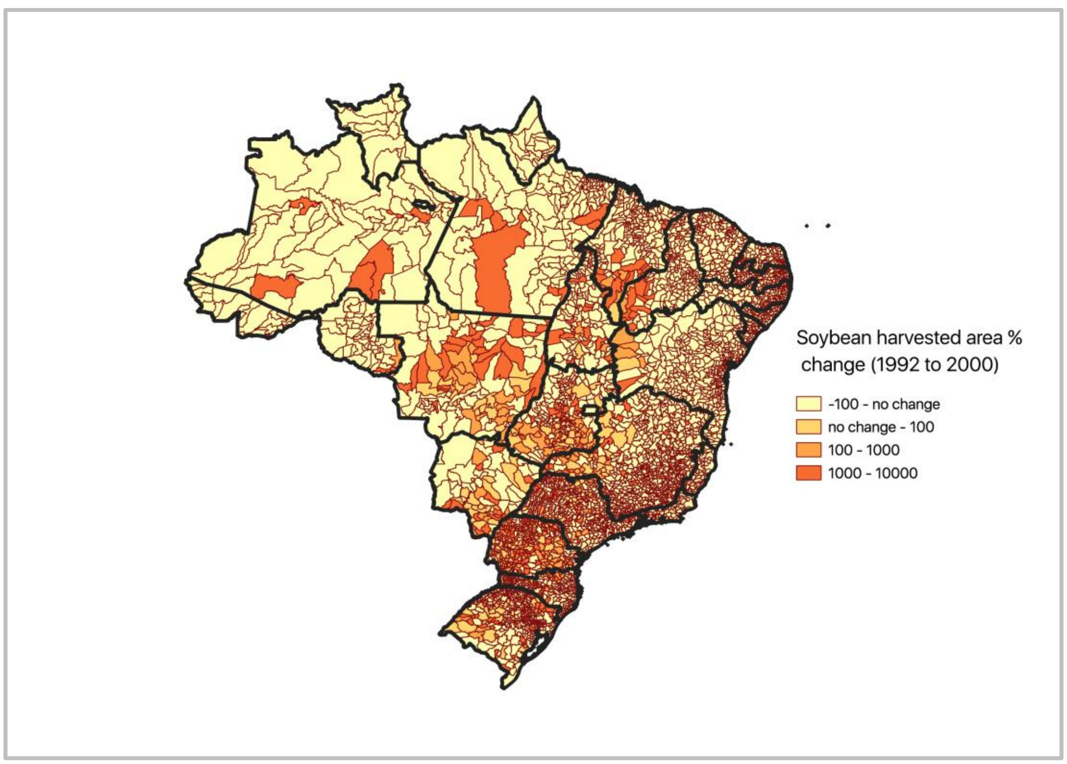
Similar to the global analyses of drivers of deforestation[21,22] at the country scale, we use a simple bookkeeping model to estimate the total (sum of direct and indirect) deforestation attributed to specific commodities. The basic assumption is that commodities can be the cause of deforestation on the landscape whether or not the commodity is produced on land where forest was recently cleared. To calculate the contribution of the commodity to total deforestation (both direct replacement and indirectly elsewhere in the landscape, we assume that the amount of deforestation that can be attributed to a commodity is proportional to the change in area of forest and commodity. Assessing the relative changes in cropland and pasture provides additional contextual information, such as croplands replacing pastures and commodities replacing other crops or livestock. The method is simple, transparent, and can be done with readily available global data for large scale analysis or where local data is not available.

Calculations were carried out at the resolution of the satellite data (typically ~30m) and then aggregated across administrative units and ecosystems. This enabled us to summarize the land use changes at various levels: district, state, or country for the administrative level bookkeeping and to the ecoregion and biome level for the natural landscape level bookkeeping. Administrative dataset information was from Database of Global Administrative Areas (GADM). Ecoregion information was from the WWF.[18] Census information was tabular and from individual countries and the FAO. Once all the datasets were spatially aligned at the highest resolution, we wrote routines to compute the administrative level and ecosystem level land use changes.

We present case studies of how this approach assesses the indirect effects of soy production in portions of Amazon and Cerrado biomes of Brazil, as well as oil palm production on Kalimantan in Indonesia. Attribution was estimated in 5-year intervals, beginning in 2000 and ending in 2015. We use intervals because the commodity crop may not be planted the year following clearing and sub-national agricultural statistics are not annually reported for most countries.

Different datasets were used for the Brazil and Indonesia case studies. The Mapbiomas[34] dataset was used to calculate changes in natural vegetation, pastures, and croplands. Soy production datasets were from the Brazilian Institute of Geography and Statistics (IBGE). We did not include data on where soy is double-cropped, which can reduce indirect deforestation. In Indonesia, the GFC dataset was used to track changes in forest. Oil palm production statistics were compiled from Badan Pusat Statistik and FAO. Oil palm production area statistics are reported as planted, mature plantation, or harvested area. Planted area is used here as the aim is to estimate the impact of oil palm's footprint, not the commodity's volume.

Attributing total deforestation to soy production in Brazil



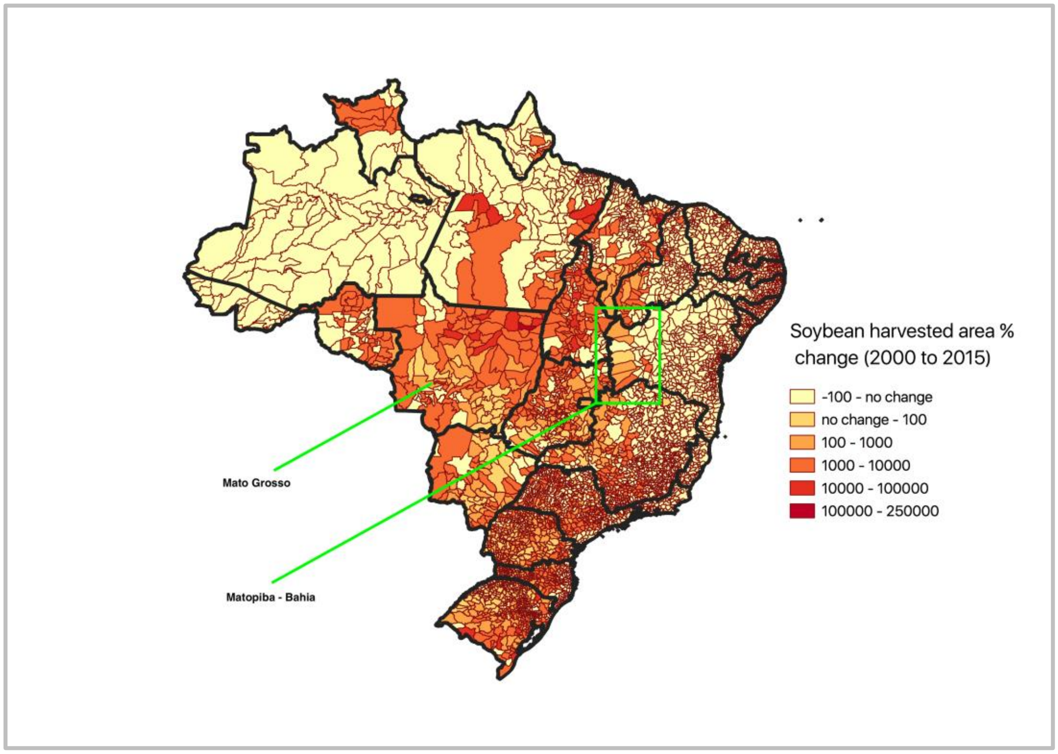


Figure 4. ***Growth in soybean area in Brazil, 1992-2015.*** *Percent growth in soybean harvested area over time periods 1992-2000 and 2000-2015 derived from census data (IBGE). The location of two areas analyzed here are indicated (Mato Grosso, and the Bahia portion of the Matopiba region.)*

Mato Grosso

Mapbiomas[34] summary statistics show that total agricultural gains were 95% of the area of natural habitat loss across the Cerrado. In the Amazon, it was 97%. As such, for simplicity we use agricultural expansion as a proxy for habitat loss. We acknowledge that not 100% of cleared land is used for agriculture, but several studies have shown that agriculture is the primary cause.

Mato Grosso – Amazon

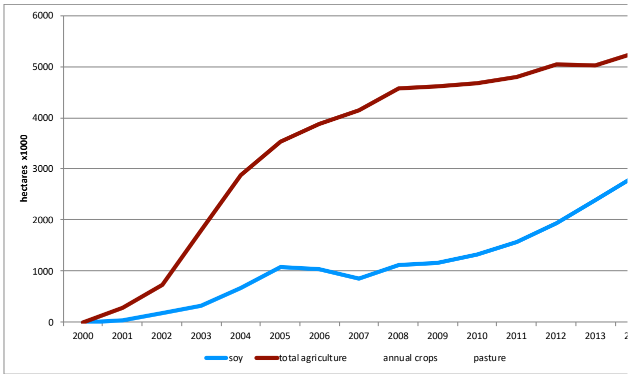


Figure 5a. Change in land use for the Amazon biome within Mato Grosso

Mato Grosso – Cerrado

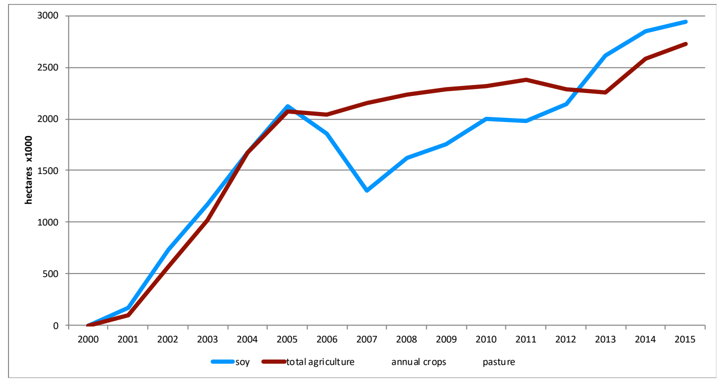


Figure 5b. Change in land use for the Cerrado biome within Mato Grosso

MT-Amazon	Change in hectares (x1000) for each period		
	2005 – 2000	2010 – 2005	2015 – 2010
Soy	1075	242	1798
Annual cropland	1238	559	1582
Pasture	2296	573	-756
Total agriculture (cropland + pasture)	3534	1132	826
Habitat loss attributed to soy	30%	21%	218%

MT- Cerrado	Change in hectares (x1000) for each period		
	2005 – 2000	2010 – 2005	2015 – 2010
Soy	2122	-123	941
Annual cropland	1625	100	780
Pasture	444	145	-367
Total agriculture (cropland + pasture)	2069	245	413
Habitat loss attributed to soy	103%	-50%	228%

Key findings and discussion

- From 2000 to 2015, agricultural land increased 8.2 Mha in Amazon and Cerrado portions of Mato Grosso. 67% of that was in the Amazon biome, 33% in the Cerrado.
- The largest gains in agricultural land occurred from 2000 to 2005, when it increased by 2.1 Mha in Cerrado municipalities (78% cropland, 22% pasture) and by 3.5 Mha in Amazon municipalities (35% croplands, 65% pastures).
- The rate of soy area expansion decreased in Amazon municipalities between 2005 and 2010. 59% of the 245 kha increase in agricultural land was pasture. This period coincides with the

beginning of the Soy Moratorium, when soy expansion onto recently cleared forests dropped to less 5%[3] or 1% in some estimates.[2] *However, here we estimate that 21% of total deforestation can be attributed to soy expansion.*

- In the Cerrado, the total area in 2010 was 123 kha less than in 2005 even though total cropland increased by 120 kha during the same period.

- Pasture area decreased in both the Amazon (-756 kha) and Cerrado (-367 kha) municipalities between 2010 and 2015, while cropland area increased in both regions, 1582 kha and 780 kha, respectively. Increase in soy area was more than double the increase in cropland area in both regions. As such, we attribute >200% of the total deforestation to soy, *meaning that 100% of deforestation is attributable to soy and that soy replaced croplands and/or pastures (it was more than new agricultural land created).* This assertion is supported by a recent study[35] that estimated that row crop area in Brazil nearly doubled between 2000-2015 and that 79% of new cropland replaced pastures.

- In the present analysis, we do not account for double-cropping. Although the area of double-cropping with soy increased from 10% to 60% across Mato Grosso between 2000-2013,[10,36] we suggest that our estimates of the amount of the deforestation attributed to soy would not decrease much even if we could account for double-cropping. Soy is planted on approximately 90% of cropland in Mato Grosso (Agrosatellite data).[37] Further, it is the primary crop, planted in the rainy season in double-cropped systems (rather than added as a second crop during the dry season). As such, soy is the crop driving change on the landscape.

- It is important to note that while we restricted our analysis to 2000-2015 to be consistent with several other studies, deforestation spiked across several of the biomes here as a result of widespread fires in addition to cutting down forests. Further, easing of environmental regulations in Brazil in 2019 led to an additional spike in deforestation.

Matopiba - Bahia

Next, we estimate the amount of habitat loss that can be attributed to soy production within seven municipalities[ii] in the state of Bahia (Fig. 6). These municipalities are part of the Matopiba[iii] region and accounted for 98% of soy area in Bahia in 2000 and 90% in 2015 (IBGE). As above, we calculated changes in cropland and pasture area from the dataset and we obtain soy production area is from the IBGE.[34] Similarly, we use agricultural expansion as a proxy for habitat loss.

[ii] Barreiras, Cocos, Correntina, Formosa do Rio Preto, Jaborandi, Riachão das Neves, São Desidério

[iii] Matopiba, acroynm for the regions of Maranhão, Tocantins, Piauí, and Bahía, has recently been a locus of deforestation.

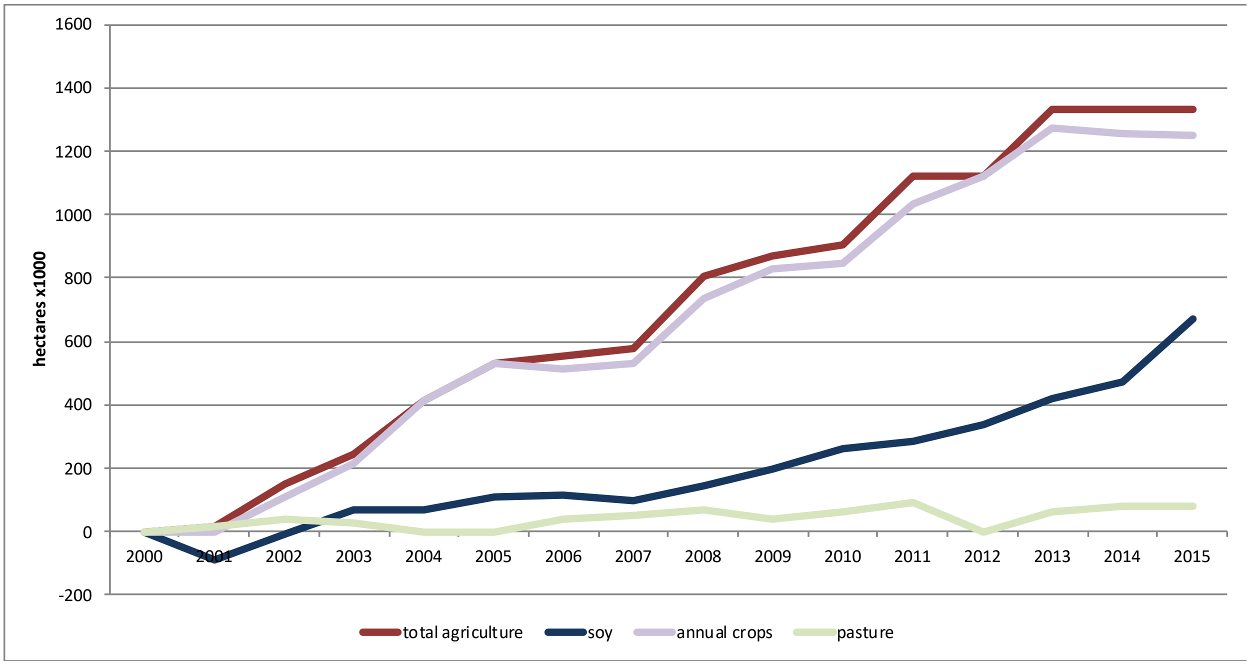


*Figure 6. **Change in land use for seven municipalities in Bahia that are part of the Matopiba region.** Total agriculture is the sum of the annual crops and pastures. As noted above, we use agricultural expansion as a proxy for loss of forest and other natural ecosystem types.*

	Change in hectares (x1000) for each period		
	2005 – 2000	2010 – 2005	2015 – 2010
Soy	112	147	413
Annual cropland	532	315	400
Pasture	1	59	23
Total agriculture (cropland + pasture)	533	374	423
Habitat loss attributed to soy	21%	39%	98%

Findings and discussion

- From 2000 to 2015, cropland accounted for 94% of the 1330 kha of increase in agricultural land in the Bahia hotspot.
- We estimate that 51% of this conversion to agricultural land is attributed to soy, as it increased by 662 kha during that time. The amount of habitat loss attributed to soy increased in each of the periods: 21% was attributed to soy in 2000-2005, 39% in 2005-2010, and 98% in 2010-2015.
- Similar to the Amazon and Cerrado parts of Mato Grosso, the agricultural land expanded most in the 2000-2005 period.
- In contrast to those regions, which had decreases in soy expansion from 2005-2010, the soy area in the Bahia hotspot increased in each of the three 5-year periods.

Attributing total deforestation to oil palm production in Kalimantan

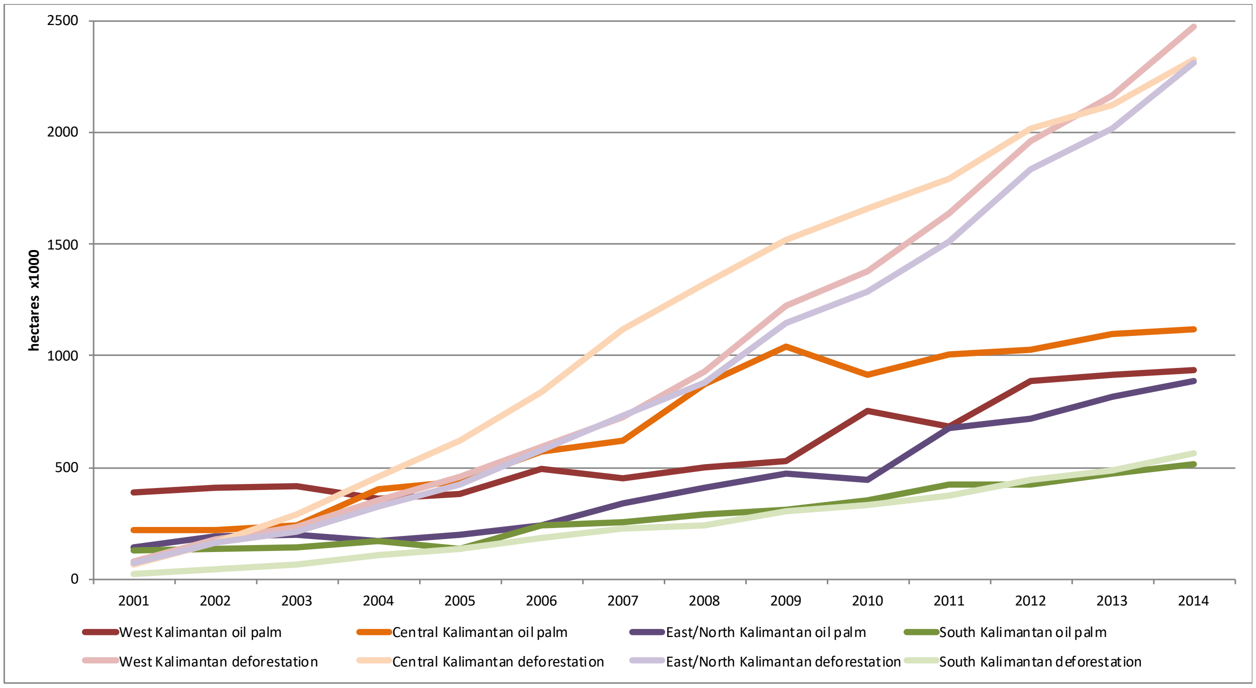


*Figure 7. **Land use change for provinces in Kalimantan.** Both annual deforestation and oil palm production area are plotted.*

Change in hectares (x1000) for each period

	2005 – 2001	2010 – 2005	2014 – 2010
West Kalimantan			
Oil palm	-7.2	369	185
Deforestation	377	918	1098
Attribution	0%	40%	17%
South Kalimantan			
Oil palm	4.9	219.1	159.2
Deforestation	115	196	231
Attribution	4%	120%	69%
Central Kalimantan			
Oil palm	217	477	204
Deforestation	554	1039	670
Attribution	39%	46%	31%
East/North Kalimantan			
Oil palm	57	245	441
Deforestation	346	863	1028
Attribution	16%	28%	43%

Key findings and discussion

- Across Kalimantan, more than 7.4 Mha were deforested between 2000 and 2014. During that same period, the area of oil palm plantations increased by 2.6 Mha, suggesting that 35% of deforestation can be attributed to oil palm.

- Total deforestation between 2000 and 2014 was similar across West Kalimantan (2.4 Mha), Central Kalimantan (2.3 Mha), and East/North Kalimantan (2.2 Mha).

- Total deforestation was lowest in South Kalimantan (541 kha), which is the smallest state, yet 71% is attributed to oil palm. Land cover change in this state illustrates how the deforestation-commodity expansion pattern can change over time.

- Deforestation rates increased over each of the three periods in all states except for Central Kalimantan, where the annual deforestation peaked in 2009.

- Our results suggest that current sustainable supply chain initiatives for oil palm have limited broader influence on reducing deforestation. These limitations are likely due to low market share or adoption rates,[27] or oil palm displacing other commodities. Further, forest products are a leading cause of deforestation, which is outside the scope of initiatives related to sustainable oil palm.

- Although it would not affect the estimates of attribution of oil palm on total deforestation (methods used here), it would be helpful to have more context of what type of forests are being cleared. For example, there can be cases where oil palm is cleared and then replanted to oil palm. Using the combination of the Global Forest Cover[17] data and agricultural census data will allow these cases. However, these cases may not have much effect on the attribution estimates when attribution is calculated over five-year periods and oil palm area estimates include all planted area (as done here), not only harvested area. However, knowing the quality of forest being cleared and which commodities follow deforestation will provide more context for attribution estimates. For example, Austin et al[20] reported that 54% of new oil palm plantations established between 1995-2000 replaced forest, whereas only 18% of new plantations replaced forest from 2000-2015. Gaveau and colleagues[19] restricted their deforestation accounting to areas that were defined as natural in 2000. As such, our deforestation estimates are higher. Analysis here could be redone to provide a more direct comparison.

- In addition, more work is needed to assess the accuracy, frequency, and geographic scope among the different estimates of oil palm plantations. For example, although the agricultural production statistics are estimated near annually through interviews, this approach introduces errors as it is a statistical sample of self-reported values. In contrast, plantation maps manually delineated from satellite data may be more accurate but are limited by time required to develop the products as well as the inconsistencies among observers that would be introduced to create products across large regions through the tropics. New methods for delineating oil palm plantations using machine learning approaches[38] hold promise, but have only been tested in limited areas.

- It is important to note that while we restricted our analysis to 2000-2015 to be consistent with several other studies, deforestation spiked in 2016-2017 as a result of widespread fires and has since decreased.[19]

Recommendations (preliminary for discussion)

The following recommendations are preliminary and intended to help guide the discussion during the June 22, 2020 Supply Chain Sustainability Research and Learning Symposium.

Insights for policy and supply chain initiatives

- Incorporate the insights and methods into discussions for improving the effectiveness of sustainable supply chain initiatives.
    - What is useful about the methods and what could be changed to make it more policy relevant?
    - Can these methods be used to refine current sustainable supply chain initiatives to have broader impact on reducing deforestation?
    - Are the methods applicable to attribute deforestation to specific commodities where public-private partnerships are using a jurisdictional approach to halt deforestation?

- Develop communications strategy for the preliminary analysis that quantifies how commodities can be 100% compliant with zero-deforestation commitments yet can still be the major driver of deforestation on the landscape.

- Refine or develop new policies that are specific to different deforestation patterns associated with commodity expansion. The shifts in deforestation and how much of it can be attributed to specific commodities presented in this report illustrate examples where new deforestation is greater, about the same as, or less than expanding area used to produce commodities. Commodity production can be zero-deforestation compliant yet still drive total deforestation in each of these cases. Policies and enforcement will likely be more effective at reducing deforestation if they are crafted with knowledge of current patterns of indirect land use change.

Future research application

- Complete analysis for the entire tropics
    - Although not presented here, we completed preliminary analysis of deforestation across all tropical biomes and administrative units and compiled additional agricultural census and statistics for commodity production. However, there were too many nuances and data limitations to complete the analysis for this report.
    - Future analysis should continue to assess commodity impact on deforestation at multiple scales, ideally connecting the scales used here to previous assessments at the property and country scales.
    - Which commodities are displaced ones tied to commitments and certification? Do they increase elsewhere, and if so, what do they replace?

- Analysis of intermediate commodities

- Detailed study of land uses and crops displaced by commodities tied to commitments and certification could provide insight into the mechanism by which indirect land use change takes place. Do they increase elsewhere, and if so, what do they replace?

- Expand this approach to non-forested biomes. Several tropical biomes that are critical regions for biodiversity conservation are not forests. Some of the priority area grassland and savanna biomes include Llanos, Cerrado, Miombo woodlands, Guinean and Congo-transition savannas, and the savannas of East Africa. There are no global datasets that could be effectively used for any of these biomes. The Cerrado is the only one with local land cover data (Mapbiomas[34]) that would enable the attribution methods used here.

- Compare estimates of a commodity's contribution to total deforestation to previous efforts that assess the area of commodity production that directly replaces forests. The results presented here suggest that the impact on total deforestation can be high even when compliance with sustainable supply chain initiatives is high. Quantifying this gap can help assess the gap between the larger intended goal of eliminating deforestation versus compliance.

- Assess the effectiveness of "bundles" of strategies—such as federal and local regulations, training, restoring degraded lands, protected areas, and reducing land speculation—at improving the broader effectiveness of reducing total deforestation.

- Develop datasets that enable consistent, global-scale analysis.
  - *Short-term: Develop best practices for combining existing global datasets and documenting their limitations.* Pendrill and Persson[39] assessed the benefits and limitations of combining two global landcover datasets for assessing changes in forest cover, croplands and pastures in Latin America. Similar efforts should be made using a broader set of data products and geographic scope.
  - *Medium- to long-term: Develop annual, global cropland and pasture maps.* The European Space Agency's Climate Change Initiative (ESA-CCI)[40] land cover product has annual data from 1992-2015. However, the preliminary comparisons that we did for this project showed many inconsistencies between ESA-CCI and Global Forest Change.[17] Annually updated pasture maps will likely be the most challenging to develop given the difficulty of distinguishing them from natural ecosystem such as grasslands, shrublands, and savannas.
  - *Commodity-specific maps:* priority should be placed on commodities driving most of the tropical deforestation: soy, oil palm, and timber plantations. Additional crops could include cocoa and coffee. Regional products based on satellite data are under development for soy in Brazil (Agrosatellite,[37] University of Maryland), as well as plantation mapping, which has largely been focused in Indonesia.
  - *Data "rescue" of commodity production statistics.* High resolution datasets are not needed to assess how much total deforestation can be attributed to a commodity. One alternative to investing in new satellite data products is to compile production statistics from reports, company records, crowdsourcing, and other sources. Such an approach, particularly in Africa, could both meet immediate data needs as well as serve as training data for developing products derived from satellite data. However, these data rescues are very time-intensive, limiting how frequently they are updated.
  - *Investment in data for Africa.* The forests of western Africa are at risk of further deforestation due to commodity expansion (particularly oil palm and cocoa) but reliable data on commodity production are generally unavailable.

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Appendix 1. Notes on data selection and limitations

Several land cover datasets were considered for this analysis, and detailed results change as a function of these choices. We tested our methodology using multiple datasets: Mapbiomas (Brazil), Indonesian plantation maps[20,41], European Space Agency-Climate Change Initiative (ESA)[40], and Global Forest Change (GFC)[17]. Each of these products is distinct because of differences in satellite source data, how land cover types are defined, geographic scope, length of the time series, algorithms, calibration, and validation. These differences created widely varying estimates of deforestation, despite the datasets being broadly similar.

This report uses the GFC data to provide a common basis for quantifying deforestation among biomes and administrative units in South America and Southeast Asia. The data is high-resolution, globally consistent, well validated, updated annually, used in Global Forest Watch, and widely used as a benchmark for related analyses. Limitations to the GFC data become evident when analyzing savanna areas such as the Cerrado in Brazil. Because savanna is similar to grassland with sparse shrubs and trees, GFC is less able to detect land use change due to its constraints on canopy height and stand density.

For the two cases considered in depth in this report, Brazil and Indonesia, we were able to rely on additional high-quality datasets. In Brazil we were able to use the Mapbiomas product to track changes in natural vegetation, croplands, and pasture. In addition, the Brazilian Institute of Geography and Statistics (IBGE) makes available high-resolution and reliable agricultural statistics. For Indonesia, reliable agricultural census data and results from careful mapping studies were available. However, both agricultural statistics and plantation mapping are only updated every few years, which means not being able to utilize the latest deforestation data, despite that being updated annually. Forest loss spiked in 2016 in both Brazil and Indonesia as a result of extensive fires in addition to cutting down forests, but that data is not included here.

Before initiating this research, we anticipated that the ESA data would be valuable for estimating changes in cropland. However, based on the results presented here, we are not able to conclude that ESA data is (or is not) appropriate for extending these results to other regions. Pendrill and Persson[39] addressed the limitations of combining various datasets to quantify agricultural expansion in South America. Future work should address this particular question.