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Article

Land Change Regimes and the Evolution of the Maize-Cattle Complex in Neoliberal Mexico

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Abstract. How globalization impacts native land cover has become an important issue in studies addressing environmental change, which draw explicit attention to processes of cause and effect operating over significant distances. The literature shows that globalization constitutes an important underlying driver of both deforestation and forest transition via demographic and economic phenomena such as migration and remittance flows. Yet, little is known about how global forces mold the spatial structure of agro-commodity production and how this impacts the balance of forces affecting land change at the meso-scale, within the boundaries of the nation-state. The research presented here fills this gap by examining production networks for Mexico, a large OECD country with complex land change dynamics that has recently experienced a dramatic opening to the world economy. Specifically, we consider how maize and beef commodity chains evolved over the past few decades into a highly interdependent maize-cattle complex, and suggest linkages to patterns of land change at the national scale. Using land cover maps for 1993, 2002, and 2012, at the national scale, governmental statistics and datasets, interviews with key informants, and field observations the article provides an analysis of the impact of

neoliberal reforms on the changing geography of beef and maize production, and argues that this process underlies the evolution of Mexico's land change regime, both before and after the NAFTA reforms. As such, the article presents an account, and a case for further research on the topic of how teleconnections are constituted by spatially-extensive food production networks.

Keywords: agro-commodity production networks; land change regime; Mexico; neoliberal reform; beef-cattle; maize; agrarian change

1. Introduction

Global land cover change continues to concern both scholars and the general public. Loss of tropical forest, in particular, creates significant impacts with respect to biodiversity resources and the carbon cycle. Recently, researchers have grown hopeful that countervailing processes of forest recovery, often referred to as forest transition, will mitigate the environmental damages imposed by forest loss [1,2]. The UN's REDD program has served to focus attention on questions about how to reduce deforestation and to encourage forest transitions [3–5]. Such policy initiatives are praiseworthy, but their ultimate success depends on uncovering the underlying drivers of land change (LC), whether forest loss or gain. Adding complexity to the policy debate are the far-reaching impacts of globalization on localities via teleconnected linkages between spatially-displaced sources of supply and demand, especially for agricultural products.

This article links broad shifts in national LC dynamics with spatial shifts of food production networks in the context of an evolving institutional regime. Specifically, it addresses the combined issues of forest loss and forest transition as they occur within the borders of an individual nation by assessing the changing territorial imprints of maize and beef-cattle (M-and-B) production in Mexico, a populous OECD country. LC is often driven by agricultural change, so it should come as no surprise that substantial research identifies M-and-B production as a proximate cause of Mexican LC. However, the present article goes one step further by embedding proximate causation within the broader social structures from which M-and-B dynamics originate. In doing so, the paper addresses LC through the "new economic geography," which over the past decade has yielded insights into the economy's embeddedness in social relations, and the dynamics of agglomeration, innovation, and international trade. Thus, the article moves beyond what has been a long-conceptual reliance on neoclassical economics, location rents, and decentralized profit maximizers. Commodity chains provide an explicit approach to analyze the material embodiment of spatial interactions, thereby providing a way to explicate teleconnections [6].

Mexico presents a useful case for three reasons. First, Mexico reveals complex LC dynamics, with some parts of the country experiencing forest loss, and other parts forest transition. The interlinked nature of forest loss and transition enables us to approach LC at the national scale as an integrated process rather than addressing deforestation or forest transition independently. Second, Mexico shows important cross-border phenomena both in the delivery of commodities to market (Mexican beef to US consumers and *vice versa*; US maize to Mexican feedlots), and in the sourcing of primary inputs

(Mexican fattening of calves from Guatemala and Nicaragua). Third, data availability make it possible to consider LC processes in periods both before and after neoliberal reforms, starting with the country's admission into the General Agreement on Trade and Tariffs (GATT) in 1986 and culminating with the North American Free Trade Agreement (NAFTA), effective on January 1, 1994. NAFTA substantially opened the Mexican economy to foreign investment and trade, and formed part of a process of economic restructuring including both privatization of the *ejido* commons [7] and state retraction from direct intervention in the economy. Thus, NAFTA and the privatization of once-communal lands reveal twin facets of Mexico's emergent neoliberalism. Substantial research addresses the effects of neoliberal reforms on welfare and rural livelihoods of small-scale producers, food security, and agrobiodiversity loss (e.g., [8–10]). Few studies however have addressed the dynamics and interactions of agro-industrial production nodes, the leading sectors that have benefited from mainstream agricultural policies. This study aims to close this gap.

With these considerations in mind, we now state the article's two prime objectives, which are: (1) to identify shifts in Mexican beef cattle and maize (M-and-B) production networks resulting from neoliberal reform and integration into global markets, and (2) to suggest links between Mexican LC and spatial reconfigurations of M-and-B production networks. We pursue our objectives by first considering prior research on the topic of globalization and LC. After this comes an argument suggesting how LC articulates with commodity chains in agriculture. We next address the Mexican case, describing both the impact of neoliberal reform on M-and-B production and trends in LC over the past several decades. This leads to a discussion of changing patterns in production and land cover suggestive of a causal link between the two phenomena. The article ends with a brief conclusion.

2. Globalization, LC and Commodity Chains

2.1. Globalization and LC

Assessing the impacts of globalization on LC has emerged as a major research area within LC science, and it is well-recognized that global forces drive for both deforestation [11,12] and forest transitions in tropical ecosystems [1,3,4,13–15]. The literature has shown that globalization underlies regional and local LC via multiple pathways, including the spatial displacement of land use [4,16,17], land sparing through technological diffusion [18,19], and shifts in the aggregate demand for land [12]. Mexico provides an important case for examining LC stemming from structural reforms encouraged by global lending institutions, such as the International Monetary Fund and the World Bank. A number of relevant efforts, several conducted under the auspices of the Southern Yucatan Peninsular Region (SYPR) Project [20], consider how macro-scale policy adjustments shape land use decisions of households at local and regional scales [21–32]. While formulations linking global processes to LC yield a perspective offering potential insight at multiple scales, effects at meso-scale, operating across an entire nation-state, have not received much attention (see [33] for an effort void of land cover data). In particular, little is known about how globalization alters regional interactions within a national land use system and how this process is manifested in LC outcomes. This article complements previous research by analyzing LC in Mexico associated with the M-and-B production system in its transition towards an export-oriented development model. We follow insights by Myers [11], Hecht [34], and

others in arguing that the political economy of global food systems provides a productive context for investigating LC processes.

The article takes LC as a broad empirical category affecting all types of land cover, in both urban and rural settings. It focuses on forest gains and losses (both temperate and tropical) and does so at the scale of the nation-state, taking Mexico as its primary focus (but also considering circumstances in Guatemala and Nicaragua, now known to supply calves to beef operations in the Mexican north). Terminologically, we refer to the social and economic forces responsible for LC, including both distal drivers and proximate causation, as an LC regime (LCR), in which case the interest here resides in describing the structure and function of Mexico's LCR in pre- and post-neoliberal reform periods. A foundational hypothesis is that LCRs possess important linkages to the agricultural production system, in this case involving M-and-B. Figure 1 depicts Mexico's LCR by combining the conventional distal driver/proximate causation heuristic [35] with commodity chain descriptors.

Before considering Mexico's changing agricultural economy, it is important to articulate our understanding of neoliberal reforms in the present setting. Specifically, we regard neoliberal reform as comprising the cultural, social, and political changes that pave the way to the liberalization of markets for consumer goods and production inputs, particularly capital. This process involves both the reduction of trade barriers—essential to economic globalization—and the privatization of state assets and communal lands. Conventional wisdom suggests globalization has profoundly affected export opportunities for both Mexican producers looking outward, and for transnational corporations interested in Mexican markets. Our focus on neoliberalism reflects our strong sense that the reform agenda has opened Mexico to global markets and foreign capital at the same time as it has privatized once communally-owned land in hopes of capturing new efficiencies of production.

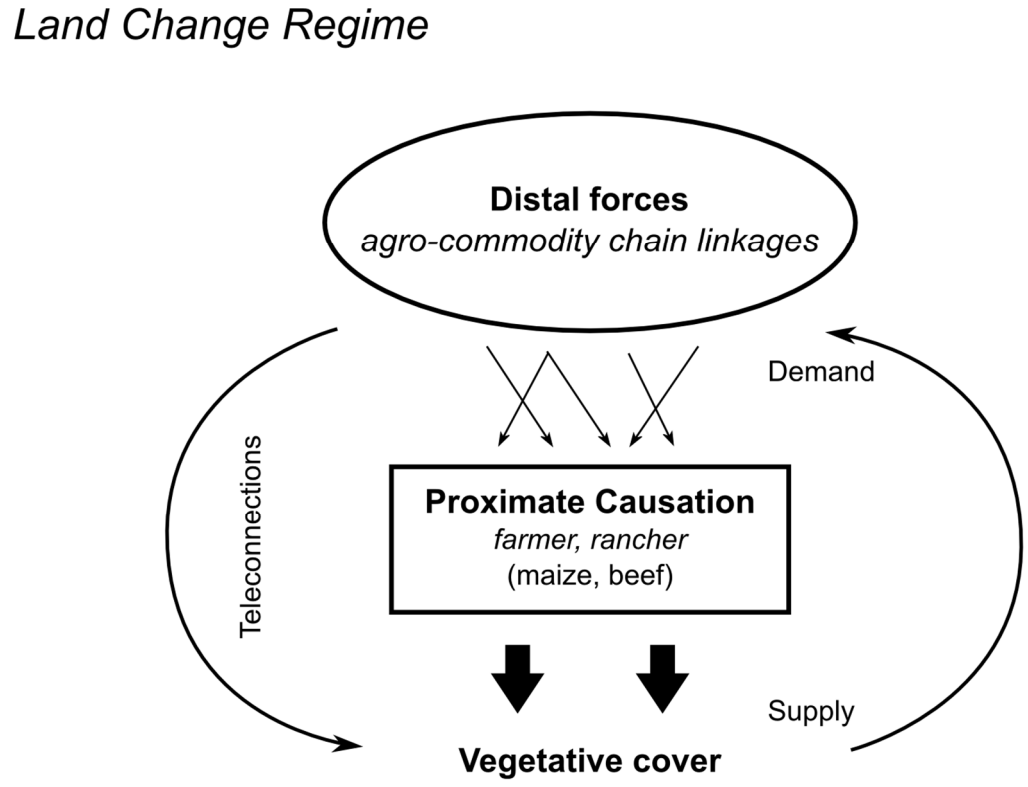

Figure 1. Conceptualization of Mexico's Land Change Regime.

2.2. Linking LC and Commodity Production Networks

Although traditional economic geography received wide application in LC science (see [36] for a review), we opt for the insights available from the "new economic geography" [37–39], a literature in which commodity chains and production networks figure prominently [40]. This body of work as yet has had little application to environmental issues, and in particular to LC [41,42]. In this regard, we heed the call by Munroe and coworkers [6] to reinvigorate LC science with new approaches that redirect our attention from decentralized land managers to corporate actors, governance systems, the cultural embeddedness of economic activities, and globalized production and distribution networks [39,43–46]. Thus, we view the world's food system as a type of global production network, comprising complex webs of production relations—or commodity chains—which ultimately yield the food products critical to human subsistence.

World systems theorists [47] first introduced commodity chain approaches. What we mean by such chains is the linked set of products and processes that lead to the creation of a given consumer good (e.g., food item) through the cascade of inputs that produced it, including capital investments, raw materials, transportation mechanisms, and labor expended at each step of production. Commodity chains have become highly popular in several disciplines for their heuristic ability to link abstract processes with the everyday materiality of localized production contexts. Although the notion of the commodity chain originates with world systems theory, Bair [48] identifies a significant disjuncture between the Hopkins and Wallerstein conceptualization and that associated with Gereffi and his colleagues (often referred to as the "global commodity chain" or GCC paradigm), which usefully differentiates between production- and consumption-oriented chains and offers a more specific firm-centered mode of institutional analysis. The GCC approach has become particularly influential in the last couple of decades.

According to Gereffi [49], a commodity chain has four main features including: (1) an input-output (IO) structure (i.e., products and services linked sequentially in value-adding activities); (2) a distinct geography (with raw materials at "production" nodes and final demand at "consumption" nodes, plus intermediate processing stages along the way); (3) a governance structure that adjudicates the allocation of financial, material and human resources, as well as economic surpluses, across the chain; and (4) an institutional context encompassing government, labor regimes, non-governmental organizations (NGOs), and other regulatory bodies.

In more recent and inclusive theorizations of commodity chains, the radiating effects of the commodity at the consumption node, the social and ecological conditions at the production node, and the complex intersections of commodity chains at various intermediating and terminal points complement simple models of commodity movements [50,51]. This expanded version integrates effects at the consumption node with the social and natural conditions at the production node in order to show how one affects the other [52]. In contrast to earlier versions, the expanded formulation sees commodity movements (the vertical dimension) connecting nodes that are *places* (horizontal dimensions) located at different points along the chain. This recognition invokes explicitly spatialized conceptions such as territory, embedding various stages in the chain in different locales with unique historical, environmental, and sociopolitical contexts [53]. Such a formulation provides an ideal vehicle for exploring LC because it equates nodes with particular places that chains simultaneously produce and within which they are ensconced, thereby establishing a material dialectic with the

environment. Chains, of course, reflect the decisions and actions of a wide variety of actors at different moments in the process of creating a good and delivering it to consumers [46].

Although the commodity chain has been used to identify local environmental impacts at production nodes, such as the use of pesticides and the clearance of coffee shade given the mechanization of production [54,55], explicit applications to LC are hard to find. We seek to fill this void by deploying the powerful concept of the commodity chain to explain a compelling set of questions in LC science. Our argument is as follows: Since food processing moves in spatial displacements from the production node, or agricultural "place," to the final consumer, a series of input-output (IO) relations manifest spatially, which is to say that a chain territorializes as value is added on route to consumers [56]. These IO relations evolve as the institutional environment changes, and with it chain governance structures. If spatial change occurs as a consequence of this cascading effect, the LCR will in all likelihood be altered. For Mexico, the conceptual implication is that changes in the M-and-B commodity chains resulting from neoliberal reforms have altered the LCR. Throughout this article, we use the terms *commodity chain,* and *production network* interchangeably, with "production network" deployed to convey a complex web of relationships beyond the strictly material movements of produced goods in the forward steps of a chain.

3. The Mexican Case

We now turn to the empirical case and briefly consider both commodity chain transformations and LC in order to set the stage for our empirical analysis. We begin with a discussion of how neoliberal reforms impacted Mexican agriculture, then provide an overview of LC occurring over the last several decades within key biomes.

3.1. Neoliberal Reform and Mexican Agriculture

Mexico's agricultural sector has changed greatly during the last 30 years. During the 1930s–1980s, food commodity chains were territorialized largely within national borders and managed by a state-led governance structure (e.g., [56]). As part of the strategy for import substitution industrialization (ISI), the Mexican government subordinated food policies to the interests of an emerging national urban-industrial complex. Like many economies in Latin America, South Asia, and Eastern Europe during the post-WWII period, Mexico implemented a development strategy focused on high value-added commodities (e.g., automobiles and electronics) [57], with food policy as a critical component. The goal was to satisfy the demands of an impoverished peasant sector with little access to urban markets while, at the same time, keeping at bay inflation in food prices for the rapidly-growing urban sector. By subsidizing food production through state-owned institutions (*parastatals*), the government contained political unrest even during times of economic turmoil and legitimation crises, while fortuitously ensuring a relatively easy transition to an outward development model [58]. During the ISI period, the Mexican government built a huge complex of state-owned subsidiaries to control food commodity chains. In sum, prior to neoliberal reforms of the 1990s the Mexican government heavily regulated food production exercising a monopoly over functions such as land distribution, price and credit policies, extension services, and food supply patterns.

The shift towards a neoliberal regime was inaugurated with Mexico's acceptance of the General Agreement on Trade and Tariffs (GATT) in 1986, and culminated with the signing of NAFTA in 1992 (with implementation on 1 January 1994). Other reforms were implemented before and after this period, but the most important changes took place between 1986 and 1994, a period referred to as the "second agrarian reform" [59]. This involved the abandonment of price controls, elimination of the parastatal system, and widespread privatization of lands held in common, the *ejidos* [60,61]. Following Harvey [62], by *neoliberal reforms* we refer to the series of policy changes directed towards the consolidation of the Mexican neoliberal state, notably including deregulation, privatization, trade liberalization, and facilitating the entry of foreign capital.

The impact of neoliberal reforms on food commodity chains was profound; food governance shifted from *parastatals* and small retailers to large domestic corporations and foreign multinationals [63], large scale and capital-intensive production systems rapidly expanded [64], and dependency on global trade greatly increased. However, far from complete withdrawal of the state from food production, in the neoliberal regime the government remains a key player re-stating, negotiating, and legitimizing nationalistic goals around food production. In line with neoliberal principles, what is different now is the strong reliance on the paradigm of economic efficiency and market mechanisms rather than equity to implement national food policies. This change is particularly evident in federal programs and policies directed to support maize production.

The following sections detail the evolution of M-and-B production networks from two loosely-integrated commodity chains isolated from global competition into a maize-cattle complex largely dependent on global input and export markets, corporate capital, and private regulation. The analysis of this complex should enable us to: (1) understand how capital intensification in agriculture, an important theme in LCS and forest transitions literature [3,4,14,19,65], can trigger unexpected effects on telecoupled land use systems, and (2) explain processes of regional specialization and differentiation of regional land change regimes in rural Mexico, specifically forest transitions in mountainous regions and deforestation in tropical biomes.

Before continuing we make a brief methodological note. This research is based on a variety of information sources: (1) land change data was estimated using land cover maps published by the Instituto Nacional de Estadística y Geografía (INEGI) for years 1993, 2002, and 2012 using a scale of 1:250,000. These data represent the most comprehensive (temporally and spatially) set of information available at the national scale for Mexico. (2) Data from the agricultural census for years 1991 and 2007 at *municipio* level, the most disaggregated agricultural statistics available for the 1990s. (3) Statistics on cattle trade from the Secretary of Agriculture of Chiapas and Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA). This data is collected from zoosanitary inspection points distributed across key trade routes. Invoices from all cattle shipments traveling through these routes are registered and include data on freight origin and destination. (3) Preliminary results from 20 semi-structured interviews and 30 informal interviews with key informants conducted between March and July of this year. Interviews included the following nodes: warehouses, producer organizations, national association of federally inspected slaughterhouses (Asociación Nacional de Establecimientos TIF, ANETIF), national association of feedlots (Asociación Mexicana de Engordadores de Ganado, AMEG), national association of cattlemen (Confederación Nacional de Organizaciones Ganaderas, CNOG), national association of retail stores (Asociación Nacional de

Tiendas de Autoservicio y Departamentales, ANTAD), feedlots, slaughterhouses, trading companies, and government officials from the Secretary of Agriculture (Federal and state branches). (4) Field observations and informal interviews conducted in Southern Veracruz and Eastern Chiapas in 2013 with ranchers, local cattlemen associations, and brokers hired by feedlot companies. Collecting datasets and conducting interviews required traveling to different locations across Mexico, including Mexico City, Sinaloa, Jalisco, Querétaro, Michoacán, Veracruz, Chiapas, Mexico State, and Tabasco.

3.2. Maize

About 14% of the national territory (28 million km^2) is dedicated to perennial and annual crops. Maize, the most important crop in areal terms, claims nearly half the total crop land. Taking advantage of a huge diversity of landraces [66], Mexican growers are able to plant maize under almost any environmental condition. Maize farming continues as an important cultural practice and represents a key component of the livelihood systems of indigenous communities and small holders [67]. An important share of the national grain production has always derived from peasant households producing for subsistence, under rainfed conditions, low capital investments, average yields between 1 and 2 metric tons (MT) per hectare and farms units of less than five hectares. A very different sector develops in agro-industrial enclaves articulated to the urban-industrial complex. Here, maize production occurs under very different conditions; average farm size is higher, input and output markets are well developed and capital intensification results in average yields above 6 MT/ha. Agriculture in this region is highly dependent on knowledge and technologies provided by foreign multinationals. For example, Sinaloa, the leading state in maize production reached an average yield of 12 MT/ha in 2014 using hybrid seeds produced by Monsanto.

Figure 2 shows the reconfiguration of the maize production network from the eras of pre-neoliberal reforms to post-reforms using an IO chain structure. During the pre-reform period (Figure 2a), state food policy was promulgated through the Compañía Nacional de Subsistencias Populares (CONASUPO), which by 1975 administered a total of 16 subsidiaries and regulated not only all grains and dairy production, but also a wide variety of consumer goods ranging from school supplies to construction materials [68]. Maize production involved six main subsidiaries operating at different nodes in the network, including input markets, warehouses, distribution and retail trade, and food processing. The subsidiaries operated in parallel to the private sector with market shares varying by node and product. For example Ochoa ([58] p. 166,183) estimates that BURUCONSA, a branch specialized in grain storage and conservation, purchased 70% of the national grain output in 1974 (including maize and other grains), while MICONSA and ICONSA, the processing industry, accounted for between 30% and 40% of the maize flour market. The retail branch, DICONSA, administered more than 11,000 stores in 1982 distributed across urban and rural areas. In other policy domains (e.g., price controls, import and export quotas), state governance was absolute. Although focused on political than on rural development goals, pre-reform food governance was able to effectively link production areas (even from remote locations) with consumption centers in the cities and in poor rural areas with low productivity.

Following the debt crisis of 1982, and forced by international creditors, Mexico shifted to a neoliberal development paradigm, with radical changes in food governance and a new geography in the maize production network. As part of the austerity measures mandated by the International

Monetary Fund, the federal government dismantled the *parastatal* system, and transferred its functions and assets to the private sector. CONASUPO was shut down by executive order of President Ernesto Zedillo in 1999 [69] and only one of its subsidiaries, DICONSA, remains today. Several other measures affected land distribution (privatization of the *ejido*), rural development, credit and finance, extension services, *etc.* Even though the Mexican government intended a gradual liberalization of maize, prices fell nearly 50% immediately after NAFTA came into force [8] and continued a downward trend that was only briefly interrupted during the 2007 world food price crisis. Consistently lower prices and dismantling of the network of state subsidiaries severely impacted an already impoverished peasant population. Mexico's farming population declined dramatically between 1994 and 2004 [70], and many who remained downgraded agriculture to a secondary role in their household livelihood strategies [70,71].

The pre-reform governance structure was replaced with what Gereffi [49] called buyer-driven commodity chain, in which three nodes emerged as lead players: the milling industry, large brokers and distributors, and feed processors and animal fattening operations (Figure 2b). In the post-reform maize commodity chain, these large buyers effectively control maize prices, storage and distribution, and increasingly quality and safety standards. MASECA, the largest maize milling company in the world, and MINSA control together 96% of the domestic maize flour market. The multinational company CARGILL is a leading player in distribution for wholesale and retail, and is increasing its participation in milling. DICONSA remain an important buyer, but today only distributes grain in small rural communities under the auspices of welfare programs. The livestock sector became the main grain consumer in this period, in particular poultry farms, feedlots, and swine farms. Most maize imports are used for animal fattening and feed processing, two activities that have expanded at astonishing rates in Mexico since the liberalization of grain markets.

One main advantage of large buyers is their ability to buy grain from different source nodes within the country or from global markets. Given the huge US grain surplus produced at subsidized costs, US maize is usually cheaper than domestic grain even considering transportation costs. Thus, in the preferred source of grain for this sector is the US. In fact, the raise in livestock production has been accompanied by a concomitant raise in US maize imports; in 2014 Mexico imported a total of 10.2 million MT of maize from the US (nearly half of Mexico's annual production), compared with less than 3 million MT during the early 1990s [72]. However, it is important to distinguish between maize varieties produced in México and the yellow variety produced in the US. Mexico produces white maize (among several other varieties) for human consumption, most of it in the form of *tortillas*. The US produces yellow maize for animal feed, to extract by-products for the food processing industry (corn starch, corn syrup, oil, *etc.*) and, more recently, to produce ethanol for biofuels. Thus, these varieties should behave as two different commodities with different use and exchange values. So why do US imports of yellow maize affect Mexican domestic prices of white maize? The answer lies in the combined effect of the rise of the livestock sector as a major consumer of grain, a problem of overproduction resulting from a transition of maize cropland area to agro-industrial enclaves, and the implementation of neoliberal food policies to allocate excess production.

White and yellow maize are substitutes for animal fattening operations within a certain range of variation in quality and price. Livestock producers prefer yellow maize, although they can opt for white maize if it is of higher grade and lower price than yellow maize. The demand of maize for

livestock fattening operations currently represents at least 1/3 of the aggregated demand of both yellow and white maize [73].

Early observers warned about losing the ability to produce food staples if public support for the peasant sector ended [74]. Nevertheless, more than 20 years later maize output almost tripled relative to pre-reform levels. What these commentators failed to predict was the relocation of production to some of the most productive lands in the country, a process that resembles the forest transitions in some contexts [3,4,65]. Although in aggregate terms the area under maize has remained stable over the last 30 years [75] regional variations are emerging (Figure 2a). Cropland area devoted to maize decreased in 53% of *municipios*, losing a total of 1.2 million ha that were relocated somewhere else (Figure 3a). Some of the maize crop land shifted to agro-industrial enclaves, such as the coastal plains in Northern Sinaloa and El Bajío and Zacatecas in West-Central Mexico. Sweeney *et al.* [75], using a different dataset, estimated that maize-planted area declined in rainfed lands at a rate of 120,000 ha/yr since 1980, but increased in irrigated lands at a rate of 49,000 ha/yr. For example, Sinaloa was not an important maize producer in 1980, but by 2011 this state alone supplied nearly 20 percent of the national output of this staple [76]. Relocation of maize cropland area did not occur only towards high input agriculture. An unexpected finding is that between 1991 and 2007 most of the areal expansion of maize crop lands took place in traditional forest frontier regions, such as the Southern Yucatan peninsula, La Selva in Chiapas, Sierra Tarahumara in Chihuahua and Tierra Caliente in Michoacán and Guerrero. While we still need additional research to confirm this finding, one possible explanation may be that the expansion of maize in some of these areas responded to processes of intensification of cattle-raising in the system of "stockering," a stage in which calves graze on pasture before entering the feedlot. This hypothesis will be addressed further in future research.

Increasing yields of white maize resulting from spatial relocation of production resulted in a problem of excess supply. Demand of white maize for human consumption in Mexico is estimated at 12 million MT/year, but annual production of this grain reached 21 million MT in 2014 [77]. Thus, 9 million MT need a market every year. The Contract Agriculture Program (PCA) was the solution offered by the government to this problem. PCA is a combination of subsidies and market instruments that effectively link white and yellow maize markets by fixing domestic prices with the international price published by the Chicago Board of Trade (CBOT). The PCA subsidizes the difference between the price of yellow and white maize at any consumption node, so buyers that enter the program can purchase white maize at the price of yellow maize. Producers on their part can fix a minimum price. The so-called Options, an insurance policy to protect against variations between futures (the price at the signing of the contract between buyers and producers) and real prices (the price when the merchandise is delivered), are also subsidized by the PCA. In 2014 14 million MT, nearly 3/4 of Mexico's maize output, was traded through PCA [73].

For a number of reasons the PCA is considered a success. First, it effectively linked white maize production to animal feed markets, allocating excess domestic production into a rapidly growing sector of the economy in need of abundant and cheap grains. Second, by securing a price between producers and buyers it reduces the effects of speculators on domestic prices. Third, PCA control of white maize prices benefits not only the livestock sector, but all consumers along the chain. Among those who benefit the most from this program are large milling corporations, which can purchase cheap and high-quality white maize, usually a more expensive alternative on international markets.

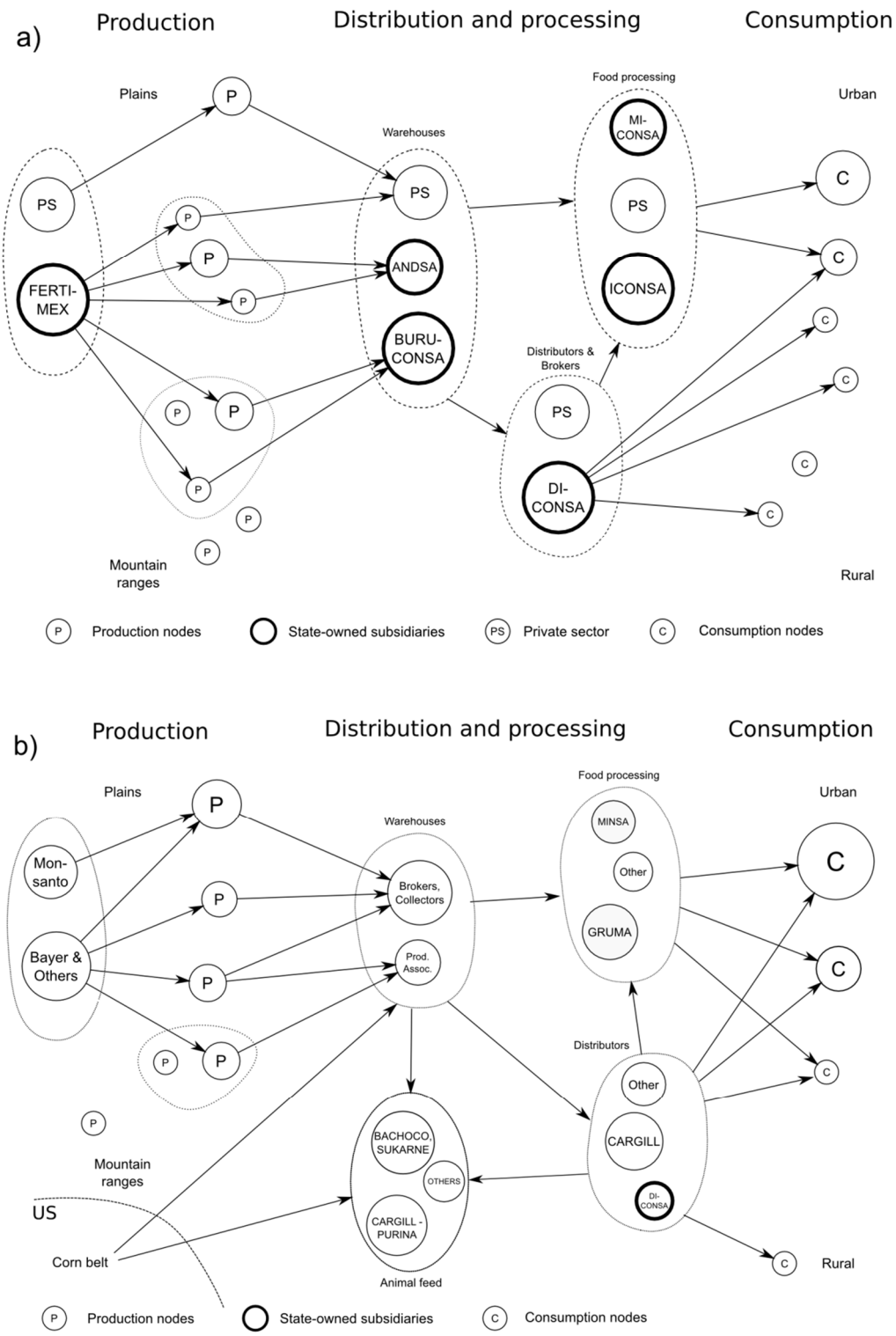

Figure 2. Maize IO production network structure. (**a**) Pre-reforms production network. ICONSA (Industrias CONASUPO S.A.), MICONSA (Maíz Industrializado S.A.), DICONSA (Distribuidora CONASUPO S.A.), ANDSA (Almacenes Nacionales de Depósito S.A.), BURUCONSA (Bodegas Rurales CONASUPO S.A.), FERTIMEX (Guanos y Fertilizantes de México S.A.). (**b**) Post-reforms production network.

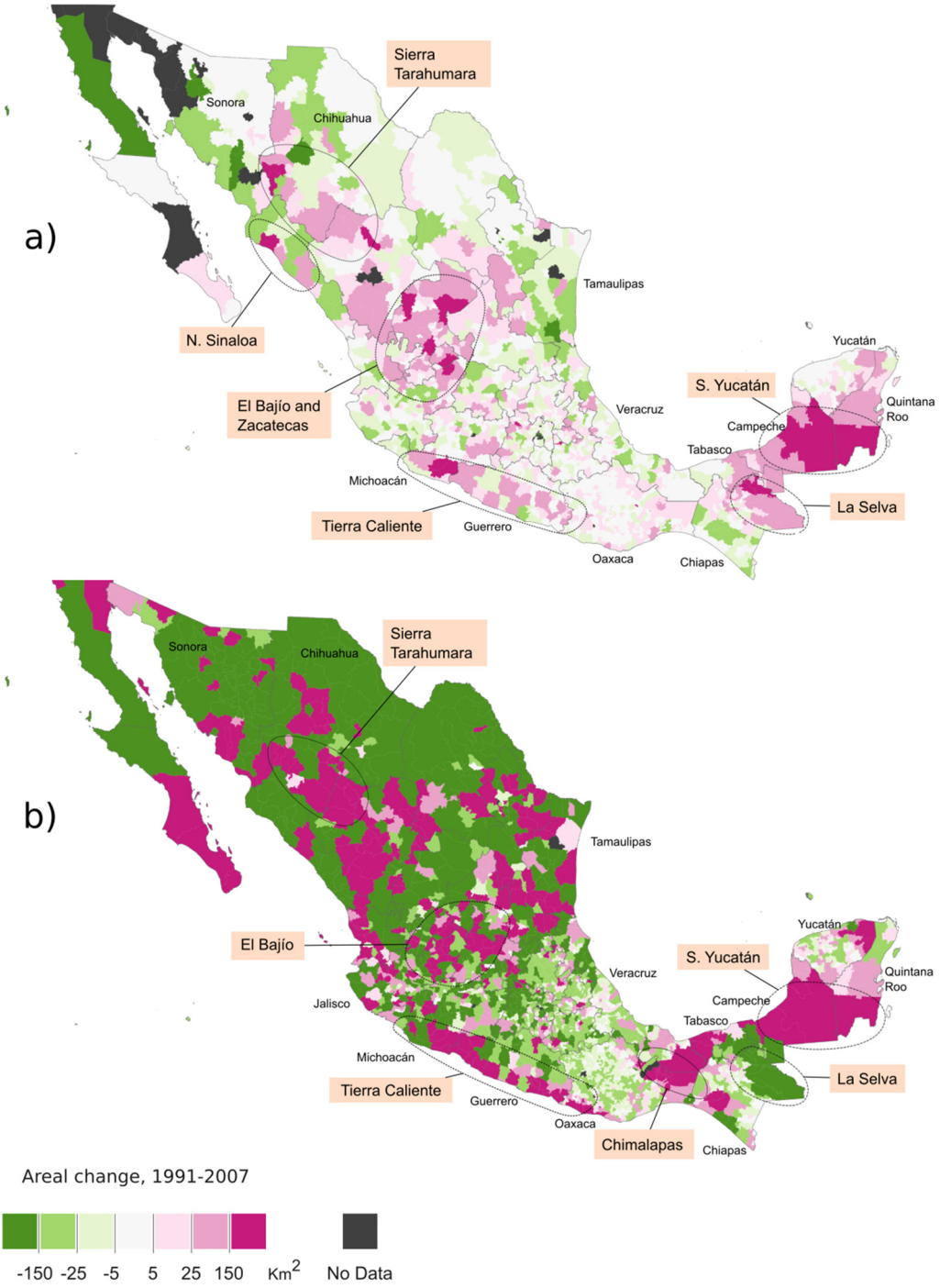

Figure 3. (**a**) Change in maize cropland and (**b**) grazing area for cattle per *municipio*. Grazing area was calculated multiplying animal inventories by regional stocking rates. Source: Agricultural census 1991 and 2007 [78] and Environmental Statistics Yearbook [79].

3.3. Cattle Ranching

Important transformations in the beef cattle IO commodity chain structure paralleled those for maize. In the pre-reform period, an extensive grass-fed-finishing system sourced beef-cattle from rangelands in dry, temperate, and tropical biomes to urban centers, and delivered carcasses to meat shops via municipal slaughterhouses (Figure 4a). The only significant export sector was calf production in the arid zones of the north. After NAFTA came into force, beef imports from the US

soared as consumer preferences switched to grain-fed cattle and new quality standards. Nevertheless, cheap maize imports in combination with the expansion of supermarkets soon sparked changes in the Mexican production system, with a rapid expansion of feedlots and forward integration of the home industry into urban and export markets; a few domestic and multinational corporations concentrated supply and retail chains for the procurement and provision of beef. In only a decade (2002–2012), Mexico shifted from a top beef importer of US beef to a top supplier for that same market [80]. A new set of relations of production evolved into a maize-cattle complex (Figure 4b), with grain suppliers, feedlots, supermarkets, and vertically-integrated food corporations emerging as key nodes in the chain's governance structure.

Changes in IO and governance structure within the beef chain were followed by changes in the spatial organization of beef-cattle production. Ranching is by far Mexico's most extensive agricultural activity, covering 60% (1.1 million km^2) of the country's land area [79]. Since the mid-20th century, cattle ranching expanded in practically every environment assisted by flexible loans from the World Bank and the Mexican government. In a few decades, large tracts of tropical humid and dry forests were destroyed to make way for grasslands [81]. Beef cattle production at this time developed in three major regions with little or no interaction among them. (1) In the arid lands of Northern Mexico, proximity to the US, a strong ranching culture, and a relatively salubrious environment (in terms of animal health) enabled the early emergence of an export market for live cattle. (2) In Southern Mexico abundance of forage, low labor costs, and proximity to metropolitan areas promoted the development of an interregional cattle trade route between cities such as the Federal District and the lowlands of Veracruz, Tabasco, and Chiapas, where large tracts of tropical humid and dry forest gave way to pastures. The emergence of ranching in southern Mexico was facilitated by an inflow of immigrants from the North, following the agrarian reforms in the 1960s and 1970s. (3) Finally, in temperate highlands near urban centers in Central Mexico dairy farms and some fattening operations developed near grain production areas, in particular near the Bajío (Michoacán and Jalisco) [82].

Unprecedented grain availability, in particular domestic production of white maize and US imports of yellow maize, enabled the development of the feedlot system in Mexico, with characteristics and scale similar to the US feedlot. The production of animals in this system involves extensive and intensive segments. The extensive portion involves the production of weaned calves and young steers in pasture. Young steers then enter the feedlot, the intensive segment, where they are finished on a grain-rich diet before slaughter. In Mexico, the production of calves, steers and finished animals has compartmentalized into specialized segments along the chain. The old regionalization of beef-cattle is being replaced by a new geography, with regions specializing in different nodes of the chain structure; production of calves is realized in pastures in tropical dry and humid biomes and often by small-scale producers. Production of steers also depends on extensive pastures in the tropics, but is performed by brokers or large ranchers who can collect animals from small farms dispersed over large areas producing just a few calves per year. Finally, brokers deliver steers in large numbers to feedlots located in Central and Northern Mexico.

Expansion of the feedlot system in Mexico explains new patterns of animal trade and animal smuggling from Central America, phenomena with important implications for land change in Mexico and its southern neighbors. Feedlots may be viewed as a land-sparing alternative compared with grass-fed finishing systems. However, the expansion of feedlots in Mexico increased the rate of

extraction of calves, steers and heifers from source nodes. The reason for this is that feedlots prefer younger animals that on average spend a year on pasture, 3–4 times less than the time spent by grass-fed finished animals. In addition the weight at slaughter for grain-fed cattle in Mexico is 400–450 kg compared with 600–700 kg for grass-fed cattle. Finally, population growth and development of an important export sector is increasing the demand for Mexican beef. The combined effect is an increase in the demand for animals from pasture lands. But keeping pace with the animal supply in source regions has been difficult for the following reasons: (1) productivity in cow-calf systems remains very low, and (2) several ranchers defaulted and abandoned the activity after implementation of neoliberal reforms. As a result, average prices for young animals increased more than 200% over the last decade according with data from the feedlot association (AMEG). Scarcity in Mexico has been partially compensated by smuggling thousands of animals from Central America. Using data from the Secretary of Agriculture of Chiapas (Comité de Fomento y Protección Pecuaria del Estado de Chiapas) for Southern Mexico, we estimate that 50% (~300 thousand animals) of the cattle exported in 2012 by this state (the 3rd largest producer) to Central and Northern Mexico is sourced from pastures located south of the border with Guatemala. This estimate does not include other potential entry points in other frontier states (Tabasco and Campeche) and thus it may underestimate the magnitude of animal flows. What is clear is that Mexico is exporting at least part of the environmental damage of cattle ranching to Central America, a region that over the last couple of decades has witnessed a rise in narco-deforestation; the expansion of pasture lands, plantations, and other agribusiness linked to drug trafficking [83,84].

From the input side, increases in maize availability removed an important constraint for the expansion of feedlots. The development of output markets for beef tells the other half of the story. The rapid "rise of supermarkets" [63], following the liberalization of capital markets and elimination of price controls for consumer goods in the early 1990s, increased the demand for Mexican grain-fed beef. Demand from supermarkets increased emphasis on food safety, as these retailers required minimum standards to increase shelf life of meat products. Multinational corporations such as WalMart applied their own inventory management protocols, which included quality and safety regulations of their home countries. Feedlots responded by integrating federally-inspected slaughterhouses, packaging plants, and in some cases sell points at one end of the chain and collection centers for live cattle at source nodes. These transformations occurred slowly during the 1990s, but created the conditions to take advantage of two crises in the US typical of modern global capitalism.

The first crisis was a case of Bovine Spongiform Encephalopathy (BSE) reported in December 2003 in Washington, which caused a generalized ban on US beef across the world immediately after an official announcement. This event was important for two reasons: (1) traditional US clients (e.g., Japan and Korea) began to search for new beef sources. Mexico was viewed as a good alternative since no case of FMD had been reported since 1946 and no cases of BSE has ever been confirmed, and (2) the ban temporally halted the massive imports of US beef and opened a window of opportunity for Mexican beef in domestic markets. The second crisis was the 2008 US recession, which hit the Mexican economy severely and drove the peso from $10 to $15 pesos/dollar in only a few days. The devaluation made US imports more expensive and Mexican beef more attractive not only for domestic markets but also for low-income segments in the US. Since 2008 US beef imports have decreased 7% per year, while exports to the US have increased 86% every year. Today Mexico exports beef to 13 countries in Asia, the Middle East, Eastern Europe and North America.

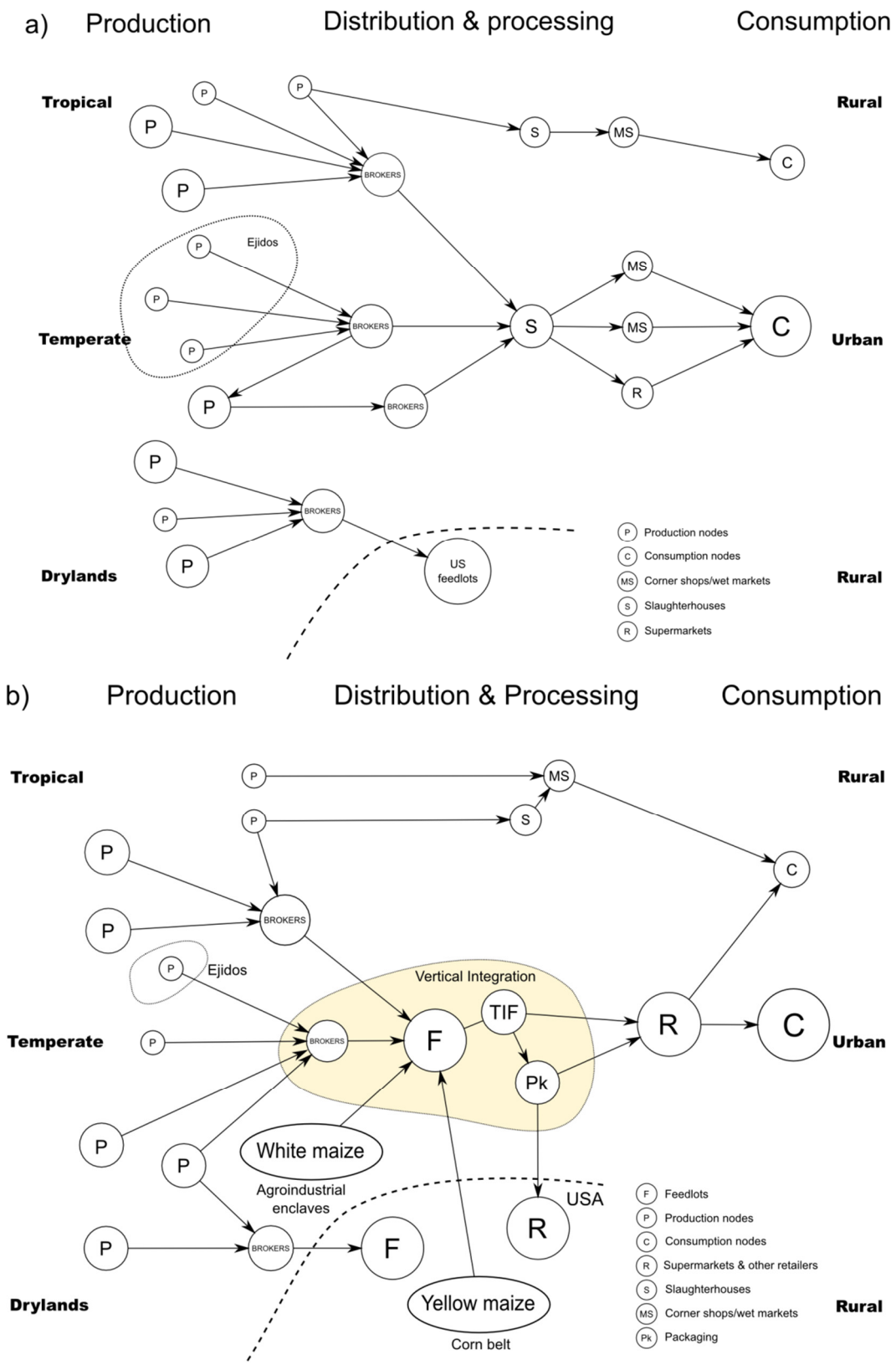

Figure 4. (**a**) Pre-reform period beef-cattle commodity chain and (**b**) post-reform period maize-cattle complex.

Figure 3b presents data from the agricultural censuses from 1991 and 2007, this time showing changes in cattle herds. As before, pink areas represent *municipios* where lands dedicated to beef-cattle

are declining and green areas, increasing. This time we highlight six main clusters of concentration of beef-cattle production. We note that cattle production is very dynamic during the period observed, with large areas losing ground and some regions concentrating production. A number of small *municipios* of high concentration spread across Central and northern Mexico and in particular around El Bajío, an important region for grain production. These outliers correspond to *municipios* with feedlots. Production is concentrating also in extensive rangelands, such as Sierra Tarahumara in Northern Mexico, Tierra Caliente in the South Pacific, and Los Chimalapas and the Yucatan Peninsula in Southern Mexico. Interestingly, La Lacandona in Eastern Chiapas is becoming less important for cattle production. However, half the production of calves delivered to other states comes from this region, and its participation has increased over the last decade [82]. This apparent contradiction is again explained by the large quantities of animals smuggled from Central America. La Selva has become a transient region in the trade between Central America and Mexico, but the character of this trade remains unnoticed by most government statistics. This finding highlights the need to conduct additional research at the regional level.

3.4. Changes in Mexican Land Cover

The geography of M-and-B commodity chains leaves its imprint on a diverse ecology. The Mexican nation, covering nearly 2 million km^2, is home to a rich biota that occupies a wide a mosaic of biomes. To describe this landscape, we use the classification system of Rzedowski [83], which defines 10 broad categories based on climatic potential. These include dry lands covered by xerophyte shrubs (in the north between the Sierra Madre Occidental and Sierra Madre Oriental, on the peninsula of Baja California and most of Sonora); grasslands (eastern margin of the Sierra Madre Occidental, from New Mexico–Sonora to Jalisco) and forests, which cover much of what remains excepting areas converted to agriculture. Tropical deciduous and semi-deciduous forests (here denoted as Tropical Dry Forest) stretch along the Pacific Coasts, from Sonora to Chiapas and the NW portion of the Yucatan peninsula. What remains of tropical humid forests extends along the lowlands near the Gulf of Mexico, from southern Tamaulipas to Yucatán, and over Campeche and Quintana Roo. Mexico's numerous mountain ranges are cloaked by temperate broadleaf (e.g., *Quercus sp., Liquidambar sp.*) and coniferous forests (e.g., *Pinussp*., *Cupressus sp.,* and *Abies sp.*).

Table 1 depicts conversions, presumably to agriculture, as well as forest loss due to logging across the forest biomes over the last 30 years. As can be seen, they effectively partition LC for the pre-reform and post-reform periods, with deforestation diminishing in intensity since 1990, consistent with a shifting LCR. The periodization of the table indicates uniformly strong deforestation processes between 1980 and 1990, after which conversion to agriculture declines for all biome types. By the 2000s, important variations emerge across biomes, with high and low rates of conversion for tropical forest and temperate forests, respectively. Regional assessments also confirm a downward trend of forest loss [32,85].

Table 1. Land change 1980–2012. Source: Data from Series de Uso de Suelo y Vegetación I, II, III & V [86–90].

Biome	1980/93 × 1000 km^2 (%)	1993/02 × 1000 km^2(%)	2002/12 × 1000 km^2(%)
All	669(−8.4)	652(−2.5)	640(−1.9)
Temperate	340(−3.4)	336(−1.1)	336(−0.13)
Tropical Humid	109(−13.5)	104(−4.1)	102(−2.3)
Tropical Dry	219(−14.7)	211(−4.1)	201(−4.7)

4. Assessing the Commodity Chain-LC Link

To this point we have explored the role of commodity chains and neoliberal reforms on Mexican LC. In the analysis that follows, we consider how changes in source nodes for M-and-B, presented in Figure 2a,b and Figure 3a,b, relate to LC for a period bracketing the implementation of NAFTA. To this end, the land change data of Table 1 are presented in map form for 2002–2012. Due to data limitations, this does not exactly correspond to the period reflecting agricultural change (1991–2007); we assume that the five year overlap is sufficient to illuminate the hypothesized linkages. We base this assumption on inertia in the response of biome areal extents to modifications in the LCR. Also, NAFTA was not implemented until 1994, so associated impacts on commodity chains likely manifested towards the end of the 1991–2007 analysis period. We acknowledge a long-term policy process at work beginning with GATT in 1986, but argue that significant economic impacts do not occur until later given lag times in institutional change and implementation. For example, the *parastatal* system was not dismantled until the 1990s, with privatization of storage, processing, and distribution facilities occurring as late as 1995–1999 [69]. Cuts in agricultural credit and the elimination of input subsidies and price supports begin early in the period [59,91,92].

A geographic pattern of LC reveals the emergence of definite deforestation hotspots along the Pacific Coast, Southeastern Mexico and the Yucatan Peninsula. These are found primarily in the tropical dry and humid biomes. Forest transition crops up mostly in temperate areas and the dry lands of Central and Northern Mexico, although some is noticeable in coastal zones along the Gulf of Mexico. Figure 5 shows six deforestation hotspots, where clusters of *municipios* have been circled as in Figure 3. Comparing the agricultural maps and patterns of LC we observe strong spatial overlap. The degree of correspondence between deforestation clusters and agricultural expansion varies between the north and south and between maize and cattle, with weaker agreement in the north and with maize. Northern maize production is more intensive, as in the State of Sinaloa, with the highest yields per ha across Mexico as we mentioned above. Moving south, the correspondence between high deforestation *municipios* and high cropland expansion increases; southern *municipios* have more extensive agriculture and a higher proportion of forest at risk for clearance. The spatial pattern of change in cattle inventories is also more consistent, reflecting the fact that cattle-raising in the northern drylands, as well as in the tropical south, is extensive. Once again, correspondence is lower in the north, an effect probably related to the fact that most feedlots are located in this portion of the country.

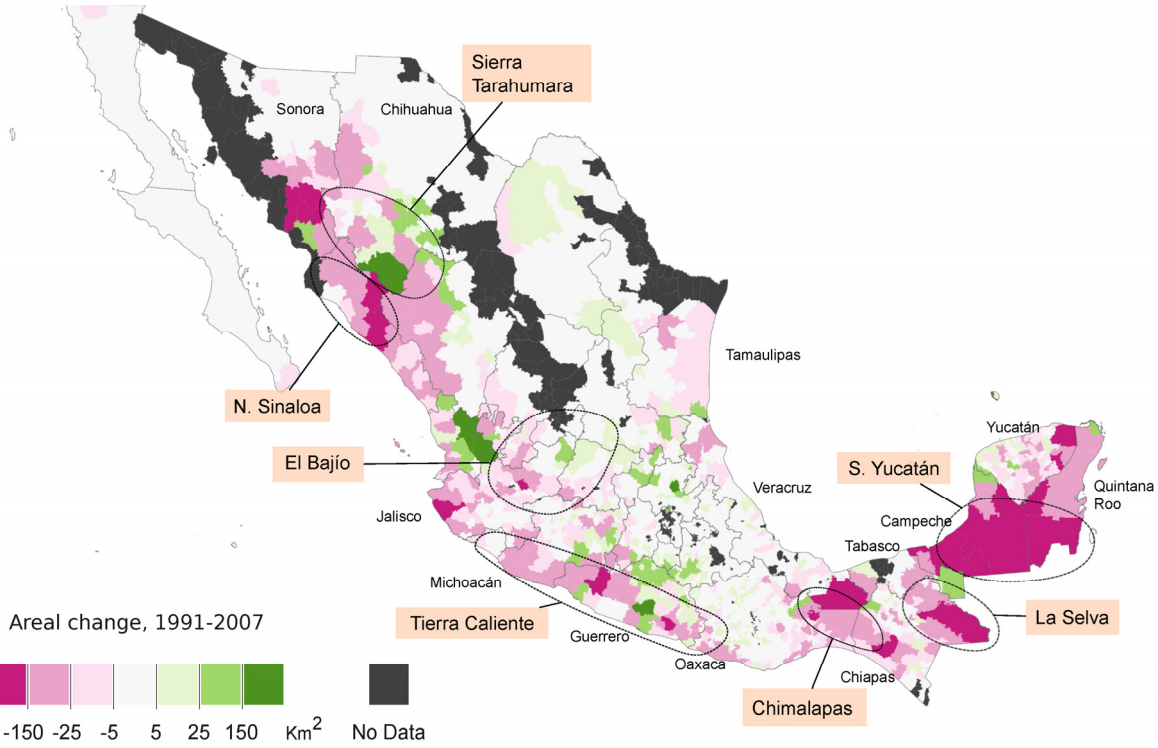

Figure 5. Changes in forest cover 2002–2012. Note that colors and class ranges are the same as in Figure 3, but the color ramp is inverted to show *municipios* with increasing forest in green and *municipios* with shrinking forest in pink. Source: Serie II and Serie V [86,88].

5. Conclusions

This paper analyzes the evolutionary reconfiguration of key agro-commodity production networks following neoliberal reforms in Mexico and its effects on long term land change processes occurring across a nation state. The study advances important elements that LC scientists urge to incorporate in LC research to better understand interactions across teleconnected landscapes [6,93,94]. First, in line with Munroe and coworkers [6], the study moves beyond an exclusive focus on 'interactions as material flows' by applying a production network approach to understand the evolution of M-and-B commodity chain governance and geographies. More specifically, we show how macro institutional structures for agricultural production evolved and adapted to a context of increasing global economic integration and how such process in turn altered the spatiality and character of material flows driving land change. Second, we were able to link two seemingly unrelated land change processes: (a) forest transitions linked to agricultural intensification at some nodes and agricultural abandonment by "inefficient" maize producers at others, and (b) deforestation linked to the expansion of large and "efficient" corporate agents. This finding highlights the need of new approaches, as the one employed here, to unveil complex interactions within teleconnected land use systems. Finally, the study moves beyond the almost exclusive attention to proximate actors within the LC literature to the analysis of interactions among heterogeneous agents whose explicit or implicit coordination determines important environmental outcomes of agro-commodity production networks, processes in which ranchers and farmers alone are often the weakest link. This is important because it opens the possibility to identify additional locus of action to address environmental and sustainability goals.

The results of our analysis are highly suggestive of the prime claims and hypotheses entertained by the paper. We have established that significant changes occurred in M&B commodity chains over the neoliberal reform period, and have demonstrated their spatial reconfigurations. We have also shown links between the changing geography of the commodity chains and shifts in Mexico's LCR, particularly for the case of beef cattle. Although intensive maize farming emerged in the wake of NAFTA, much of it remains rain-fed and continues to supply peasant families. Thus, the maize production pattern has remained stable, at least in comparison to the spatial dynamics of cattle herding. As for beef, pastures are Mexico's most extensive land use, in which case forage provision necessarily impacts native ground cover, despite the strong post-reform period emergence of fattening operations. The spatial changes of the beef component of the M-and-B commodity network (Figure 3b) correspond in many ways with changes in forest cover (Figure 5). When herds diminish, we often see forest transition; when herds grow large, forests are lost.

As for Mexican LC, the data suggest that the nation as a whole is on the verge of reaching zero net deforestation, with the very real prospect of an aggregate forest transition in the near future. The extent to which this outcome can be attributed to the downstream effects of neoliberal reforms remains an important empirical question, of possible interest to the architects of the UN REDD program. That said, a disaggregation of LC by biome suggests that forest transition appears most pronounced in temperate pine and dry northern forests, while deforestation has concentrated in the tropical humid areas of the south. Although Mexico's net measure of forest area may soon stabilize, the pattern of forest gain and loss with forest type suggests that biomass and biodiversity are hemorrhaging with the reconfiguration of the beef commodity chain and its increasing dependence of calves from Southern Mexico and Central America. Furthermore, the consolidation of the maize-cattle complex prelude a second boom of cattle ranching expansion, which soon may get back idle lands once left to natural regeneration or even reclaim new forest for pasture beyond current deforestation hotspots. Thus, one should be cautious in concluding that neoliberal reform in Mexico has yielded a win-win in development and environment, by raising incomes, sequestering carbon, and conserving a rich ecological heritage. Additional research will be needed to better understand future land change pathways in neoliberal Mexico, including research on specific commodity chain interventions to mitigate deforestation and land degradation.

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Author Contributions

Galvan and Walker contributed with the research design and field work. All authors contributed with literature review, analysis, and writing.

Conflicts of Interest

The authors declare no conflict of interest.

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