Environmental impacts of the U.S.-Mexico avocado supply chain

by

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ABSTRACT

The U.S. imports 87 percent of its avocados from one region (Michoacán) in Mexico. Although environmental and social costs associated with avocado production are significant, consumers and retailers in the U.S. are not aware of them in part due to complex, opaque supply chains. In this paper, we use a methodology known as TRACAST (*Tracking Corporate Actors Across Space and Time*) to reconstruct avocado supply chains between U.S. retailers (e.g. Kroger and Costco) and Mexican producers and exporters. Using remote sensing and machine learning, we document how avocado plantations have led to significant deforestation in Michoacán, whose forests are important reservoirs for biodiversity, especially the Monarch butterfly (*Danaus plexippus*). We estimate that ~20% of the total forest loss (15,000 ha) in Michoacán between 2001 and 2017 is associated with expansion of avocado orchards. Despite these impacts, interviews reveal that industry experts (namely representatives of firms and government officers) do not consider avocado production to be a driver of deforestation in the region. This disconnection between *actual* and *perceived* environmental impact can be addressed by the U.S. governmental agencies (namely USDA APHIS) who play influential roles in regulating avocado imports for sanitary and health purposes and by the vertically integrated avocado trading companies who connect Michoacán packing houses to Kroger, Costco, and other large U.S. grocery retailers. Key measures to make the U.S.-Mexico avocado trade more sustainable include greater information transparency and multi-stakeholder initiatives.

Introduction

My interest in corporate sustainability and concern for environmental justice motivated me undertake a master's thesis on the environmental impacts of the U.S.-Mexico avocado trade. Globalization processes have produced transnational supply chains that allow consumers to purchase daily items from across the world. Research has highlighted the negative environmental and social impacts from transnational supply chains, showing that the lifestyles in many wealthy countries are both unsustainable and reliant on the unjust concentration of impacts in certain regions (Lavelle, 2018; Martinez, 2017; Vijay et al. 2016).The opacity of the supply chains bringing goods to market makes it hard for consumers to know the environmental or social impacts of their choices (Goldstein and Newell, 2020). This disconnect makes it challenging for consumers to consume sustainably and for companies to source responsibly.

An important step towards more sustainable and just supply chains is to make them transparent, so that negative environmental and social change can be revealed, and responsible parties identified. This transparency creates the possibility for positive change through boycotts, regulatory tools, or multi-stakeholder initiatives (MSIs) on sustainability that not only promote organized industry effort to reduce its environmental impact but also invite participation of formerly excluded and marginalized groups to the roundtable. The goal of this thesis is to bring transparency to the U.S.-Mexico avocado supply chain. I focus on the links between this trade and deforestation in the Mexican state of Michoacán, and on identifying the actors with power to govern the sustainability of that supply chain.

Early on in my thesis, I was introduced to the theories of global commodity chains (GCC), global value chains (GVC), and global production networks (GPN) that provide frameworks for understanding how supply chains are organized and governed. Studies using these theories have found differential power relations between trading companies, with important implications for environmental and social outcomes across supply chains (Gereffi and Korzeniewicz, 1994). For instance, large corporations operating vertically integrated supply chains can often more effectively transmit environmental standards to their suppliers compared to more diffuse and unstable supply chains (Ponte, 2019a). This is key given that corporations, alongside NGOs, have come to fill the governance gap created by supply chains that transcend the jurisdictional boundary of any one country (Gereffi and Korzeniewicz, 1994; Bush et al. 2015). Through their operations, large corporations can either exacerbate environmental and social challenges while increasing their bottom line, or works towards meaningful positive change (Ponte, 2019b).

U.S.-Mexico avocado supply chain serves as a good case study of transnational supply chain governance, because of its product characteristics, industry structure, and environmental significance. Fresh avocado is a perishable product requiring post-harvest treatments for USDA phytosanitary inspections as well as logistics system to protect fruit quality during shipments (Peterson and Orden, 2008; Calavo Growers, Inc. 2019). These characteristics of avocados serve as a relatively high entry barrier for avocado for farmers or other small actors that want to enter the lucrative U.S. market. This has produced a concentrated industry structure with 26,000 farmers supplying just 60 avocado exporters

(APEAM, 2017). As multiple small-scale suppliers are dependent on a small number of big buyers, the current industry structure allow greater pressures from buyers on Mexican producers (Gereffi et al. 2005). Another unique industry structure of the U.S.-Mexico avocado supply chain is designation of Michoacán by the USDA as the only Mexican state allowed to export avocados to the U.S. (APEAM, 2017). This concentrates the environmental and social pressures from U.S.-Mexico avocado industry expansion in Michoacán.

The U.S.-Mexico avocado trade is also in interesting case because of its multi-scalar environmental impacts. Locally, Michoacán supports multiple natural forests, including but not limited to *pinus oocarpa* (Mexican Yellow Pines), which contain a wide variety of flora and fauna (Sáenz-Romero et al. 2006). Michoacán has multiple microclimates from its wide elevation range (0-3930m) allowing it high biodiversity and genetic variations (Barsimantov and Kendall, 2012; Sáenz-Romero et al. 2006). Thus, avocado expansion in Michoacán poses a threat to this biodiversity hotspot (Associated Press, 2018; Lavelle 2018; Pskowski, 2018). Of special note is the Monarch Butterfly which passes through the region on its annual migration. Destruction of butterfly habitats through deforestation and high agrochemical uses has implications for the entire North American monarch butterfly population (Vidal et al. 2013; Pskowski, 2018). Deforestation also decreases Michoacán's carbon mitigation capacity and its tolerance to climate change by bleaching altitudinal genetic variations of Michoacán forests (Sáenz-Romero et al. 2006; de Jong et al. 2007).

Deforestation from avocado expansion in Michoacán also has social dimensions. Mexican yellow pines are great sources of the firewood, saw timber, plywood, and resin products to Michoacán residents (Sáenz-Romero et al. 2006). Thus, destruction of the pines habitats driven by the avocado industry means decreased ecosystem services to local populations who do not benefit from this boom crop. In addition, avocado farming in Michoacán has become a lucrative industry, attracting organized crime groups that were traditionally involved with deforestation through their illegal logging activities (Lavelle, 2018). Numerous activists and journalists concerned with deforestation in Michoacán have become targets of violent crime and even homicide (PRI, 2020; Wamsley, 2020). My hope is that by bringing transparency to the U.S.-Mexico avocado trade, my thesis can help reduce both the social and environmental costs of these supply chains.

The main part of this thesis, presented in the following section, is a manuscript entitled “Where does your Guacamole come from? The environmental impacts of the U.S-Mexico avocado supply chain”, which has been prepared for submission to the journal *Environmental Research Letters*. The article was prepared with input from my supervisors Benjamin Goldstein, Dimitrios Gournaridis, and Associate Professor Joshua Newell. In it, I used a methodological framework, Track Corporations Across Space and Time (TRACAST), to follow the avocado from the fields of Michoacán to large retailers in the U.S., including Kroger and Costco. Using remote sensing I found that avocado expansion is an important driver of deforestation in Michoacán, including encroachments on key biodiversity hotspots. Interviews with industry experts revealed that many

powerful supply chain actors do not acknowledge linkages between avocado production and environmental degradation. I conclude by suggesting supply chain disclosure and multi-stakeholder initiatives as two ways to improve the sustainability of U.S.-Mexico avocado trade.

This thesis makes both academic and practical contributions. Academically, it addresses the lack of research in supply chain sustainability literature on the individual corporations that move and shape the global economy. It also advances methods to investigate global supply chains by combining interviews, material flow analysis, remote sensing, and other disparate data and methods. Practically, it makes transparent the link between U.S. diets and distant environmental change and identifies powerful actors who could be pressured to reduce these impacts. This opens avenues to reshape both personal and corporate practices around principles of environmental sustainability, equity, and justice.

Where does your Guacamole come from? The environmental impacts of the U.S-Mexico avocado supply chain

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1. Introduction

The popularity of fresh avocados in the United States (U.S.) is soaring. U.S. per-capita avocado consumption tripled from 2.4 pounds to 8 pounds between 2001 and 2017 (USDA AMS, 2020). These are primarily Hass avocados, prized for their rich creamy textures (AFM, 2017). U.S. production cannot satisfy this growing appetite. In 2018, 87% of avocados sold in the U.S. were from Mexico—the world's number one avocado producer and exporter (USDA FAS, 2019). The U.S. market consumes approximately three-quarters of total Mexican avocado exports (USDA FAS, 2018).

In 1914, the U.S. banned avocado imports based on phytosanitary grounds. This ban ended in November 1997 with the signing of the North American Free Trade Agreement (NAFTA) (Peterson and Orden, 2008). The United States Department of Agriculture (USDA) designated the Association of Producers and Packers Exporters of

Avocado in Mexico (APEAM) as the only legal Mexican avocado exporter, tasking APEAM with ensuring that all Mexican avocado exports are from Michoacán orchards that passed phytosanitary tests (APEAM, 2018). APEAM has been wildly successful, solidifying Michoacán as the only Mexican state allowed to export avocados to the U.S. (Coronado et al., 2010; APEAM, 2018). Michoacán avocado exports increased sixty-fold between the years 2000 and 2018 (United Nations Statistical Division, 2019), putting pressure on the environment and people of Michoacán.

One pressing environmental challenge associated with growing avocado production is deforestation (Barsimantov and Antezana, 2012; Martinez, 2017). Michoacán has sandy soils with excellent drainage that suppresses the fungus growth causing root rot in avocado plants (Aguilera-Montanez and Salazar-Garcia, 1991). These soils already support large, natural stands of *Pinus oocarpa* (Mexican yellow pines) and other forests, which contain a wide variety of flora and fauna (Duellman, 2019). These forests are thus prime sites for avocado expansion, rendering this advantage to a growing threat to biodiversity (Sáenz-Romero et al., 2006), especially to declining populations of natural species such as the Monarch butterfly population that annually passes through region (Associated Press, 2018; Lavelle, 2018; Pskowski, 2018). Researchers have shown that avocado orchards are encroaching on these forests and driving negative environmental changes through deforestation, high water consumption, and the use of agrochemicals (Bravo-Espinosa et al., 2014; González-Estudillo et al., 2017). These pressures show no sign of abating as the export trade continues to climb.

A first step in addressing these environmental challenges is to identify powerful actors in the supply chain—a network of actors that produce, market, and distribute a commodity (Gereffi et al. 2005)—who influence how avocados are produced. Researches on global value chains and global production networks identify companies, government agencies, civil society organizations, and the media as the major actors in supply chains. Research on transnational agricultural supply chains shows how the large retailers in importing countries use their clout to dictate conditions at the farm level and increase profits through certification schemes (e.g., organic and fair-trade), quality standards, and other tools (Ponte and Gibbon, 2005). Powerful actors, including but not limited to big retailers, have also used their powers to reduce deforestation and improve labor conditions often in response to NGO 'brand-activism' campaigns (zu Ermgassen et al., 2020; Doorey, 2011).

Despite their importance in shaping farming practices and related environmental impacts, powerful actors in transnational avocado supply chains have received scant attention in research on Mexican avocados. Research on U.S.–Mexico avocado trade has focused on the economic and phytosanitary aspects of these supply chains (Peterson and Orden, 2008; Lamb, 2006). Other research has focused on either municipal level ecological analyses of avocado-driven deforestation (Bravo-Espinosa et al., 2014) or theoretical-level calculations of the avocado industry's environmental impacts without considering where those impacts occur and accumulate (González-Estudillo et al., 2017). No effort has been made to link the environmental pressures taking place in Michoacán to supply chain actors. To date, we have lacked a complete picture of the avocado supply

chain—who is involved and where they operate—as well as a full accounting of the environmental impacts of avocado production.

This paper addresses these gaps through a detailed examination of U.S.–Mexico avocado supply chains. It has three objectives:

1. To reveal which companies are operating in this supply chain and to locate their operations in the U.S. and Mexico by using the methodological framework known as TRACAST (tracking corporate actors across space and time).
2. To estimate how much deforestation between 2001 and 2017 was associated with avocado expansion by using remote sensing and global deforestation data to provide the first complete mapping of avocado orchards in Michoacán and global deforestation data.
3. To identify the key corporate actors who can make avocado production more sustainable in the region and to gauge their perceptions of avocado industry as a driver of environmental deterioration in Michoacán and through interviews.

Our remote sensing result revealed that 14,614 hectares of avocado orchards overlap with deforestation, accounting for 17% of total forest loss in Michoacán between 2001 and 2017. We found 100,794 hectares of avocado orchards, about 25.4% of the total avocado planted areas, are in the key biological areas (KBAs) defined as sites vital to the preservation of threatened species (BirdLife International, 2017). We found the U.S. government and vertically integrated avocado trading companies to be the actors with

power to improve the sustainability of the production practices. However, our interviews revealed that just one-quarter of industry experts recognize the avocado industry as a driver of deforestation. Powerful actors did not reveal information they have about their practices or their production locations to consumers who shop at Kroger, Costco, and other grocery retailers, essentially stopping concerned consumers and NGOs from targeting reckless actors (Henriksen and Ponte, 2018). The methodology we used to reconstruct U.S.– Mexico avocado supply chain can be a model for other efforts to understand the environmental and social impacts associated with the production of goods and services.

2. Materials and Methods

We used the *Tracking Corporate Actors across Space and Time* (TRACAST) methodological framework to reconstruct U.S.–Mexico avocado supply chains and link them to deforestation in Michoacán. TRACAST consists of four sequential steps that systematically combine heterogeneous data to uncover supply chain actors, locate their activities in space, connect activities to environmental and social hotspots along the supply chain, and identify key nodes in the supply chain with power to ameliorate those hotspots (Goldstein and Newell, 2020).

2.1. Step 1 - Scope study

Here, we state the overall goal of the study, identify the specific food product it concerns, delineate the spatiotemporal scope of analysis, and outline the portion of the supply chain we studied.

Our primary goal was to map the U.S.–Mexico Hass avocado supply chains and clarify its role in deforestation in Michoacán. We studied fresh Hass avocados (HS code 080440). Our geographic scope was Michoacán, which supplied ~800,000 metric tons to the U.S. in 2018 (three-quarters of total U.S. consumption of avocados) (Williams and Hanselka, 2018; United Nations Statistical Division, 2019), as well as U.S. and Mexican cities and ports containing supply chain actors. We traced the supply chain for the year 2018 and focused on deforestation during recent years of avocado expansion in Michoacán, 2001 to 2017.

We used industry reports (AFM, 2017; Williams and Hanselka, 2018) and academic literature (Coronado et al., 2010; Salazar-Garcia et al., 2005) to sketch the avocado supply chain. This supply chain consists of five corporate actors treated as nodes (figure 1): *Growers* (1) are avocado farmers producing Hass avocados in Michoacán; *Packers* (2) prepare avocados for U.S. export in accordance with phytosanitary regulations (APHIS, 2001); *Exporters* (3) ship suitable avocados to U.S. importers; *Importers* (4) receive avocados at border crossings or ports and deliver them to distribution centers; *Retailers* (5) receive avocados from importers and sell them to individuals or restaurants. Our analysis covers all five supply chain nodes.

Figure 1. Corporate actor (node) diagram of the avocado supply chain.

2.2. Step 2 - Collect data

We used multi-sourced data to construct *internal linkages* between companies and *external linkages* with actors outside the supply chain. Our main sources of information were customs data, remote-sensing data, documents, and primary data collected through interviews (table 1).

Customs data detail individual cross-border shipments and include company names and locations, product descriptions, and trade volume (Goldstein and Newell, 2020). We used global supply data from Panjiva (2019) to estimate the mass of avocados traded between Mexican exporters and U.S. importers, removing entries lacking company names. We used document analysis and semi-structured interviews to qualitatively link and locate Mexican packers and exporters, and U.S. importers and retailers. Although we located avocado orchards using remote-sensing techniques (see Section 4.3), we lacked data to link packers to individual growers or municipalities, a goal for future work.

Table 1. Heterogeneous approaches used in tracking corporate actors and environmental impacts.

Approaches	**Observed Applications**				
	Identifying stakeholders	Building linkages	Geocoding	Documenting stakeholder perception	Documenting environmental impact
Customs Data analysis	√	√	√		
GIS analysis			√		√
Document analysis	√	√		√	√
Interviews	√	√	√	√	

Document analysis and interviews revealed stakeholders' perceptions of environmental issues and related corporate sustainability efforts. Interviews were

performed with 12 industry experts through phone or on site at the MHAIA (Mexican Hass Avocado Importers Association) Annual Meeting held September 17–18, 2019, in Las Colinas, Texas. The interviewees included major Mexican avocado importing and distributing company employees, the U.S. importer and Mexican exporter association (MHAIA, APEAM, AFM) representatives and an environmentalist from Forests for Monarchs that is working on a reforestation project partially sponsored by MHAIA.

2.3. Step 3 - Construct and verify corporate actor linkages

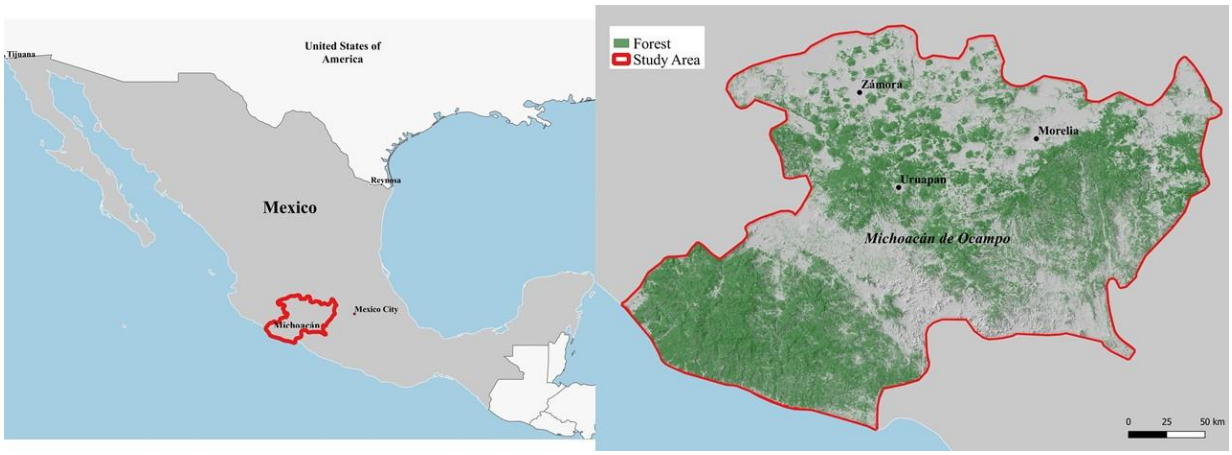
We built linkages from customs data using pivot tables. With unstructured data from text documents and interviews, we kept track of linkages using Excel tables and network diagrams. To check the accuracy of custom records, we compared total trade volume in 2018 from Panjiva data to official statistics from UN Comtrade (United Nations Statistical Division, 2019). Panjiva captured 57.1% of official trade, suggesting that Panjiva data are reliable (Goldstein and Newell, 2020). To verify linkages from unstructured data, we analyzed company statements, third-party audits, and government documents.

2.4. Step 4 - Evaluate environmental impact (deforestation)

To link avocado farming with deforestation in Michoacán, we mapped avocado orchards and identified the co-occurrence of orchards and deforestation. To map orchards, we applied the Random Forest (RF) machine-learning algorithm to remote-sensing data from the year 2019. To identify areas of forest loss, we used the Global Forest Change dataset, which classifies the removal of vegetation over 5m high as forest

loss (Hansen et al., 2013). We summed annual volumes of forest loss from these data for the years 2001 to 2017.

Figure 2. Location and topography of the study area: Michoacán de Ocampo.



2.4.1. Data Pre-processing

We used six multi-spectral Landsat images to cover the Michoacán area (figure 2). We prioritized images unobscured by clouds and used images from April and May to minimize phenological variation (Appendix 1). We performed radiometric and atmospheric corrections in line with Gounaridis et al. (2014). To minimize topographic effects (Michoacán's elevation ranges from 0 to 3930m), we applied the C-correction method (Reese and Olsson, 2011). Corrected bands per image were mosaicked and clipped to achieve full coverage for Michoacán.

2.4.2. RF Classification

We opted to use RF since it can handle data from different scales and sources (Gounaridis et al., 2016) and outperforms other classifiers in the face of heterogeneous classes (Gislason et al., 2006; Rodriguez-Galiano et al., 2012). The algorithm does not require normal distribution of inputs, and collinearity between the predictor variables is

not an issue (Breiman, 2001). It is also less likely to overfit and is robust against outliers and input noise (Breiman, 2001; Belgiu and Drăguţ, 2016).

As predictors, we used the six mosaicked reflective Landsat bands and the first output of a principal components analysis (Wold et al., 1987). To improve predictions, we also included the enhanced vegetation index (EVI) (Huete et al., 2002), the normalized burn ratio (NBR) (Key and Benson, 1999), the normalized difference vegetation index (NDVI) (Tucker, 1979), the soil adjusted vegetation index (SAVI) (Lyon et al., 1998), the weighted difference vegetation index (WDVI) (Clevers, 1989) and the brightness, greenness and wetness layers from the Tasseled Cap transformation (Crist, 1985).

We trained the model to distinguish ten land uses and collected 500 to 1500 samples per category, depending on area occupied and heterogeneity. To collect training samples, we visually inspected high-resolution imagery from Google Earth (nominal year 2019) and assigned values per land use category, avoiding boundaries between adjacent categories and fuzzy spectral values (Gounaridis et al., 2016). The model was implemented in R using the randomForest package (Liaw and Wiener, 2002), specifying five predictors at each decision-tree split and 1500 trees for each run.

2.4.3. RF result post-processing

After classification, the initial ten categories were aggregated into avocado plantations and non-avocado areas. We removed noise from isolated pixels using the mode values of neighboring cells of a 5x5 moving window centered on the isolated pixel.

We validated results against 1,000 independently sampled points assigned with the aggregated two-category (avocado and non-avocado) and found 95% accuracy. Results were cross-tabulated against the Global Forest Change dataset to quantify co-occurrence of deforestation hotspots and the existence of avocado plantations (Hansen et al., 2013). Finally, we cross-classified our post-processed results with the global forest cover loss layer and calculated the surface area of deforested land occupied by avocado orchards.

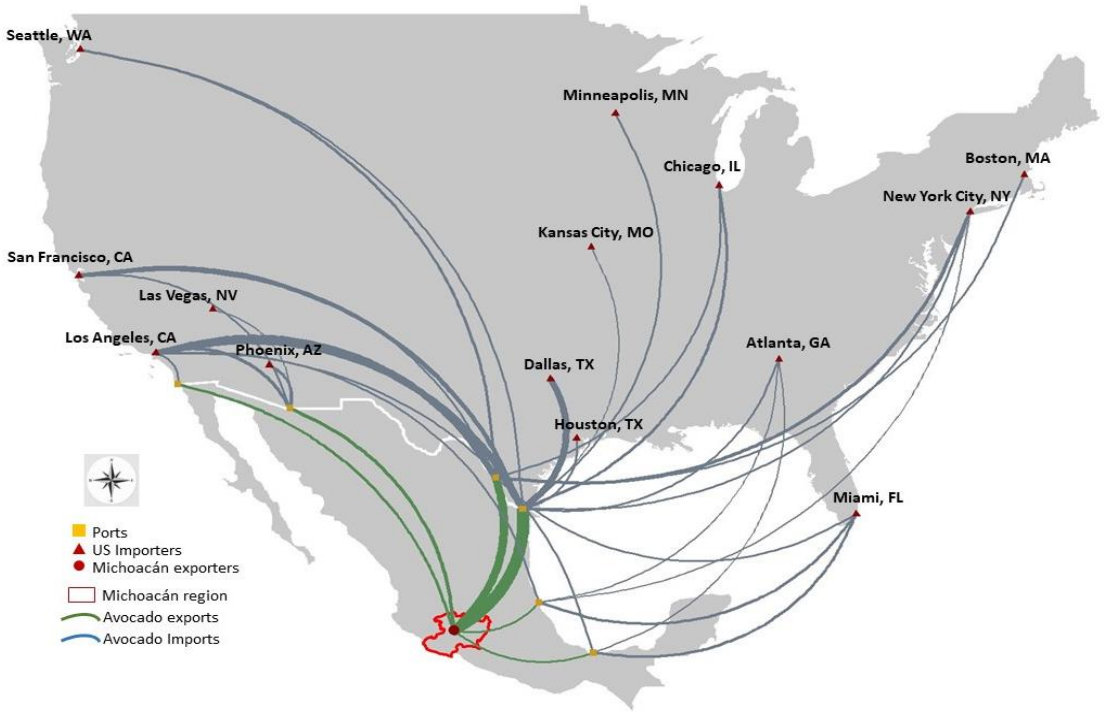
3. Results

3.1 Supply Chain Reconstruction

When avocados are ready for harvest, Michoacán growers (node 1) get contacted by three to four packers (node 2) and sell their avocados to the highest bidder. Packers truck avocados to packing houses for quality control and packaging. Although all packers are also exporters (node 3), standalone exporters also operate. After processing, refrigerated trucks transport fresh avocados from packing houses to ports for USDA inspection and transfer to trucks for delivery to importers (node 4). Distribution centers then ship avocados to retailers nationwide (node 5). Figure 3 maps the avocado trade from Mexico to the U.S. by geocoding locations of companies in the supply chain.

Our customs data contained 7,115 usable transactions, from which we identified 243 U.S. importers and 202 Mexican exporters. Avocados reached the U.S. overwhelmingly by truck (97%), with maritime and air transport accounting for remaining shipments. One border crossing, Ciudad Reynosa, Tamaulipas, handles nearly two-thirds of total U.S. imports of Mexican avocado.

Figure 3. Simplified flow map of trade logistics from Mexico to the U.S. Line width determined by trade volumes.

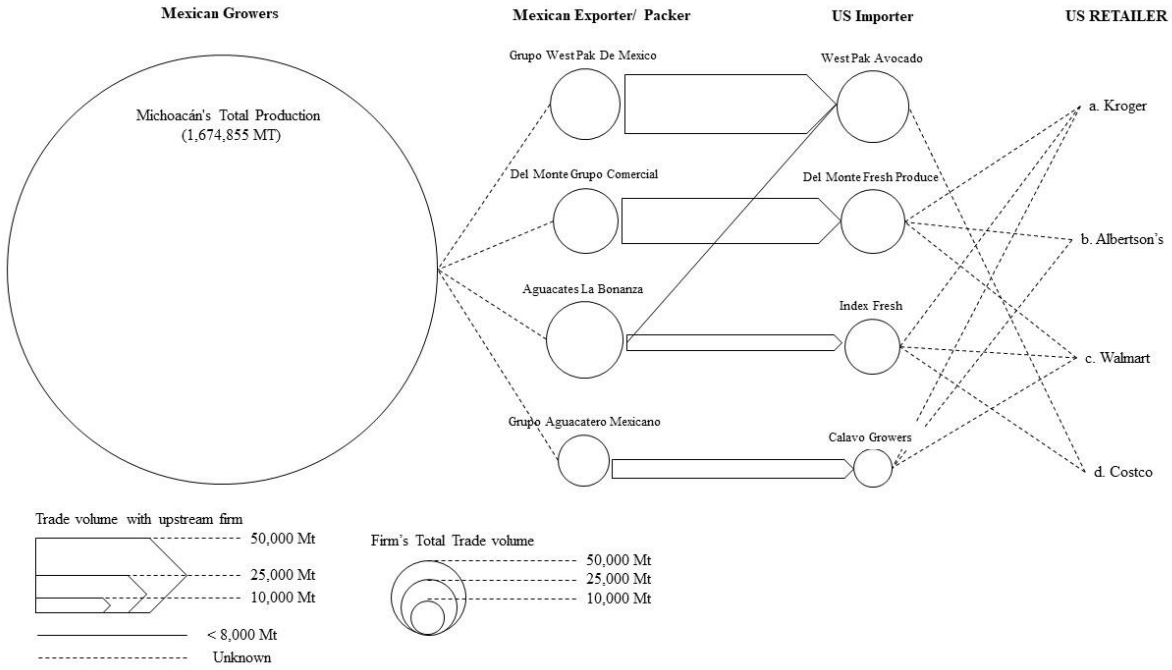


The top ten importers and exporters in the customs data accounted for 56% and 59% of total traceable avocado trade, respectively. The top 20 importers and exporters accounted for roughly three-quarters of shipments (Appendix 2). We found six of the top 20 importers supplied avocados to major U.S. retailers, including Kroger, Costco, and Walmart, in 2018 (Appendix 3). Seventeen of the top 20 avocado exporters are also packers (APEAM, 2017), essentially collapsing nodes 2 and 3 into a single node.

A grower must be a member of APEAM to supply avocados to the U.S. market. In 2018, APEAM listed more than 26,000 growers, all in Michoacán. Most growers work on a small scale, typically producing less than 100 tons annually (APEAM, 2017; USDA FAS, 2018). Small growers rarely have a set contract with packers. Lacking location data

on registered growers, we instead mapped avocado plantations in Michoacán. Being the only state permitted to export to the U.S., we can link Michoacán avocado supply chains all the way to the national-scale U.S. retailers: Kroger, Albertson's, Walmart, and Costco (figure 4).

Figure 4. Avocado supply chain from Mexican packers to major U.S. retailers for the year 2018.

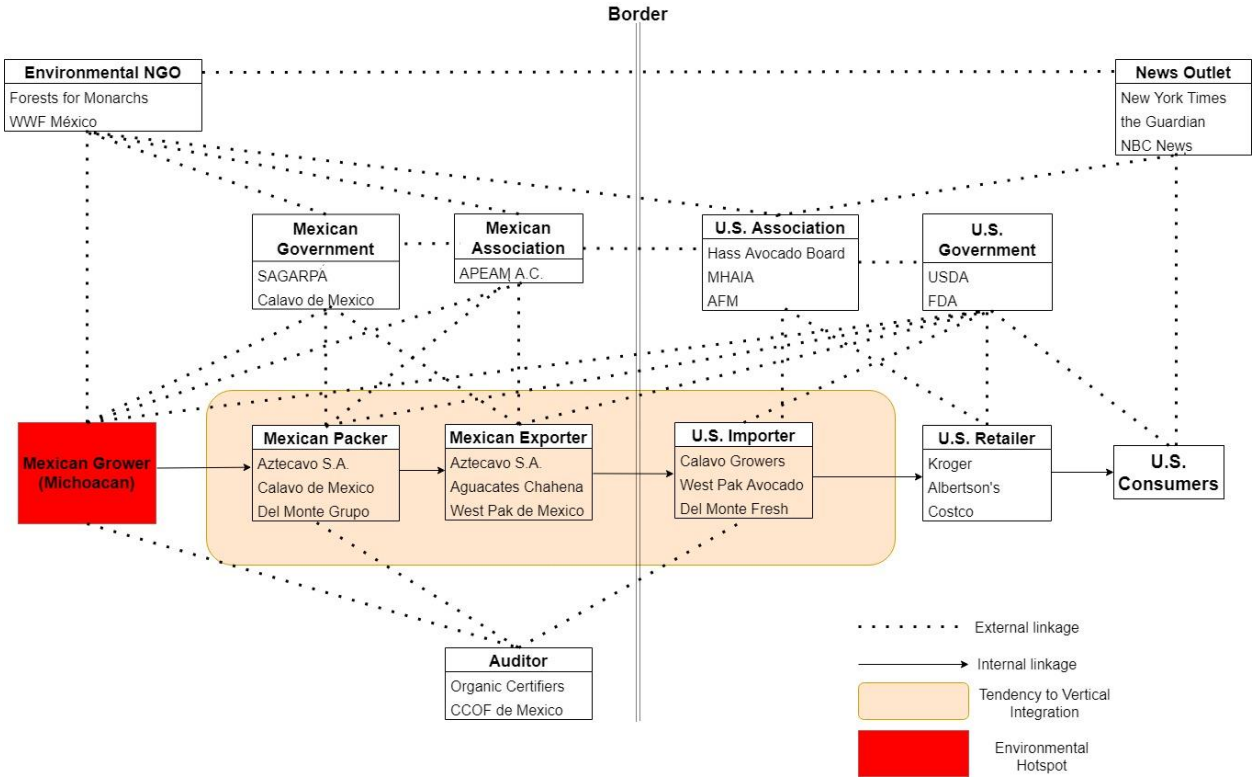


3.2. Key actors influencing the supply chains

Semi-structured interviews with avocado industry employees and document analysis clarified important linkages between companies and influential actors outside the supply chain (represented by external linkages). Ponte and Gibbon (2005) define two types of influence: *direct management*, i.e., vertical integration, and *indirect management*, in the form of conventions or certifications, such as USDA phytosanitary standards and organic certification. Using their influence, the actors compete to set

quality and price norms and to reorganize supply chains to achieve their goals (Ponte and Gibbon, 2005).

Figure 5. Simplified network of key actors in the Mexican avocado supply chain.



Influential external actors include the U.S. and Mexican governments, industry associations, certification auditors, NGOs, the media, and consumers (figure 5). Important direct managers are the industry associations that licenses growers and packers to export, and the government agencies that approve and inspect avocados for export. Indirect managers include the NGOs and media outlets that shape public opinion (e.g., linking gang violence to the avocado trade) and consumers who react to these reports. However, the key external actor is the U.S. government, which has linkages with all supply chain actors. It manages directly through phytosanitary inspections at farms and

packing houses and manages indirectly by designating Michoacán as the only legal avocado supplier to the U.S., thus concentrating production in a limited geographic area.

Interviews and document reviews showed that packers, exporters, and importers tend to vertically integrate to ensure a steady avocado supply (Appendix 4). These vertically integrated entities are key actors that bridge farmers and retailers, transmitting demands to farmers from the top of the supply chain (concerning product quality such as freshness and textures) and laterally from outside actors (concerning phytosanitary protocols). Although vertical integration allows more control over price and volume, interviewees mentioned that key aspects of the importing process were still outsourced to customs brokers and third-party phytosanitary auditors.

3.3 Perceived Environmental Impacts

Seven out of twelve interviewees (58%) recognized deforestation as an important environmental issue occurring generally in Michoacán, but only 25% of the interviewees acknowledged that avocado expansion was one of the drivers of deforestation. Two respondents (17%) refused to comment, while the other 17% of respondents denied an association or causal relationship between the avocado industry and deforestation in Michoacán, saying, for instance, ‘A lot of deforestation took place before the avocado industry . . . started to blossom. . .. There was barren land ready and the avocado industry kind of moved in.’

Interviewees did not mention their direct influence on the environmental practices of farmers. Instead, to tout the industry’s environmental responsibility, 75% of

interviewees emphasized the reforestation project for Michoacán's monarch butterfly reserve, which is partially funded by MHAIA. This suggests corporate actors prefer indirect, as opposed to direct, environmental management.

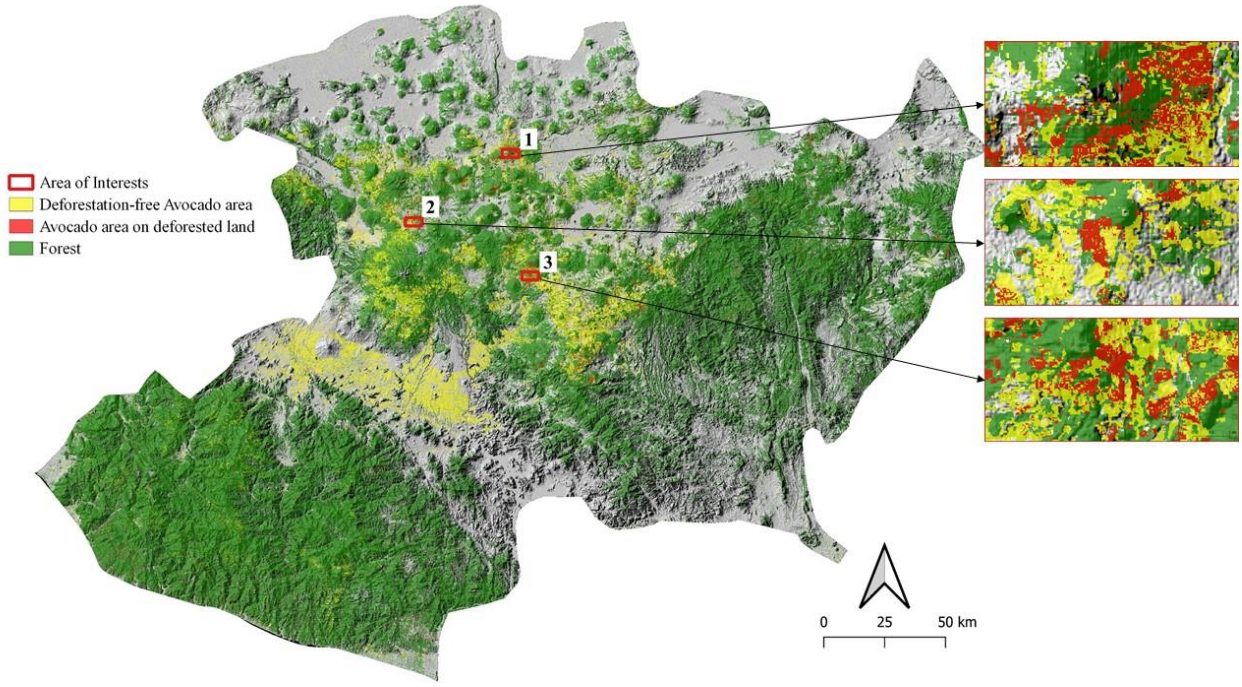
A secondary environmental issue of concern was climate change, with 40% of interviewees identifying it as a risk to avocado production. Of these interviewees, only one viewed avocado production as a driver of carbon emissions (e.g., through food miles and land use change). Another 34% of interviewees viewed climate change as a global crisis beyond their control, a phenomenon they must cope with to avoid financial loss. They portrayed the impacts from climate change as occasional catastrophic events, such as hurricanes and frosts, that disrupt avocado farming. However, climate change was rarely considered a chronic threat to Michoacán avocado farming, as illustrated in this statement: 'Our area [Michoacán] is very safe in terms of weather. . . There's some freeze damage in some areas, very specific areas, but very low stats.'

All interviewees recognized Michoacán as indispensable to U.S. avocado consumption. This market dominance depends not only on production volume but also on maintaining high phytosanitary and quality standards. Supply chain traceability is key to this. Nearly all vertically integrated avocado companies (90%) can trace individual cartons of fruit back to the orchard when quality or phytosanitary issues arise. However, they do not do this for environmental or social issues, nor do they share high-resolution information with end consumers unless quality or phytosanitary issues occur.

3.4 Estimated Deforestation from Avocado Orchards in Michoacán

Based on the Global Forest Change data, we estimated that 85,754 hectares (ha) of forest loss occurred between 2001 and 2017 in Michoacán. The rate of deforestation appeared to be increasing throughout the years, with 40% occurring between 2001 and 2010, and 60% occurring after 2010, with 2013 showing the highest forest loss (10,146 ha).

Figure 6. Avocado orchards in areas deforested from 2000 to 2018 in Michoacán.

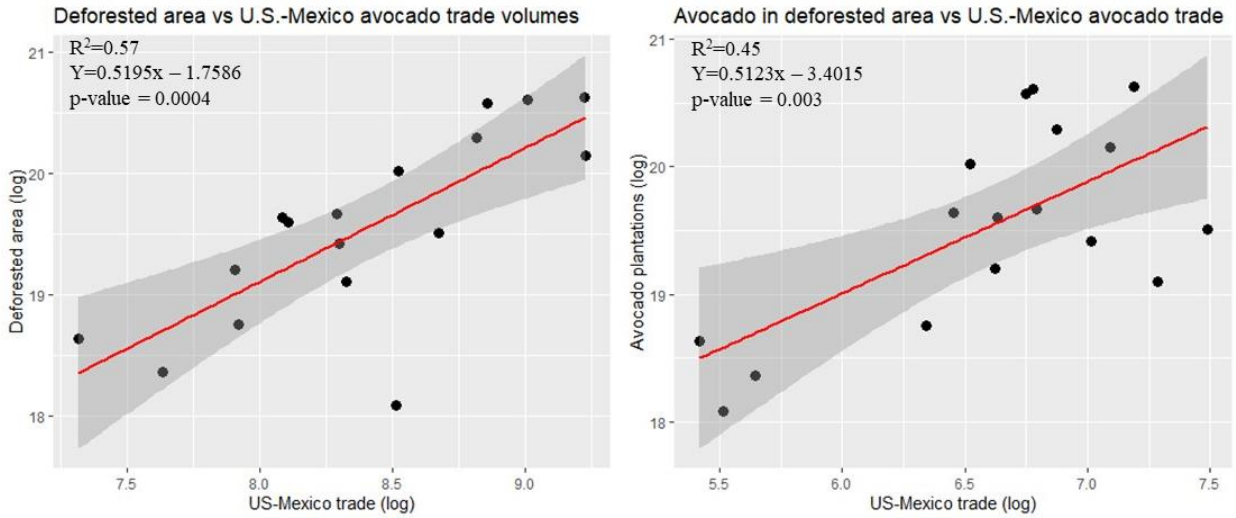


RF classified 395,946 ha of Michoacán as avocado orchards (5.91% of Michoacán's total land area). Avocado orchards are typically adjacent to existing roads, which facilitate truck transport of fruit to packing houses. Orchards are typically found between other crops in pre-existing agricultural areas. More than half (53%) of the orchards are

concentrated in 14 municipalities, including Uruapan and Tancítaro where packers are concentrated as well.

We found 14,614 ha of avocado orchards located within recently deforested areas, which accounts for 17% of total deforestation in Michoacán between 2001 and 2017 (figure 6). Based on annual volumes of forest loss, we found avocados planted on the 23% of the land deforested between 2001 and 2010, and on the 13% of the land deforested since 2010.

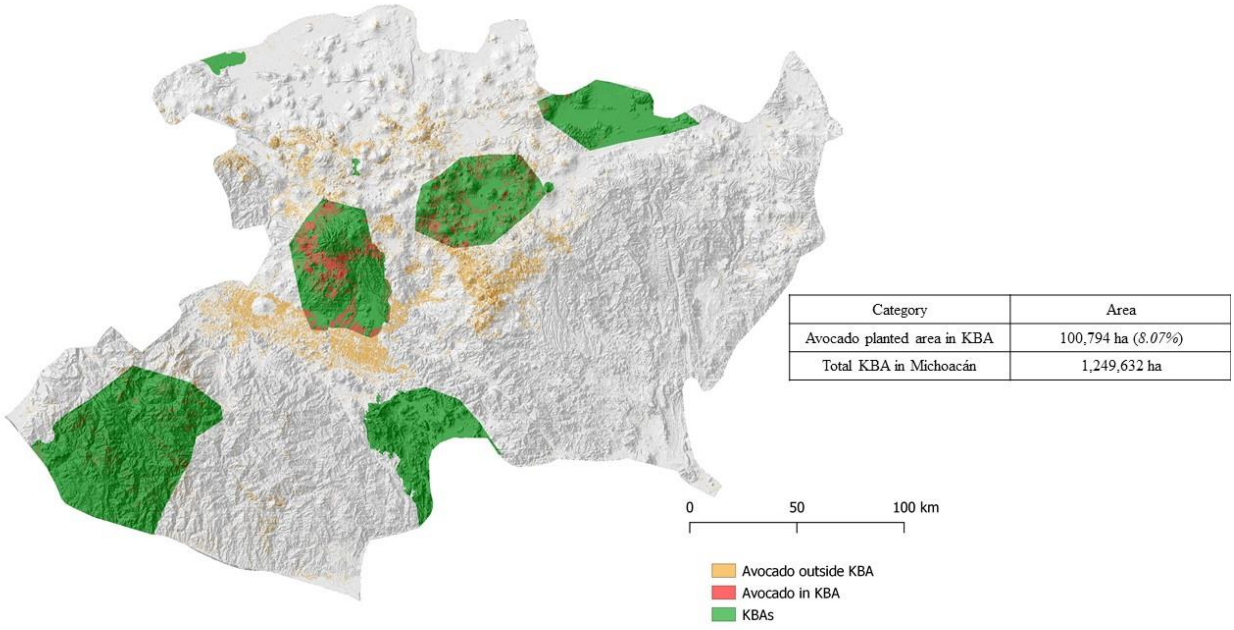
Figure 7. Linear regression of U.S.–Mexico avocado trade volume and deforestation between 2001 and 2017.



Further analysis with trade data revealed a strong correlation between U.S. avocado imports and the expansion of avocado plantations in the region (R^2: 0.45; $p < 0.001$) as well as with total forest loss in the region (R^2: 0.57; $p < 0.001$) (figure 7). In 2018, Mexico exported ~60% of its total avocado production to the U.S., while domestic consumption varied with export demand and price (USDA FAS, 2019). Since Mexican avocado producers prefer to export their products to the U.S. due to the higher returns

they get in comparison with the domestic market, the demand from the U.S. is a greater driver of avocado industry expansion and associated deforestation than Mexican domestic demand is (USDA FAS, 2019).

Figure 8. Avocado orchards in Key Biological Areas (KBA) identified by BirdLife International.



Portions of Michoacán have been classified as Key Biological Areas (KBAs) that are vital to the preservation of threatened species (BirdLife International, 2017). Figure 8 shows that over 100,000 ha (25%) of Michoacán avocado plantations are in KBAs. This suggests that land use change induced by avocados causes habitat loss and threatens important species. Such species include the monarch butterfly, which the industry claims to support through the MHAIA-funded Forests for Monarchs project and an APEAM-sponsored reforestation project.

4. Discussion

This study has reconstructed avocado supply chains to link prominent U.S. grocery retailers to Michoacán, where avocado orchards are associated with nearly one-fifth of forest loss in the state between 2001 and 2017. We found one-fourth of avocado orchards are in KBAs, suggesting that avocado expansion in Michoacán is negatively influencing the region's biodiversity. The U.S. government and vertically integrated avocado exporter–importer firms are the key actors that can address these environmental challenges. However, most interviewees (e.g., avocado trading firm and association representatives) failed to acknowledge an association between avocado expansion and deforestation, highlighting a discrepancy between perceived and actual environmental impacts. In this discussion, we identify measures to reduce the discrepancy between perceived and actual environmental impacts and to promote a more transparent, sustainable avocado supply chain.

4.1. Supply chain transparency

More transparent and accessible information is a precondition for promoting a more sustainable avocado industry. Mexican avocado exporter–importer companies maintain a farm-tracking database at the carton level, but they only share information about the country of origin with retailers and end consumers. Interviews revealed that large retailers have market power and can demand certain production conditions to vertically integrated avocado trading companies, but they lack direct connections to producers. Interviews also revealed that producers have limited market information,

suggesting that the two end nodes of the current U.S.–Mexico avocado supply chain have information deficits.

Avocado production has also been a source of social dislocation in Mexico. Avocado farming has become a lucrative industry, attracting organized crime groups. Recent victims of targeted murders in this sector include environmental activists and journalists concerned with deforestation (PRI, 2020; Wamsley, 2020). Our interviews found that the industry players are anxious about these developments.

Information deficits affect consumer behavior on multiple fronts. Most consumers are unaware of the environmental and social impacts of the avocados they consume. Concerned consumers are often not given enough information to allow them to differentiate between sustainable and unsustainable avocados. Blanket boycotts can potentially lead to indiscriminate penalties to both responsible and reckless producers (Henriksen and Ponte, 2018).

With their market power, retailers can demand farm-level tracking information from suppliers and share this information with consumers. However, transparency is only a means to an end. Along with the ‘stories’ behind avocado production, consumers also need to know whether the avocados they choose are socially and environmentally sustainable (Gardner et al., 2019), using evidence of certification, multi-stakeholder initiatives (MSIs), and related approaches.

4.2. Potential MSIs for more sustainable practices in avocado cultivation

MSIs allow supply chain actors at the top of the supply chain, such as retailers, to seek assurances of certain production conditions. Instead of having to directly monitor and manage production practices of a shifting portfolio of ~26,000 avocado farmers, MSIs facilitate indirect management through codified standards (Henriksen and Ponte, 2018). These standards are often developed through negotiations between large firms, industry associations, NGOs, government officials, citizens, and other stakeholders. Third-party auditors certify products that meet the standards of being deforestation-free, organic, fair trade, or some other designations. Through certification labels, sustainable practices are communicated to retailers and consumers, enabling them to source and shop more responsibly.

The Roundtable on Sustainable Palm Oil (RSPO) is a paradigm of how MSIs can influence industry behavior through the transmission of codified standards. RSPO was created in 2004 in response to NGO campaigns against irresponsible expansion and production methods in the palm industry (Schouten and Glasbergen, 2011; Laurance et al., 2010). Its members include supply chain actors from producers to retailers and NGOs (Schouten and Glasbergen, 2011; RSPO, 2019). This MSI has codified 39 sustainability criteria for RSPO certification to induce more sustainable business practices (Laurance et al., 2010). By branding their certification, RSPO can allow consumers to support more sustainably produced palm oil.

The success of an MSI, however, lies not in its creation but in its impacts on the ground. Some question their efficacy, claiming MSIs produce marginal environmental

improvements while protecting corporate interests from government regulations that could be more effective (Schouten and Glasbergen, 2011; Dauvergne, 2017). Others note that certification may increase burdens on impoverished farmers, who often have little representation in MSIs (Ponte, 2019; Schouten and Glasbergen, 2011). Schouten and Glasbergen (2011) also point out that consumers have marginal influence in MSIs when the supply chains and certification processes are opaque.

Notwithstanding these criticisms, MSIs can still contribute towards more sustainable production and consumption, especially in regions where the capacity for regulation is compromised (O'Rourke, 2014; Gereffi, 2001). In-place phytosanitary licensing and certified avocado production programs for the U.S.–Mexico avocado supply chain provide a ready platform for an MSI. Including NGOs is necessary because individual firms have little or no incentive in linking environmental and social issues with their product, as is providing open access to spatially explicit logistics information (that shows where environmental and social pressures occur and accumulate) maintained by the avocado trading companies. Given that some avocado associations have already adopted approaches using blockchain and mobile applications (AFM, 2017), this industry show its capacity to build a novel MSI that allows producers and consumers to have more influence on certification processes and make responsible purchases, which would benefit producers and traders committed to sustainability (Ellwanger, 2020; Henriksen and Ponte, 2018).

4.3. Attitudes and governance of supply chain actors

Interviewees ranked environmental and social concerns below quality, speed, reliability of supply, and phytosanitary concerns in the U.S.–Mexico avocado supply chains. This provides some explanation for why these actors take a direct management approach for their primary concerns—quality, speed, price—but an indirect approach to issues related to the environmental impacts of production. Externalization of quality management allows the key actors to maintain distance and outsource risk related to supply chain issues but retain 'control of control' of the avocado supply chain (Ponte and Gibbon, 2005).

More direct management would require trading companies to change prevailing attitudes by recognizing and taking a stance against unsustainable avocado production and then working on strategies to reduce these impacts. An alternative option would be to pressure firms through consumer boycotts or stricter regulations by the U.S. or Mexican governments. For instance, through the U.S. Lacey Act, American companies have had to pay stiff penalties for importing illegally sourced timber (Gibson and Warren, 2016). Although the idea is currently stalled for political reasons, the U.S. government could also release Michoacán from immense pressure by allowing other Mexican states to export avocados to the U.S. (Benzinga, 2019).

5. Conclusions

Michoacán plantations provide most of the avocados consumed in the U.S. Despite increasing awareness in popular media of the environmental and social fallout from the avocado boom, these impacts have not been linked to specific distributors and

retailers in the U.S. The opacity of this supply chain has so far hindered our ability to produce and consume avocados more sustainably. The research presented here begins to address these gaps.

We used TRACAST to reconstruct the avocado supply chain from Mexican farms to U.S. retailers. Using remote sensing and machine learning, we mapped the extent of avocado farms in Michoacán and identified the overlap between these plantations and recent forest loss. Interviews demonstrated that companies in the avocado supply chain, including key actors with the ability to address this challenge, do not see avocado production as a driver of environmental change in the region. Avocado trading companies actively outsource their environmental and social commitments while ensuring control over quality and price. Making avocados more sustainable thus requires both changes in attitude and improved supply chain governance.

The strict control currently exercised over phytosanitary conditions and the ability to track avocados back to individual farms in Michoacán make it technically feasible to know if an avocado in a U.S. grocery store is associated with environmental deterioration or violence. Like other boom crops, such as palm oil or soy, coordination between companies and key external actors is needed for any action, be it setting up an MSI or passing legislation, to make avocado supply chains more sustainable. Identifying the actors in this and other supply chains is a vital first step towards more environmentally, socially, and economically responsible production and consumption.

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Conclusion

This project estimated that 17% of the total forest loss (14,614 ha) in Michoacán between 2001 and 2017 is due to the expansion of avocado orchards, while 25% of the total avocado orchards (100,794ha) are in the key biological areas, which are important to the preservation of the threatened species. Despite these impacts, interviews revealed that the 75% of interviewed industry experts do not acknowledge avocado export industry to be a driver of forest loss in Michoacán, suggesting low environmental awareness of key actors of U.S-Mexico avocado supply chain who currently hold the power to drive environmentally and socially positive changes in the supply chain governance.

Although the manuscript above could not explore all possible environmental and social impacts of the U.S.-Mexico avocado trade, it showcased how heterogenous data could be combined on a map and used to link corporate actors to specific environmental degradation. Similar approaches could help link supply chain actors to social problems at these and other hotspots. My study also showed how the reconstructed actor-based supply chain can help NGOs and other stakeholders identify targets for brand-activism campaigns or partners in multi-stakeholder initiatives to bring about sustainability in the Mexican avocado industry.

The presented manuscript suggested transparent locational information and multi-stakeholder initiatives (MSIs) as measures to improve the sustainability governance of the U.S.-Mexico avocado supply chain, but they are not the elixirs for a more sustainable and just avocados. Bloomfield (2017) shows how activism targeting the recognizable jewelry brands to stop malicious practices of gold mining companies have been hindered

by the existence of alternative markets outside the U.S. and gold's role as an investment asset. This suggests that the branded jewelry companies do not possess power to drive industry behavior change, despite of their large shares in the transnational gold supply chain they currently hold (Bloomfield, 2017). Although avocado is not an investment asset like gold, boycotting the brands of vertically integrated avocado companies may result in mere shift of export destination of Mexican avocados. Interviewees also mentioned that although the U.S. avocado market is dependent on Mexican producers, Mexican export industry is not dependent on the U.S. market due to alternative markets. This suggests involving the leading industry actors in developing initiatives may have more positive outcomes than targeting the key actors for public shaming and boycotting (Bloomfield, 2017).

MSIs, however, are not also the ultimate solution for sustainable supply chains. Dauvergne (2017) writes how the companies involved in the sustainability initiatives can undo the benefits of the initiatives they are involved by lobbying for weaker regulations, continuing the rapacious business operations, and actively hiding the environmental and social costs by keeping supply chains opaque. In such cases, MSIs will only serve as a haven for irresponsible companies from accountability (Dauvergne, 2017). Building an effective avocado MSI requires rigorous inspections by the non-corporate actors (NGOs, governments, and consumers) who will ensure that 'good' players are rewarded and 'bad' players are not (Henriksen and Ponte, 2018). Although they can produce positive change, MSIs have been criticized for harming impoverished farmers by creating barriers to entry and increasing costs and demands on the small-scale producers who often have little say

in the MSI production process (Ponte, 2019b; Schouten and Glasbergen, 2011). MSIs can also turn into a “vote with your fork” movement that fails to positively change the entire industry behavior and only creates additional niche market for the concerned upper-class white consumers (Kojola, 2013). The future MSIs should be more inclusive and just to become efficient in building a sustainable supply chain. In its essence, this means the need for introduction of environmental justice framework in future transnational MSIs for their efficacies (McElroy, 2015).

For my future research, I will continue to develop a method to systematically pinpoint potential hotspots of environmental injustice along supply chains. By doing so I hope to address the marginalization problems and improve the performances of the sustainability MSIs. This can contribute to conviction that we need to design production and consumption systems that respect both people and planet.

APPENDICES

Appendix 1. Characteristics of the Landsat satellite images

Date	Satellite	Sensor	Path	Row	Resolution
2019-05-12	Landsat 8	Operational Land Image (OLI)	27	46	30
2019-05-12	Landsat 8	Operational Land Image (OLI)	27	47	30
2019-05-03	Landsat 8	Operational Land Image (OLI)	28	46	30
2019-04-01	Landsat 8	Operational Land Image (OLI)	28	47	30
2019-05-10	Landsat 8	Operational Land Image (OLI)	29	46	30
2019-04-08	Landsat 8	Operational Land Image (OLI)	29	47	30

Appendix 2. Top 20 U.S. Importers and Mexican exporters of Mexican Hass avocado

Rank	Importers	Gross weight (Mt)	Exporter	Gross weight (Mt)
1	Henry Avocado	62592	Aztecavo S.A.	53915
2	West Pak Avocado	47257	Aguacates Chahena Y Mas	41533
3	Del Monte Fresh Produce	33844	Grupo West Pak De Mexico	41401
4	Healthy Avocado	32379	Del Monte Grupo Comercial	34291
5	Index Fresh	26733	Frutas Finas De Tancitaro	28961
6	Tacintaros Finest Fruit	21937	Aguacates Seleccionados JBR	28420
7	Villita Avocados	18135	Grupo Aguacatero Mexicano	25815
8	Green Fruit Avocados	16361	Global Frut	18479
9	Mc Daniel & Chirico Distribution	15693	Aguacates La Bonanza	18325
10	Sweet Seasons	15230	Promotora Mexicana Gaitan	13303
11	Calavo Growers	13784	Ramon Valencia Espinosa	10451
12	London Fruit	10569	Empacadora Avehass	9671
13	Westfalia Fruit Marketing	10458	Agricola La Vina	9384
14	Promexavo	9202	Mission De Mexico	8693
15	Prometo Produce	8755	Prometo Produce	8422
16	Mission Produce	8675	Frutas Acapulco	7699
17	T And L Produce	8286	T&L Produce Mexico	7587
18	Stonehill Produce	8047	Garcias Quality Frut And Produce	7356
19	Valvilla Produce	7580	Valencia Quality Avocados	7317
20	Lgs Specialty Sales	6357	Iscavo Mexico	6216

Appendix 3. The U.S. importers supplying Mexican avocados to the U.S. retailers

Retailer	Importer	Source
Kroger *(Ralph's)*	Del Monte Fresh Produce	Fresh Del Monte Produce, Inc. (2019)
	Index Fresh Inc.	Linden (2016)
	Calavo Growers Inc.	Calavo Growers, Inc (2019)
	Mission Produce	Hoops (2015), Interview (2019)
Albertson's	Del Monte Fresh Produce	Fresh Del Monte Produce, Inc. (2018)
	Calavo Growers Inc.	Calavo Growers, Inc (2017)
	Mission Produce	Hoops (2015), Interview (2019)
Walmart	Del Monte Fresh Produce	Fresh Del Monte Produce, Inc. (2019)
	Index Fresh	Walmart, Inc (2014)
	Calavo Growers Inc.	Calavo Growers, Inc (2019)
	Mission Produce	Hoops (2015), Interview (2019)
Costco	West Pak Avocado Inc.	Costco wholesale (2018)
	Index Fresh	Ponder (2013)
	McDaniel and Chirico Distribution Co.	Ponder (2013)
	Calavo Growers Inc.	Ponder (2013), Calavo Growers, Inc (2017)
	Del Monte Fresh Produce	Fresh Del Monte Produce, Inc. (2018)
	Mission Produce	Costco wholesale (2018)
Target	Del Monte Fresh	Fresh Del Monte Produce, Inc. (2018)
	Calvo Growers Inc.	Calavo Growers, Inc (2017)
	West Pak Avocado	West Pak Avocado (2020)

Appendix 4. Vertical integrations of major avocado trading companies: Exporter-Importers

Importers	**Exporters**
West Pak Avocado Inc.	Grupo West Pak De Mexico S De Rl De Cv
Del Monte Fresh Produce Co.	Del Monte Grupo Comercial Sa De Cv
Tacintaros Finest Fruit Llc	Frutas Finas De Tancitaro S.A. De C.V.
Calavo Growers Inc.	Calavo De Mexico Sa De Cv
Westfalia Fruit Marketing Usa Llc	Aztecavo S.A. De C.V.
Prometo Produce Corp	Prometo Produce S.A. De C.V.
Mission Produce	Mission De Mexico Sa De Cv
T And L Produce Inc.	T&L Produce Mexico Sa De Cv

Appendix 5. U.S. regulations on international trade's environmental impacts

The U.S. government also had standards for the environmental justice (Executive Order 12898) and the Endangered and Threatened Species Act (16 U.S.C. 4332 et seq.) other than phytosanitary standards, but these standards were only enforced when the U.S. government was changing its policy related to the supply chain.

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