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Are Ecological Modernization Narratives Useful for Understanding and Steering Social-Ecological Change in the Argentine Chaco?

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Abstract: During the past decades, the Ecological Modernization Theory, and associated ideas such as the Forest Transition Theory and Land Sparing Hypothesis, have dominated the academic and policy arenas regarding the solutions to current environmental crises. However, critiques were raised as these theories, originally conceived for developed countries, started to be applied in developing countries for explaining and prescribing social-ecological transitions. Here, we assess the validity of five key assumptions of Ecological Modernization narratives as applied to the Argentine Chaco, a global deforestation hotspot. We reviewed existing literature and conducted straightforward analysis to disentangle relationships among key variables. Although agriculture intensified, there is no evidence that this intensification inhibited agricultural expansion. Rural depopulation took place between 2001 and 2010; however, deforestation rates did not decrease, and the quality of life of migrants did not increase compared to those that stayed in rural areas. Our review suggests that the consequences of agriculture intensification on biodiversity and the provision of multiple ecosystem services exceeds the area used. Therefore, available evidence does not support the assumed causal relationships of Ecological Modernization, and even contradicts most assumptions. We propose a series of analytical shifts to better capture the complexity of social-ecological transitions in modern commodity frontiers.

Keywords: forest transition; land sparing; agricultural adjustment; rural-urban migrations; land use change; deforestation; agricultural frontiers; agriculture intensification

1. Introduction

The need for solutions to the current environmental crisis has never been greater. In the last three decades, growing attention has been paid to the arguments of the Ecological Modernization Theory about how these problems can be solved [1]. Proposed in the early 1990s, one of the main arguments of this theory is that further advancement of technology, industrialization, and urbanization is the most economically and politically feasible way of overcoming the environmental crises [2]. The interest in Ecological Modernization has grown along with the emergence of theoretical developments in other environmental disciplines also inspired in modernization theory [3,4]. For example, the Environmental Kuznets Curve [5] posits that as incomes rise over time, pollution emissions also rise, but when incomes reach a certain level, emissions level off and then decline. Similarly, the Forest Transition Theory [6,7] proposes that forest cover area declines during early development, but at some stage a transition occurs, and forest cover thereafter expands. More recently, the Land Sparing Hypothesis [8] posits that

technological development promotes agricultural intensification, which allows achieving the same production on less land, therefore sparing land for nature conservation. The social-ecological processes and outcomes proposed by these theoretical developments are linked in a complex chain of events (Figure 1). The written and spoken account of these connected events has given rise to Ecological Modernization narratives, which are increasingly promoted by environmental scholars, conservation NGOs and agricultural associations as a means to achieve sustainability [9].

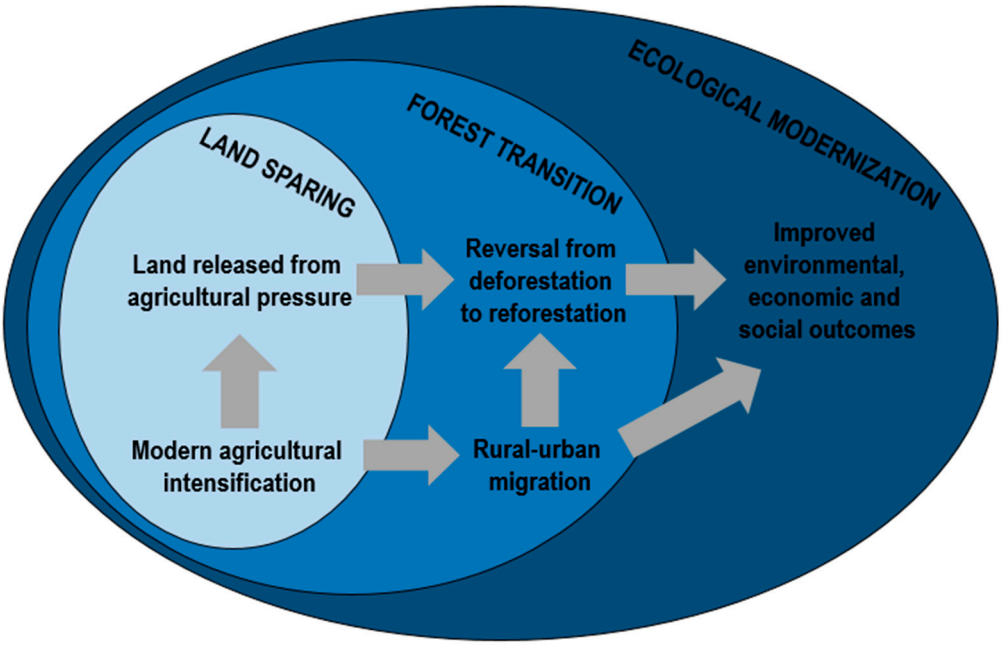

Figure 1. Processes and outcomes that relate Ecological Modernization narratives, encompassing the Forest Transition Theory, and the Land Sparing Hypothesis.

The theoretical underpinnings of Ecological Modernization narratives share the abstract and universalist arguments of a "grand theory". These arguments are related to inevitable long-term development transitions that nation-states undergo driven by endogenous processes and result in a reversal from environmental degradation to recovery [3,4]. They also share an origin from observations of historical patterns of development and environmental change in developed countries. The Forest Transition Theory, for instance, emerged from studies of national forest cover change in advanced industrial countries such as the United States, France, and Norway [10,11]. The theoretical underpinnings of Ecological Modernization narratives also have in common many criticisms. The main observation raising doubts about the universality of their arguments is the heterogeneity of social processes driving environmental change in developing countries [12]. Social-ecological changes compatible with Ecological Modernization narratives have also been described for small developing countries such as Panamá and Costa Rica [13] and Vietnam and South Korea [14]. However, strong debates exist around the occurrence of forest transitions and land sparing effects over large areas of developing countries known as modern agricultural or "commodity" frontiers [15,16]. These are bio-culturally diverse regions where international demand for agricultural commodities is driving rapid environmental change, and where sustainability solutions are thus most urgently needed.

Despite criticisms, Ecological Modernization narratives have gained renowned interest among scholars (e.g., the ecomodernist manifesto, www.ecomodernism.org) and have penetrated into modern commodity frontiers [17]. Although some of the social-ecological processes and outcomes of these narratives have been assessed for some of the major modern commodity frontiers, such as tropical and sub-tropical forests in Argentina, Brazil and Indonesia [18,19], much of the knowledge is fragmentary and controversial [20–22]. Therefore, syntheses of available empirical evidence are needed to test the usefulness of Ecological Modernization narratives for understanding and steering social-ecological

change in modern commodity frontiers. The Argentine Chaco is a major modern commodity frontier and a global deforestation hotspot [23], where Ecological Modernization narratives have become the dominant discourse to solve unabated social and environmental problems. This region thus represents an ideal case to test the validity of Ecological Modernization narratives in modern commodity frontiers of developing countries.

The South American Gran Chaco contains the largest continuous relicts of subtropical dry forests, an endangered and understudied biome [24], from which 60% approximately is in northern Argentina. It was originally inhabited by a diversity of indigenous groups, and then gradually occupied by colonist families, known as campesinos or *criollos* (i.e., mestizo peasant farmers). These traditional inhabitants used grasslands and forests for hunting and gathering, wood extraction and charcoal production, and cattle ranching through management systems that were compatible with the maintenance of forest cover [25]. By 1970s, the introduction of Green Revolution technologies initiated an incipient expansion of modern agricultural systems and deforestation in the western and central sub-humid portions of the region [25]. By mid-1990s, the introduction of genetically-modified glyphosate-resistant soybeans in a context of neoliberal economic policies stimulated large-scale land acquisitions by capitalized farmers and investors from outside the Chaco region, who expanded modern agricultural frontiers all along the sub-humid portions [26]. Between 2000 and 2012, annual crops and pastures expanded from the sub-humid fringes towards the semiarid core of the region, producing annual deforestation rates of 1–1,5% (global average: 0.2%, [27]) and leading to the loss of natural vegetation over 20% (16 million ha) of the region [28]. In 2007, the social and environmental impacts of agriculture-driven deforestation led to the enactment of the National Forest Law (Ley 26.331) which mandated provincial governments to design and implement land-use zoning plans and prohibit further deforestation in forests of medium and high conservation value [29]. Despite being an unprecedented effort for environmental protection, the high lobby power of modern agribusiness and the low political interest of provincial governments to enforce the law, determine that illegal deforestation and continued socio-environmental problems are severe after 10 years of the enactment of the Forest Law [30,31].

Ecological Modernization narratives propose "win-win-win" (i.e., social, ecological and economic) outcomes resulting from state- and market-led processes such as industrialization, urbanization and agricultural intensification. Theses narratives pose that agricultural intensification brings more food production, improved biodiversity conservation and reduced poverty. The mechanism by which these synergistic outcomes may be produced involves a causal chain of regional ecological, socio-economic, cultural and political processes enabled by a mix of endogenous and exogenous factors (Figure 2). According to these narratives, more production without further affecting the environment is possible through advances in agricultural technology leading to (i) agricultural intensification on the most suitable lands (i.e., agricultural adjustment, [32]), (ii) confinement of environmental impacts to already cleared lands (i.e., conservation sacrifice, [15]), and (iii) agricultural intensification dis-incentivizing agricultural expansion and therefore halting deforestation [33]. Simultaneously, improved biodiversity conservation outcomes rest on the assumption that high-intensity modern agricultural systems competitively displace low-intensity traditional systems and lead to land abandonment on marginal lands, thus releasing forests from human pressure and sparing lands for forest protection and recovery [34]. Finally, it is implicit but untested in these narratives that land abandonment by traditional smallholders due to modern agricultural intensification leads to improvements in their quality of life because they either (i) migrate to urban areas and find jobs in the industrial or service sectors, or (ii) stay in rural areas and are employed by the modern agricultural sector.

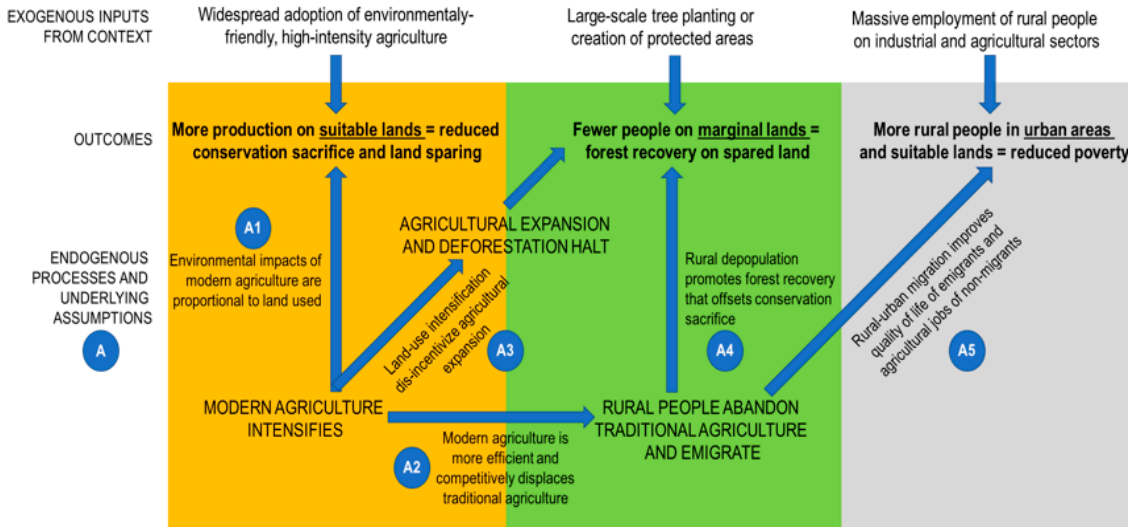

Figure 2. The five untested assumptions (A1 to A5) underlying the causal pathways proposed by Ecological Modernization narratives to achieve more agricultural production on suitable lands (**left**), better forest conservation on marginal lands (**centre**), and better quality of life of rural migrants (**right**) of the Argentine Chaco.

For the Argentine Chaco, previous studies have partially evaluated the occurrence of some of the patterns and processes proposed by Ecological Modernization narratives. Volante and Paruelo [35] assessed the occurrence, magnitude, and localization of forest transitions in the North-Western Argentine Chaco by analyzing forest cover dynamics at the landscape level for the 1997–2007 period using remote sensing data. In their analysis, a long-term landscape dynamic compatible with a forest transition had to include the following features: (i) Historical presence of forest cover in 1977, (ii) human-induced forest cover changes during the first stages of the 30-year period, and (iii) increase of forest cover during the last decade of the period. They found that only 4.8% of the landscapes of the study area had a forest cover dynamic compatible with a forest transition, which is in line with recent analyses of reforestation patterns across Latin America [36]. In contrast, 34% of the landscapes (9.57 million ha) showed a clear negative trend in forest cover during 1997–2007, in coincidence with areas of soybean and pasture expansion. In turn, Matteucci et al. [37] evaluated some of the untested assumptions underlying the Forest Transition Theory as applied to the Argentine Chaco. They analyzed changes in land cover and socio-demographic variables between 2001 and 2010 for a subset of administrative units in the North-Western portion of the region, to test if (i) low-income peasants use land inefficiently, (ii) development drives rural–urban migration of low-income peasants in search of a better life quality, and (iii) expansion of intensive agriculture occurs in the most productive lands. While evidence to refute these assumptions is presented, they tested some of the causal relationships proposed by Ecological Modernization narratives in isolation, and through analysis of the spatial congruence between changes in land-cover and socio-demographic variables that fall short to describe the underlying processes.

These studies offer an initial assessment of processes and contextual factors behind changes in forest cover in the Argentine Chaco. However, to contrast narratives encompassing multiple dimensions of social-ecological change against empirical data necessitates the integration of multiple sources of evidence, both qualitative and quantitative, and from diverse disciplines. Here, our objective is to review and synthesize multiple sources of information to challenge the untested assumptions (Table 1, Figure 2) of the Ecological Modernization narrative as applied to the Argentine Chaco with the most up-to-date evidence regarding regional social-ecological dynamics. We do this by qualitatively analyzing published evidence in the light of the debate about the validity and usefulness of Ecological Modernization narratives for explaining social-ecological change in this region. Where necessary, we assess links among key variables using available census or survey data to test correlative relationships

that have not been explored in previous studies. We believe that this empirical assessment contributes to theoretical discussions on the validity of Ecological Modernization narratives in rural regions of developing countries in general, and modern commodity frontiers in particular. Furthermore, it provides scientifically-sound arguments to understand whether these narratives are useful to inform policy and management decisions related to sustainability in the Argentine Chaco.

Table 1. Criteria used to search peer-reviewed literature relevant for testing the five assumptions of Ecological Modernization narratives as applied to the Argentine Chaco.

Assumption	Search String	References Relevant for Testing Assumption
1. Environmental impacts of large-scale, modern agriculture are proportional to the land area used	Chaco AND agriculture AND (environment OR ecosystem) AND impact	38–52
2. Modern agriculture is more efficient and competitively displaces traditional agriculture	Chaco AND agriculture AND efficien* AND farm*	53–58
3. Land-use intensification dis-incentivizes agricultural expansion	Chaco AND agriculture AND intensification AND expansion	59–62
4. Rural depopulation promotes forest recovery in marginal lands that offsets conservation sacrifice in suitable lands	Chaco AND agriculture AND (abandonment OR recovery OR regeneration)	63–70
5. Rural-urban migration improves quality of life of emigrants and agricultural jobs of non-migrants	Chaco AND population AND migration	71–75

2. Methods

We conducted a literature search to find published evidence relevant for empirically testing the five assumptions underlying Ecological Modernization narratives as applied to the Argentine Chaco. To find peer-reviewed literature relevant for each assumption, we used specific keywords and search strings in English and Spanish using Google Scholar (Table 1). We also explored the grey literature and doctoral theses for relevant evidence. We filtered literature search results and retained 38 articles and documents that contained evidence relevant for testing one or more assumptions. We complemented the evidence gathered from the literature search with straightforward correlative analyses to test assumptions 2, 3, and 4. To compare the land-use efficiency of small-scale and large-scale production systems (assumption 2), we used data from a large-scale farm survey conducted in 2016 to test the relationship between farm revenue per area and farm size. To assess the links between crop intensification and expansion (assumption 3), we used data from surveys carried out by the National Secretary of Agroindustry (http://datosestimaciones.magyp.gob.ar) to test the relationship between crop yields and harvested area between 2001 and 2010 at the department (smallest administrative unit in Argentina) level for the four major summer crops (i.e., maize, sorghum, soybean and sunflower). To evaluate the link between rural population and forest cover (assumption 4), we analyzed the relationship between the proportion of dispersed rural population and the proportion of remnant forest at the department level in 2010 (more recent population census) for all the departments contained in the Argentine Dry Chaco (n = 89). Forest cover data is from a plot-level database (http://monitoreodesmonte.com.ar/) and population data is from national population census (https://redatam.indec.gob.ar).

3. Results

3.1. Assumption 1: Environmental Impacts of Large-Scale, Modern Agriculture are Proportional to the Land Area Used

For the environmental sacrifice of intensified agricultural lands be offset by recovering ecosystems in spared land, large-scale, modern agricultural systems should not impact the environment beyond the area they occupy. Otherwise, the environmental gains from agricultural intensification would be diminished because of negative externalities (e.g., water pollution) flowing from agricultural,

sacrificed lands to non-agricultural, spared lands [33]. This necessary condition for the improvement of environmental conditions of non-farmed (i.e., forest and urban) lands is seldom observed in the Argentine Chaco. To the contrary, multiple studies provide evidence of the leakage or spillover effects of agricultural intensification in this region. First, loss of forest cover due to agricultural intensification diminishes the capacity of ecosystems to reduce wind speed and protect soils against wind erosion, leading to increased wind speed and frequent dust storms in towns and cities surrounded by modern agriculture [38]. This negative externality is perceived by urban inhabitants to originate from cleared and intensively cultivated lands, and is the cause of prevalent respiratory diseases [38]. Second, habitat loss and fragmentation and modern agricultural management have been shown to negatively affect native flora and fauna even far from cleared lands. The diversity and abundance of forest-dependent birds in remnant forests decline abruptly as the amount of habitat in the landscape is reduced due to forest clearing for agriculture [39,40]. Similarly, forest fragmentation driven by agricultural intensification negatively affects different guilds of mammals such as top predators [41–43] and frugivore seed dispersers [44], and also the recruitment of native trees in forest fragments, threatening the viability of valuable tree species (e.g., quebrachos, algarrobos, palo santo) over large areas [45]. Third, the replacement of native perennial vegetation for annual crops with comparatively lower transpiration raises groundwater table levels in and around cleared areas, leading to more frequent and extensive flooding in rural areas and downstream urban areas [46]. Fourth, increasing groundwater recharge due to crop cultivation on deforested lands also produces shallower saline water tables that increase the risk of soil salinization over large areas [47,48]. Fifth, the herbicide glyphosate was shown to produce lethal and sublethal effects on 23 native plant species even after the application of 25% of recommended field application rates [49]. Given the widespread use and overuse of this herbicide in agriculturally intensified landscapes, glyphosate application and drift produces biodiversity loss and selection of glyphosate-tolerant biotypes in native vegetation remnants [49]. Sixth, agricultural intensification causes abrupt reductions in plant biomass and increases in growth seasonality that change biophysical attributes and processes that control regional and local climate [50]. Such changes have been associated to observed increases in regional temperature ranging from 1 °C [51] to 5 °C [52]. All these sources of evidence show the far-reaching negative environmental impacts of agricultural intensification, thereby undermining the assumption that such effects are confined to agriculturally intensified lands.

3.2. Assumption 2: Modern Agriculture is More Efficient and Competitively Displaces Traditional Agriculture

A main tenet of the Ecological Modernization narrative is that small-scale, traditional, peasant production systems are inefficient and inevitably lead to land degradation, and that this condition eventually forces them to abandon rural lands and migrate to urban areas in search for employment in the industrial or services sectors. If efficiency is measured based on how much land is used (proxy for conservation costs) and how much food is produced (proxy for production benefits), then traditional production systems are indeed less efficient than modern production systems, as suggested by Grau et al. [34]. However, it is implicitly assumed in this way of measuring efficiency that (i) the conservation costs per area due to land-use in small-scale systems are similar to that of large-scale systems, and (ii) the production benefits due to land-use in small-scale systems are much lower than that of large-scale systems. The validity of these implicit assumptions is dubious in the Argentine Chaco because (i) biodiversity losses due to land-use per ha in large-scale systems are significantly higher than in small-scale systems as the latter provides higher habitat quality than the former (see assumption 1 and [53]), and (ii) productivity gains due to land-use in small-scale systems are not necessarily lower and are enjoyed locally, while those from large-scale systems are not always higher and accrue elsewhere. There is evidence that the productivity of small-scale, traditional production systems can be as high or even higher than that of large-scale, modern production systems. In a survey of 235 farms of the Northern Dry Chaco, we (unpublished data) did not found a clear productivity/size relationship that could support a claim of higher efficiency for any type of production system (Figure 3).

Indeed, small- to medium-size farms (0 – 2,500 ha) achieved annual gross revenues per area in 2016 that ranged from 0 to more than 1400 USD/ha/year, indicating that small farms are not necessarily less efficient than large farms. The reasons behind the large variability in productivity in small- to medium-size farms is related to differential access to production factors (e.g., land titles, financial credit) and not the presence of intrinsic barriers to increase efficiency (e.g., motivations, knowledge) as implicitly assumed by the Ecological Modernization narratives.

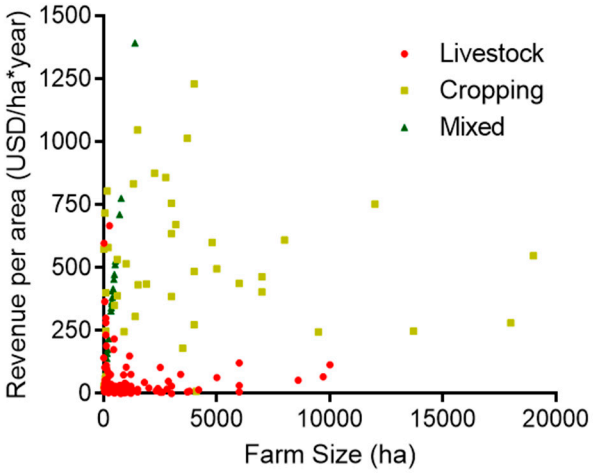

Figure 3. Relationship between revenue per area and farm size for 235 farms surveyed in 2016 across the Northern Argentine Dry Chaco. Revenue per area was calculated based on available 2016 price data for agricultural products and data of farm size and composition collected on field surveys. Colors and forms indicate the main type of agriculture system developed in each farm: Livestock production (red circles), crop production (dark yellow squares), and mixed crop-livestock production (green triangles). Unpublished data from the authors.

It is also assumed that traditional rural people abandon their lands and migrate to urban areas as a consequence of the expansion of modern capitalized farmers because small-scale production systems are less efficient and thus are competitively displaced by more efficient large-scale production systems. In the Argentine Chaco, agricultural expansion is driven by non-local actors who arrived to the region to deploy modern, export-oriented production systems, which replaced traditional systems oriented to family subsistence and small-scale commerce [54]. Thus, markets are not the arena of land-use competition between modern and traditional farmers as their agricultural produce has different destinies and their power to access production factors is highly asymmetrical [55]. These observations weaken the support to the assumption of indirect, competitive displacement. Moreover, several observations point to more direct forms of displacement. The Observatory of Lands, Natural Resources and the Environment of REDAF [56] documented 224 conflicts around access and tenure of land in rural areas of the Argentine Chaco to 2011, which affected 127,886 persons over 2.79 million hectares all along the main agricultural frontiers of the region. More than half of these land conflicts involved direct evictions of traditional smallholders (*criollos* and indigenous people) by private actors, and 80% of these evictions occurred between 2000 and 2009, in coincidence with the period of higher rates of deforestation for agricultural expansion [56]. These observations indicate that the process behind the co-occurrence of modern agricultural expansion and abandonment of smallholder lands cannot be explained solely by an indirect, competitive displacement. Rather, Cáceres [57] proposes that two forms of "accumulation by dispossession" underlie such massive displacement. On one hand, modern capitalized farmers use their economic power to influence provincial governments and modify land policies to create "neo-enclosures", that is, the privatization of communal or public lands to be used for modern agricultural production, which requires the eviction of pre-existing traditional families and communities. On the other hand, the economic power of new private actors is used for

land grabbing, that is, to acquire large tracts of lands that had been possessed by smallholder farmers during many decades. Seghezzo et al. [58] identified 132 large-scale land acquisitions in the Chaco of Salta province in the period 2000–2018, covering an area of 1.75 million hectares (21.5% of the Chaco of Salta). All of the large-scale land acquisitions were destined to modern agricultural production and 86% of them were acquired by domestic private investors, mostly from the Pampas region. Almost half of these large-scale land acquisitions were associated to conflicts around access and tenure of land between private investors and indigenous communities or small-scale producers.

3.3. Assumption 3: Land-Use Intensification Dis-Incentivizes Agricultural Expansion

One of the main assumptions underlying Ecological Modernization narratives is that the intensification of agriculture (i.e., increases in yields) disincentives agricultural expansion and spares land for conservation [59]. However, the empirical support for this assumption is weak, and depends on multiple issues, such as the type of intensification (market-induced or technology-induced, [20]), the scale of analysis (local, regional or global, Byerlee et al. 2014), and the elasticity of the demand of the output [60]. It has been suggested that rebound effect or Jevon's paradox (i.e., higher intensification promotes expansion rather than contraction) is common in modern commodity frontiers where there are no physical or institutional restrictions to land use change, and where the demand is elastic to price (e.g., feed or energy crops, such as maize and soybeans) [60]. In this context, Ceddia et al. [61] analyzed the relationship between the yield and cultivated area of soybean in the Chaco of Salta province and found evidence supporting the Jevon's paradox. However, their study only analyzes soybean for a few departments of the Argentine Chaco.

We followed Ewers et al. [33] approach for describing the relationship between crop yields and cultivated area for the four major crops (maize, sorghum, soybean, sunflower) of the Argentine Dry Chaco. A negative relationship between crop yields and cultivated area would suggest land sparing. However, for the four crops that we analyzed, we found a weak but positive relationship among yields and cultivated area, suggesting that land sparing has not occurred in the Argentine Dry Chaco between 2001 and 2010 (Figure 4). On the contrary, for all four crops, there were departments that had increases in yield and cultivated area, therefore evidencing Jevon's paradox. Furthermore, mainly for sorghum and soybean, numerous departments had reductions in yields between 2001 and 2010 (negative values in logarithmic scale). This could indicate that the viability of agriculture in the region is low and/or that the adoption by farmers of high-yield locally adapted cultivars is not taking place. Moreover, the fact that an important fraction of the departments presented a Jevon's paradox behavior suggests that the surplus capital from modern production systems is being reinvested in land acquisitions further inside the frontier, either for productive or speculative purposes, in both cases ending up in additional land clearing. This form of expansion could be related to the contagion process described by Volante et al. [62] where forest conversion is highly determined by the proximity to already cleared land.

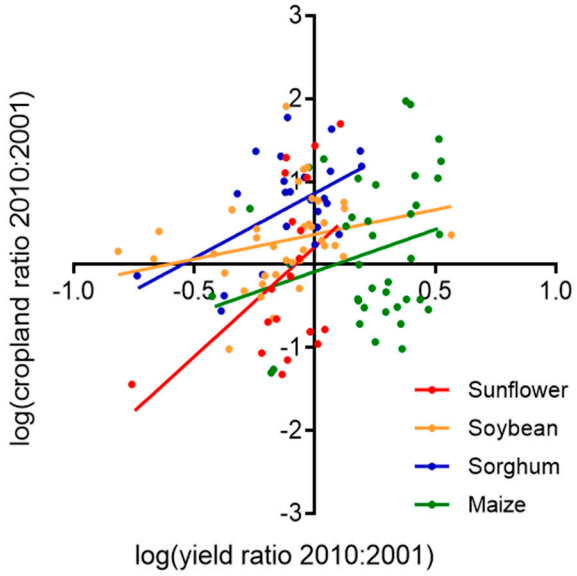

Figure 4. Relationship between yield and cropland changes between 2001 and 2010 at the department scale for all the units contained in the Argentine Dry Chaco. The four major summer crops are plotted. For each period three agricultural seasons were averaged: 2000–2001, 2001–2002, 2002, 2003 for the beginning and 2009–2010, 2010–2011, 2011–2012 for the end. The data is from surveys carried out by the National Secretary of Agroindustry http://datosestimaciones.magyp.gob.ar).

3.4. Assumption 4: Rural Depopulation Promotes Forest Recovery in Marginal Lands that Offsets Conservation Sacrifice in Suitable Lands

One of the key processes for explaining forest resurgence is rural–urban migration of traditional farmers followed by land abandonment and a post-agricultural secondary succession, particularly in lands with less suitability. By means of visual interpretation of Landsat imagery and field visits, early findings reported that some areas of the northern portion of the Argentine Chaco were experiencing this process [34]. In the Argentine Chaco, traditional agricultural systems occur mainly in puestos which are comprised by a house, a water reservoir, corrals, and in some cases by a small plot devoted to horticulture. In terms of land cover, it represents a piosphere, i.e., a localized impact of grazing on vegetation and soils, where degradation diminishes at increasing distance from the water reservoir. Grau et al. [34] reported that many of these puestos were abandoned between 1970 and 2002, while Matteucci et al. [37] reported a widespread reduction in rural population. However, Volante and Paruelo [35] found that during the last 40 years forest recovery occurred in less than 5% of the region, despite abandonment of traditional production systems and rural depopulation. These pieces of evidence contradict the assumed causal relationship between rural-urban migration and forest recovery proposed by Ecological Modernization narratives in the Argentine Chaco.

We analyzed the relationship between dispersed rural population and the maintenance of native forest at the department scale for the year 2010 (most recent population census). Although the relationship is weak, evidencing high variability, there is a positive relationship among these two variables (Figure 5). The analysis indicates that low levels of dispersed rural population is related to different proportions of remnant forests. However, in almost all departments with high levels of dispersed rural population, the proportion of remnant forest is high. This pattern is probably explained by the fact that traditional subsistence farming in the Argentine Chaco, unlike what happens in other agricultural frontiers, does not remove large tracts of native forests. On the contrary, their livelihoods depend on forest maintenance, since their diets are heavily based on hunting, gathering and the consumption of livestock (goat and cattle) reared under extensive forest-based grazing [63,64]. Hence, the link between rural demography and forest cover changes in the Argentine Chaco is best described by a hollow frontier [65] dynamic. Under this dynamic, rural depopulation and the abandonment

of land is not followed by a post-agricultural secondary succession of forests, but instead, is highly vulnerable to the expansion of modern production systems.

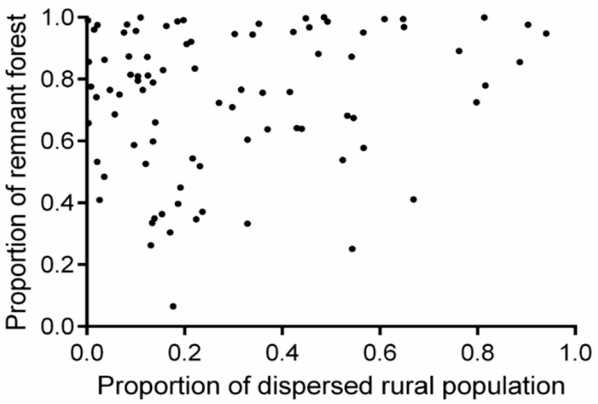

Figure 5. Relationship between the proportion of dispersed rural population and the proportion of remnant forest at the department scale in 2010 for all the departments contained in the Argentine Dry Chaco. Data of forest cover is from a plot-level database (http://monitoreodesmonte.com.ar/) and of population is from national population census (https://redatam.indec.gob.ar).

An additional critique to the Forest Transition Theory is the fact that not all forest should be considered equivalent, since primary (i.e., old growth), secondary (i.e., post-agricultural succession), and degraded (under selective logging and livestock grazing) forests, have contrasting structural and functional attributes, and therefore provide different ecosystem services [4]. Recent studies described the structural [66] and functional [67] similarities between primary and secondary forests. They found that after 15 years of abandonment, some aspects of ecosystem functioning, and species composition are restored (i.e., similar between primary and secondary forests). Similar results were found in another study for vegetation biomass soil organic carbon [68,69]. However, it is important to highlight that most of the secondary forests are immersed in an agricultural matrix where edge effects are high and connectivity to other forest fragments is low. Thus, the quality of these fragments as habitat for wildlife might be low and, furthermore, the high edge effects might determine that these forest fragments, and the ecosystem services they provide, are highly vulnerable. Another study described the changes in vegetation and bird communities at increasing densities from the puestos [70]. They conclude that vegetation is highly degraded near these piospheres, but at distances between 500 and 1000 m, structural attributes of vegetation saturate, suggesting that degradation is highly localized. Conversely, several avian guilds increased their abundance near to puestos in response to a resource gradient. Therefore, forest cover dynamics in the Argentine Chaco are highly complex as different types of forests have contrasting conversion probability and provide a differential supply of ecosystem services. Therefore, forest loss due to crop and pasture expansion in suitable lands might not be compensated by forest recovery in marginal lands.

3.5. Assumption 5: Rural-Urban Migration Improves Quality of Life of Emigrants and Agricultural Jobs of Non-Migrants

The positive social outcomes of Ecological Modernization narratives rest on the assumption that the population displaced from their traditional lands migrate either to urban areas or to agriculturally intensified lands where they are employed in the industrial or agricultural sector, respectively. It follows that waged labor and better access to services (electricity, sanitation, education, etc.) improves their quality of life. Unfortunately, scientific evidence to assess the occurrence of these processes and outcomes at the regional scale is scarce in the Argentine Chaco. However, available sources of evidence offer some insights. Looking at the fate of those who migrated, spatio-temporal correlation analyses showed that it was the periurban, and not the urban, areas of medium-size cities which increased their

population as intensified agriculture expanded in the Argentine Chaco [37]. This suggests that rural people has mostly migrated into periurban areas where living conditions are usually worse than in rural areas. In the same line, analyses of the social, cultural, and economic conditions of peasant families that migrated into (peri)urban areas due to modern agricultural expansion consistently point that rural emigrants have strong difficulties to get jobs that provide enough income to maintain the minimum living standards in cities [71,72]. Instead, they usually become dependent on social assistance by the State, which is exchanged for political support in clientelist political networks [57]. Even if they find precarious non-qualified jobs or had the chance to sell their land, they don't have the mindset and skills to invest in urban economic activities that can sustain a good quality of life in cities [72].

Looking at those who stayed in rural areas, the prospect for rural non-migrants of being employed in the agricultural sector is hampered by the low and decreasing amount of labor demanded by modern forms of production. Between 2002 and 2010, agricultural production in Argentina increased by 44.2%, while the amount of agricultural jobs increased by only 7%. This represents a very low employment-production elasticity in the agricultural sector (0.18) compared to that in the overall economy (0.52) [73]. Modern agriculture replaced more labor-intensive forms of production, and technological advances drastically reduced the amount of person-days needed for agricultural activities. For example, in two decades there was a fourfold decrease in the amount of person-days needed to complete the cultivation cycle of soybeans, with 1 person-day for 1 hectare in the 1970s to 1 person-day for 4 hectares in 1990s [74]. Rather than being employed by modern agriculture, non-migrants were deeply affected by outmigration driven by modern agricultural intensification. Outmigration of young people led to labor shortages for traditional farming activities, with a consequent reduction in the scale of farming and land-use diversification [75]. The work overload of non-migrants and the resulting sociability reduction weakened reciprocity exchanges and the local social networks, leading to erosion of social and cultural capital. These observations raise profound doubts about the positive social outcomes portrayed by Ecological Modernization narratives in the Argentine Chaco.

4. Discussion

Theoretical developments derived from the grand theory of Ecological Modernization such as the Forest Transition Theory and the Land Sparing Hypothesis have been underpinning narratives portraying modern agricultural intensification as the solution to end hunger, revert environmental degradation, and improve people's quality of life in agricultural frontier regions of developing countries. Drawing on multiple sources of evidence (i.e., literature review and straightforward correlative analysis of key variables), we have challenged the five key assumptions regarding the processes and outcomes proposed by Ecological Modernization narratives as applied to the Argentine Chaco. Contrary to early findings [34], recent studies suggest that a forest transition is not taking place in the Argentine Chaco, neither in its outcomes (i.e., forest recovery, [35,36]), nor in its processes (e.g., agricultural adjustment, [37]). By expanding the analysis of these previous studies, we found that for the Argentine Chaco, none of the assumptions underlying the social-ecological transition proposed by Ecological Modernization narratives was supported by available evidence.

Although deforestation rates have been reduced in the past years, the Argentine Chaco is far from undergoing a forest transition. The long-term effectiveness of the main factors contributing to reduced deforestation, i.e., declines in soybean prices and implementation of the Forest Law, is threatened by economic and political fluctuations [29–31,76]. Hence, the priority is to reduce deforestation through a better implementation of the Forest Law and by complementing it with other policy instruments (e.g., supply chain management, [77]). Contrary to Ecological Modernization narratives, our results and review suggest that rural depopulation might be an effect of forest cover change, and not a cause. Therefore, the permanence of rural population in their lands by granting titles to peasants and indigenous people might be an effective policy to reduce deforestation, as has been proven in other agricultural frontiers [78,79]. Besides, this could also probably reduce social unrest due to evictions of traditional land-users with land tenure insecurity. However, we acknowledge that

traditional land-users are associated with localized forms of environmental degradation [43,64,70] and poverty [80]. Thus, far from romanticizing traditional livelihoods, we consider that better social, ecological and economic outcomes in the Argentine Chaco could be reached by fostering public policies for the permanence of these social actors (e.g., infrastructure, agricultural technology), rather than by promoting rural-urban migrations.

4.1. Limitations and Caveats

We addressed the validity of Ecological Modernization narratives through the analysis of a case study region. Theory validation through the case study approach is subject to selection bias, whereby theory supporters tend to analyze successful cases and theory critiques have the opposite tendency [81]. Our case study analysis is based on the best available knowledge of the region, but for some processes (e.g., rural-urban migrations) it cannot be deemed representative of the region due to the presence of knowledge gaps. For these reasons, our findings cannot be transferred uncritically to other contexts. Nevertheless, many processes and outcomes described for the Argentine Chaco have also been observed in other contexts and at larger scales, as shown in Section 3.2. Therefore, from an epistemological point of view, we recommend the use of a middle-range theory in further studies that seek to compare social-ecological transitions of multiple modern commodity frontiers. This would enable an explicit account for context-specific properties of each frontier and generalizable characteristics and/or similarities that emerge from their comparison.

Our analysis describes the flaws of the Ecological Modernization narrative for explaining social-ecological change in the Argentine Chaco and similar modern commodity frontiers. This does not mean that other narratives are more appropriate, as we did not compare the relative merits of alternative explanations. However, we believe that critical analyses of Ecological Modernization narratives as applied to different contexts are needed because the uncritical exportation of explanations from one context to another can be dangerously misleading for decision and policy-making. To go beyond this critique and warning, in Section 3.3 we propose some avenues to refine the analytical frameworks for assessing how valid are social-ecological explanations to understand and steer environmental problems.

4.2. Generality and Context-Specificity of Processes and Outcomes

Some of the social-ecological processes and outcomes driven by agricultural modernization described here for the Argentine Chaco have been also observed in similar contexts. Agricultural intensification was generally accompanied by increases in cropland area at the global scale between 1970 and 2005, except in countries with grain imports and conservation set-aside programs [82]. In central and northern Brazil, agricultural intensification coincided with expansion of crops and pastures between 1960 and 2006 [83] supporting the notion that technological advances can create incentives for expansion in agricultural frontiers rather than contraction [20]. In Amazonia, more intensive land management was clearly linked to increased deforestation and fire frequency between 2003 and 2007 [84]. One of the better described exceptions of the pattern of expansion amid intensification in Latin American agricultural frontiers is the "Amazon swerve" in Mato Grosso and Pará states [85]. There, a rapid decline of deforestation after 2004 occurred in response to national and international pressure for better environmental performance of modern soybean production and cattle ranching [85]. However, the reproducibility and effectiveness of the Amazon swerve has been challenged by analyses of the context and scale of this singular process. On one hand, the combination of forces that reduced deforestation included consumer boycotts, powerful NGOs, governments committed to deforestation reduction and protected area expansion, and a coalition with major soybean production companies, which can hardly be replicated outside the Brazilian Amazon, where the international appeal to conserve Amazon forests creates unique conditions [17]. On the other hand, deforestation slow-down in the Amazon fringe triggered deforestation acceleration elsewhere in Brazil, Bolivia, Paraguay and

Argentina –a leakage effect driven by the ability of deforestation agents to move their operations and "escape" from tight environmental regulations [86].

Also contrary to a central tenet of Environmental Modernization narratives, the trend in urbanization has been associated with greater, rather than lower, pressures for forest clearing in many places [87]. In the Darien region of Panama, the rural population decreased by nearly 20% from 1990 to 2000, but pasture area increased by nearly 50% and the number of cattle by 100% as a result of forest regrowth suppression via expansion of low-intensity land-uses [65]. In the Bolivian lowlands, deforestation rates higher than 150,000 ha per year occurred despite very low population densities [88]. The Brazilian Amazon frontier urbanized at a high annual rate during the 1980s (5.3%); however, deforestation rates increased (from 10,000 to 20,000 km^2 per year) along with land tenure and access conflicts [89]. These outcomes resulted from an increasing influence of non-local agents and exogenous factors in driving deforestation, as local people out-migrate from rural areas leaving behind the so-called "hollow" (i.e., depopulated) frontiers [65]. As shown for the Argentine Chaco, these demographic changes have been a consequence of the direct displacement of rural stallholders by modern large-scale agricultural operations. The expansion, concentration and mechanization of soybean production in Santa Cruz (Bolivia) by large transnational companies lead to the displacement of smallholder farmers [90]. Land dispossession of smallholder farmers has been also extensively documented across Asian and African regions. In Malaysia and Indonesia, tens of thousands of local smallholders have been dispossessed from their lands due to oil palm production, which expanded from 3 million ha in 1990 to 9 million in 2003, but only employs one person per 10 ha [91]. As in the Argentine Chaco, traditional land-users dispossessed from their land and means of production have become "surplus" populations, unemployed and marginalized in the outskirts of modern cities [57]. Contrary to the expectations of Ecological Modernization narratives and to historical patterns of developed countries, the population displaced from modern commodity frontiers rarely finds jobs in urban areas since industrial and service sectors are undeveloped or too small [57,91].

4.3. Towards Systemic Explanations of Social-Ecological Change

Researchers have searched for manifestations of Ecological Modernization narratives, such as forest transitions and land-sparing effects, mostly looking at temporal trends or balances in biophysical indicators (e.g., forest cover, agricultural yields, species richness) at aggregated, mostly national or sub-national, levels (e.g., [11,33,92,93]. Observed trends and balances can tell us "what" is occurring but are usually silent about "how" and "why" questions, and its level of aggregation impede asking "who" drives the patterns observed and "whose" quality of life is affected. These questions are critical if knowledge production seeks to transcend mere academic interest and be useful for understanding and steering social-ecological systems towards sustainability [94]. Answering these questions and moving towards systemic explanations requires four analytical shifts, mainly related to the grain and extent of analysis, and with the social-ecological properties analyzed and its relation to global and or regional processes.

First, explanations should not uncritically assume that land-use agents behave in a fully rational way, or that they operate in a social vacuum free from power asymmetries and vested interests [95–97]. The rational economic actor model has underpinned explanations of farmer choices, for instance, to abandon marginal lands in response to decreasing economic returns, to halt agricultural expansion when intensification allows larger returns from the same land, or to shift to tree planting when faced to environmental threats and/or forest scarcity [14,98]. None of these behaviors has been observed in farmers and ranchers of the Argentine Chaco. There, analyses of agent behavior has shown, for instance, that modern farmers seek to clear forests in marginal lands for speculative reasons, among them, to increase the price of land and/or to expand low-intensity cattle ranching operations to secure land tenure rights [99].

Second, explanations should situate regional social-ecological processes in the larger political and economic system to capture countervailing forces operating at different spatial and temporal

scales [81]. If we want to know the net social-ecological outcomes of ecological modernization we need to look at regional and global processes, particularly the international trade of agricultural commodities and the associated flows of ecosystem services and impacts [100]. Looking at interactions between distant places (i.e., teleconnections and telecouplings, [101]) revealed that gains in forest cover in one place often drive deforestation in other places, causing the displacement of land-use change and environmental impacts [86,102]. Situating current processes in a larger historical context is also needed as the likelihood of "win-win-win" outcomes arising from ecological modernization in developing countries is strongly path-dependent. Land use transitions are highly conditioned by past experiences of colonization, continued political and economic dependency, subordination to foreign actors and export-oriented production [3,4].

Third, explanations should move from analyzing the relative efficiency of alternative land-use systems at the local scale, towards assessing the efficiency and resilience of regional land-use trajectories and global commodity chains. For example, assessing accumulated social and environmental impacts all along the soybean supply commodity chain raises serious doubts about the efficiency of modern soybean production systems. Soybean exports are driven by demand for feedstock from concentrated animal feed operations, mainly from China and Europe, and for the biofuel international market [103]. Life-cycle assessments demonstrate that concentrated animal feed operations relying on soy-based feedstock are extremely inefficient forms of producing protein for human food, and soy-based biodiesel is only carbon efficient when produced in small-scale diversified production systems [104–106] and could be related to higher greenhouse gas emissions due to indirect land use displacement [107,108]. Similarly, assessing aggregated (regional) resource consumption of modern soybean production systems shows persistent increasing trends of agrochemicals use despite alleged decreases in agrochemical input used per unit of product (i.e., Jevon´s paradox).

Finally, explanations should explicitly assess the distribution of costs and benefits from social-ecological change across individuals and social groups at different spatial and temporal scales [109]. In 2010, the Argentine Chaco produced enough food to feed a population that is 30 times larger than its number of inhabitants; however, it was the region of the country with higher levels of hunger, malnutrition and poverty [80,110]. This evidence contradicts the assumption that more agricultural production brings better social outcomes through trickle-down, since modern agriculture expansion and intensification increases the asymmetries in people´s access to means of production and ecosystem goods and services [111]. Disaggregating impacts by ethnicity and gender raises further concerns, as indigenous people, particularly women, are the most affected by neo-enclosures of large-scale modern farms, which impede the mobility of indigenous people through their ancestral lands and their access to wild food, fibers, fuelwood and medicinal plants [112]. Meaningful analyses of the distributional impacts of ecological modernization are critical to avoid increasing, rather than decreasing, socio-economic inequality in agricultural frontiers.

5. Conclusion

Available evidence from multiple sources does not lend empirical support to the occurrence of the social-ecological processes and outcomes purported by Ecological Modernization narratives for the Argentine Chaco. None of the five key causal relationships on which the positive social, economic, and environmental outcomes of these narratives lie should be assumed without empirical testing in modern commodity frontiers. The uncritical exportation of ideas from universalist theories like Ecological Modernization from developed to developing countries neglects the context-specificity of social-ecological dynamics and can be dangerously misleading in the search for sustainability. The processes of agricultural expansion amid intensification, and deforestation amid rural depopulation, observed in the Argentine Chaco illustrate the poor validity and usefulness of Ecological Modernization narratives for understanding and steering social-ecological change towards sustainability in this region.

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