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Research Letters

From whom and for what? Deforestation in Dry Chaco from local-urban inhabitants' perception*

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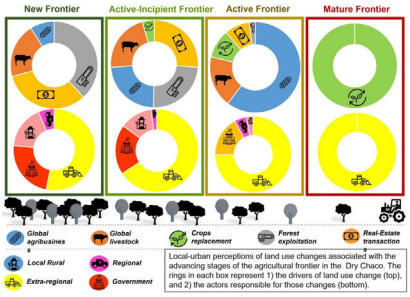
HIGHLIGHTS

- Agriculture-frontier classification allows organizing social-ecological processes.
- Forest exploitation and real-estate transactions are daily drivers in the early stages.
- Global agribusiness and livestock are drivers dominating the advanced stages.
- Only crop replacement takes place during mature frontier stages.
- Extra-regional people and governments are mentioned as the responsible social actors.

GRAPHICAL ABSTRACT



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ABSTRACT

To meet the global-human population increase, deforestation resulting from agriculture expansion threatens the ecological and social dimensions of subtropical and tropical forests. Here, we identified classes of agricultural frontiers in the Dry Chaco ecoregion based on land-use changes between 2000 and 2013, in which we performed interviews and quantified local-urban people's perception regarding (1) main drivers of deforestation, (2) main actors responsible for it, and (3) if deforestation drivers impact positive or negatively on their welfare. Whereas in early frontier' stages (i.e. new and incipient-active frontiers) the drivers perceived as responsible for deforestation were forest exploitation and real-estate transactions, in a later stage (i.e. active-frontier class) global agribusiness and livestock emerged. In mature-frontier stages, only cropland replacement was perceived as responsible. Across all agricultural-frontier classes, extra-regional people were the most pointed as responsible for deforestation, but governments were mentioned concerning weak policies and absence of plans. Global agribusiness was the driver most mentioned as impacting positively and negatively on local-urban people's welfare, mostly related to job opportunities. This likely reflects that not all the population can take part in the economy boosted by commodities production. The identification of stages of agriculture-frontiers resulted in a simple and rigorous classification that could allow predicting social-ecological trajectories.

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Introduction

The booming global human population and food demand have driven deforestation for commodity expansion in many tropical and subtropical areas (Graesser et al., 2015; Curtis et al., 2018). Therefore, land-use changes received much attention from the academic sector, especially in Amazonia and Dry Chaco ecoregions, which harbor the largest and most continuous forests of South America (Lambin et al., 2013). Studies made efforts to demonstrate land-use changes' impacts on the environment by mostly reporting consequences on forest' structure and functionality, such as biodiversity loss (Barlow et al., 2018) and climate change (Baccini et al., 2012; Hansen et al., 2013). However, the impact of the agricultural frontier advances on the social dimension of those systems is frequently neglected (Zepharovich et al., 2020). Approaches integrating the biophysical, social, and economic factors influencing conservation and productive outcomes are needed, particularly in social-ecological systems of agricultural frontiers (Mastrangelo et al., 2019).

Land-use changes rarely occur in places isolated from people. Rather, they take place in social-ecological systems, where the social and ecological dimensions feed into each other, conferring unique features to the integrated. On the one hand, land-use changes may boost settlements' development, associated with infrastructure creation and job opportunities from the agriculture expansion (Riethmuller, 2003; Sacchi and Gasparri, 2015). On the other hand, land-use changes also generate shifts in the actors' portfolio, with local-rural people outmigration and their replacement by extra-regional people related to agricultural activities (Sacchi and Gasparri, 2015; Ceddia, 2019). In parallel, social aspects as inequality in income and land distribution in developing countries have been demonstrated to accelerate deforestation rates (Koop and Tole, 2001) or agriculture expansion (Ceddia, 2019), thereby representing key variables when attempting to understand land-use drivers and consequences. The Dry Chaco ecoregion provides an opportunity to assess different social perspectives on land-use changes. Firstly, it is a global hotspot of deforestation driven by agricultural production (Hansen et al., 2013), mainly for soybean and livestock (Fehlenberg et al., 2017). Secondly, the ecoregion has recently experienced normative restrictions regarding the allowance of land-use changes, tied to a forest zoning associated with the Forest Law (Marinaro et al., 2020). This is due to the great biological diversity that Dry Chaco shelters, which converted it into a conservation target ecoregion for NGOs and governmental organisms. Thirdly, the Dry Chaco ecoregion is home to a wide ethnic and cultural diversity (Marinaro et al., 2017). Indigenous communities, local peasants, and medium and large-scale agricultural producers coexist tensely (Bucher and Huszar, 1999; Cáceres, 2015; Marinaro et al., 2017). This scenario deserves a better understanding of the impacts of land-use changes on local population, from a local and broad perspective, for anticipating social and environmental conflicts.

In the Dry Chaco ecoregion, agribusiness expansion has strong links with small and medium-sized cities in the region, which work as logistic, administrative, and economic hubs (Gasparri et al., 2015; Piquer-Rodríguez et al., 2018). The evolution of small (less than 5000 inhabitants) and medium-sized agglomerations (between 5000 and 50,000 inhabitants in the study area), associated with deforestation, are commonly exposed by the agricultural sector as an example of the success of the agricultural expansion in terms of social progress. In contrast, local-rural people commonly argue that the agribusiness establishment represents a new restriction to the common pool of natural resources (Altrichter and Basurto, 2008; Marinaro et al., 2020). In addition, research studies commonly focus only on rural population and their use and perception of natural areas and productive land uses, to better understand land-use decisions (Cáceres et al., 2015; Le Polain de Waroux et al., 2018). However, information about perceptions and values of land-use changes from local-urban people, an important component of these dynamic social-ecological systems, remains a debt.

A better understanding of the interactions between the natural and human dimensions of the system, while considering the multiplicity of actors including the human dimension, is necessary for appropriate decision-making on land management (Anton et al., 2010). In this work, we attempt to move forward in this direction: we propose tackling the natural dimension by classifying agricultural frontier stages across a large area of the Dry Chaco ecoregion (i.e. the Northern Argentina Dry Chaco), while approaching the social dimension by conducting extensive personalized semi-structured interviews. Thus, we pursue contributing to a better understanding of the impact of deforestation on local-urban people's perception, helpful for actors-centered decision-making on land management. This is particularly useful in the context of the regular updates of the forest zonation of the National Forest Law, in one of the most active hotspots of deforestation globally (Hansen et al., 2013).

The overarching goal of our work was to explore local-urban people's perceptions regarding the social dimension of deforestation in agricultural frontiers of the Dry Chaco ecoregion. We specifically focused on the period 2000–2013, since the decade 2000–2010 had the highest agricultural expansion rates and agricultural production since the Second World War (Cáceres, 2015; Pengue, 2014; Graesser et al., 2015). To address our general goal, we first identified stages of agricultural frontiers in Dry Chaco (specific objective #1), that were used as a baseline to answer three research questions (each of them tackled by one specific objective):

1 Which are the drivers of deforestation according to local-urban people's perception? (Specific objective #2).
2 Who are the actors perceived as responsible for those changes? (Specific objective #3).
3 How different land-use change drivers are perceived to impact their welfare? (Specific objective #4).

Methods

Social-ecological features of the study region

Argentina is the world's third-largest producer of soybeans after the United States and Brazil (USDA, 2019), and the fourth-largest producer of cattle after the same countries, plus China (http://www.fao.org/faostat/es/#data, last accessed: November 16, 2021). Land-use changes associated with these yields strongly impacted on Dry Chaco ecoregion, where agriculture has expanded rapidly since the 1990s (Cáceres, 2015; Baumann et al., 2016; Piquer-Rodríguez et al., 2018). In this work, we focus on the Northern Argentinian Dry Chaco (henceforth, NADC), at the center of the American Gran Chaco (Fig. 1).

Our study area comprises 175,785 km^2, embracing seventeen departments (equivalent to 'municipalities') distributed across five provinces: western Formosa province, eastern Salta province, northwestern part of Chaco province, northern Santiago del Estero, and northeastern Tucumán province (Fig. 1). The mean annual temperature range is 19–24 °C and rainfall is 400–700 mm/yr, except for two moister fringes in the Eastern limit (the isohyet of 900 mm, which corresponds to the arbitrary limit between Dry and Moist Chaco ecoregions), and in the Western, the Chaco limits with the Yungas humid forest ecoregion (Burkart et al., 1999). Rainfall mostly occurs between October and March (i.e. a monsoon regime), when 80% of the rain falls (Morello et al., 2012).

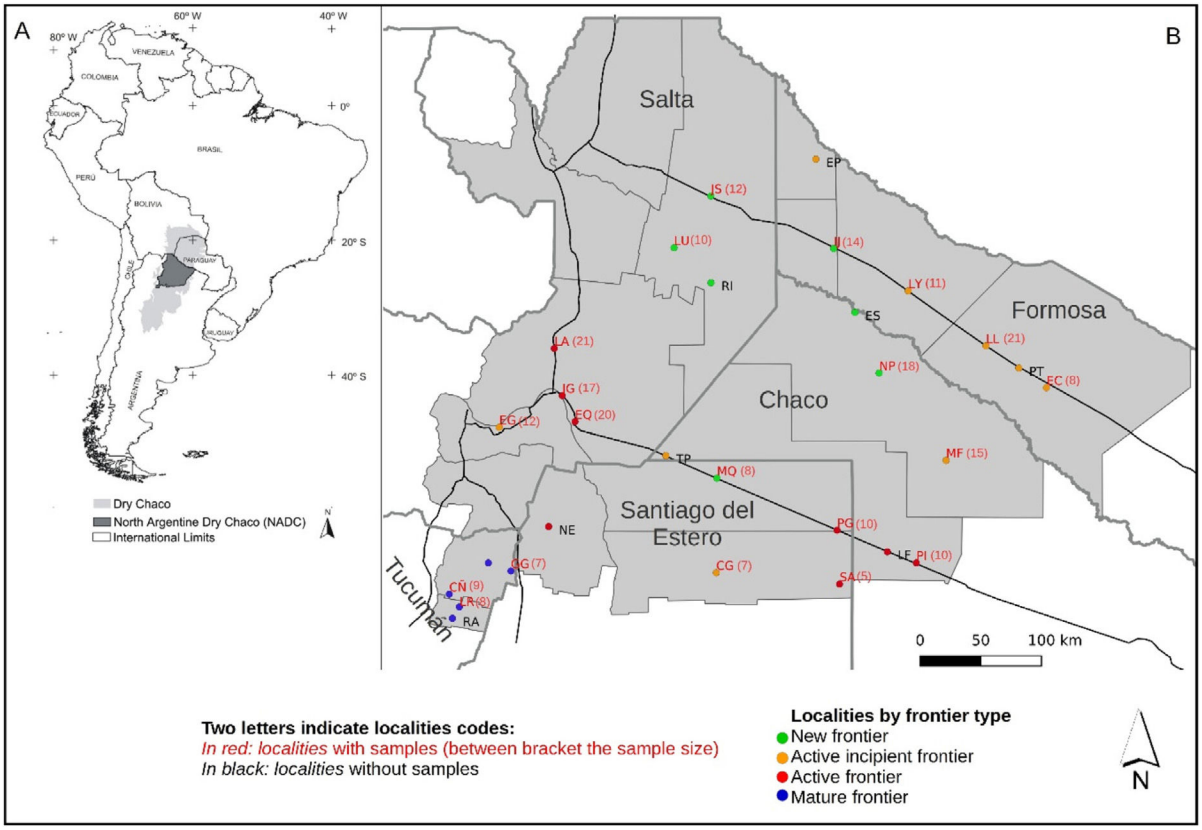

Fig. 1. Study area showing the classification of localities into stages of agricultural frontiers, and pointing out those where interviews were performed, as well as in which number. Table S.2 of the supplementary material includes the name of each code and more details for each locality.

Typical landscape in the NADC is represented by xerophytic vegetation in mosaics dominated by semi-deciduous forests of *Aspidosperma quebracho-blanco, Schinopsis lorentzii*, and species of the genus *Acacia, Mimosa, Prosopis, Celtis, Opuntia*, and *Cereus* (Bucher, 1983). These dry forests harbor high levels of biodiversity, including endemic and threatened species of different biological groups (TNC et al., 2005).

Cities in Dry Chaco are relatively new, with foundation dates after 1850 ('*late colonization*') (Grau and Foguet, 2021). Cities' late foundation also implies a late Spanish influence and its social-ecological consequences in the region. The livestock arrival was the most impacting in Dry Chaco, as it changed the frequency and intensity of the fires drastically, and led to the shrub encroachment of the region (Bucher and Huszar, 1999; Grau and Foguet, 2021). Additionally, the expansion of the railroads and colonization programs into the region since the 1880s allowed the greater spread of the peasants (i.e. *campesinos* or *criollos;* local people of European and indigenous descent) into the forests, with the practices of extensive cattle ranching and wood extraction (Bucher and Huszar, 1999).

More recently, the arrival of transgenic soybean in the 1990s, coming from the Pampa ecoregion (where had started in the 1970s), brought large-scale producers as a new type of actor in the region (Pengue, 2014). These actors brought technology, capital, know-how, and machinery to develop intensive agricultural activities in the region, often leasing the land (Le Polain de Waroux et al., 2018). By the 1990s, soybean had expanded into the Dry Chaco region due to increasing soybean prices (Cáceres, 2015; Leguizamón, 2016) and new political and economic reforms that facilitated the increased production of crops in Argentina (Pengue, 2014). These land-use changes resulted in around 14% of the Argentinian Chaco being converted into agriculture by 2015 (Baumann et al., 2016).

Progressive impoverishment of forests by unplanned logging and overgrazing, coupled with a lack of rural employment opportunities, stimulated the migration of young people to the periphery of the cities (Bucher and Huszar, 1999). Currently, the region harbors people with the highest poverty levels of Argentina (Krapovickas et al., 2016), the population is low (*c.* 550,000 inhabitants in 2010) and very sparse (<3.1 inhabitants/km^2), and represents 68% of the total Argentinean rural population (INDEC, National Census 2010, www.indec.gob.ar; last access: April 6, 2021). However, Dry Chaco's cities are relatively young, (Grau and Foguet, 2021) and likely continue growing.

Study design and data collection

Within the study area, we considered as urban centers all towns with more than 2000 inhabitants in 2010 (according to the classification of the Argentinian Institute of Statistics and Census, INDEC, 2010). Among those, we discarded towns that were part of larger agglomerates, since their population dynamics are usually strongly influenced by the provincial capital. When two or more towns were closer than 30 km, we selected the one with better accessibility. These criteria were used in previous work to define the deforestation stages around towns in the Dry Chaco (Sacchi and Gasparri, 2015).

We performed cluster analysis and tree classification with the 29 centers complying with the criteria (Fig. 1) to classify them across agricultural-frontier stages. We based classes on the percentage of converted-land area in a buffer of 50 km at the beginning of the study period (%CLA$_{00}$), and during 2000–2013 (%CLA$_{00-13}$).

This period 2000–2013 was selected for our analysis since it experienced the highest agricultural expansion rates and agricultural production since the 1940s (Pengue, 2014; Cáceres, 2015).

To explore local-urban people's perception regarding the relation between land-use changes and people's well-being, we conducted semi-structured personal interviews in the urban centers previously classified according to the deforestation frontier stage. Guiding questions can be found in Supplementary Material S.1. We gathered data at the household level along the cities reported in the annex (each household as a case), and synthesized results per agricultural-frontier stage for the entire Northern Argentinian Dry Chaco (at the regional level).

Fieldwork was conducted during 2013 during four field trips of variable duration. Interviews were conducted by two properly trained interviewers, in Spanish, during 3–5 days per town. Local-urban people were randomly selected to embrace a wide range of knowledge, personal values, ages (but only older than 20 years were included), and educational levels; until the information given by respondents was not new at all, according to the concept of theoretical saturation (Bowen, 2008; Cáceres et al., 2015). Additionally, people pointed as a 'leader' of the town, and/or belonging to producers' associations (e.g. the Argentinian Consortium of Agricultural Experimentation, i.e. CREA, and the National Institute of Agricultural Technology, i.e. INTA), were included as respondents to gain a better understanding of the local dynamics and perceptions.

Though a questionnaire was elaborated, interviewers were kept flexible enough to allow people to express about topics not included on it (Cáceres et al., 2015). The questionnaire included the following information sections: (A) personal data, where we included: gender, age, place of birth (i.e. people was considered as 'local' when his/her place of birth was the same town or surrounding rural areas; or when the person was born elsewhere but spent his/her childhood in the town where the interview took place; 'regional', when the person was born in another place, which is within the limits of the Chaco ecoregion; and 'extra-regional' when the person was born outside the Chaco ecoregion), educational level (according to the academic formal system, i.e. primary, secondary, and higher education), and main work activity. (B) Perceptions regarding deforestation (i.e. presence/absence of deforestation, recent/outdated process -if deforestation occurred after or before 1990, respectively-, local/distant process -if deforestation in the study area occurred within or outside the province in which the interview takes place-, actors and drivers responsible for deforestation); and (C) arguments in favor and opposing the different drivers of deforestation, regarding their impact on their well-being. Actors responsible, drivers of deforestation and arguments, emerged from the interviews and were *a posteriori* organized into different categories for the three of them.

Data analysis

To identify agricultural stages in the study region (specific objective #1), we used land-cover maps and data calculated by Baumann et al. (2016). They used compositions of Landsat TM and ETM imagery to estimate the area of forest, croplands, and grazing, and the transitions between those categories for the years 1985, 2000, and 2013. The forest class included woody vegetation whose canopies cover more than 50%; croplands included mostly intensified soybean, maize, and cotton fields; while grazing included natural grasslands, implanted pastures, and silvopastures (Baumann et al., 2016). We used those maps to classify a buffer area of 50 km around each town into different classes: forest, croplands, or grazing; for years 2000 and 2013. We assume that the converted-land area (i.e. croplands and grazing area) is equivalent to the deforested area since in Dry Chaco land conversion replaced natural vegetation, including mostly dry forests and, only exceptionally, small portions of natural grasslands and sectors previously affected by fires (Sacchi and Gasparri, 2015). Then we calculated the percentage of area converted to croplands and grazing at the year 2000 (% CLA_{00}), and of area converted during the period 2000–2013 (% CLA_{00-13}). We finally performed cluster analysis on the 29 urban centers of the study area to identify deforestation frontiers (average linkage based on Euclidean distance), and decision trees to explore limits between classes (Fig. 1). We used %CLA_{00} and %CLA_{00-13} as the independent variables for each town in the Chaco region. The Los Ralos locality was considered as a mature frontier though no data analysis was possible for the period 2000–2013. However, this locality was already a mature frontier during 1990–2000, a period when increased from 66.35% of converted land area (in 1990) to 72.97% (in 2000) (Sacchi and Gasparri, 2015).

To address second to fourth specific objectives, we transcribed and analyzed interviews with the Atlas Ti (v7) software. We only included data coming from interviews which *i)* recognized the presence of deforestation, and *ii)* perceived it as a local and recent process. In many cases, people who recognized deforestation perceived it as a process with more than one option, among the combinations of deforestation as a local/distant, recent/outdated process, and addressed by more than one type of actor, and for more than one driver. Thus, we obtained a higher number of mentions regarding how people perceive deforestation than the number of people interviewed. With the subset of interviews, we analyzed the perception of local-urban people regarding which are the drivers of deforestation (specific objective #2), and who are the actors responsible for each of those changes (specific objective #3), for the different contextual situations defined by the agricultural frontier stage. At each frontier, we counted the total number of mentions about drivers, and responsible actors, and we then presented percentages of each driver and actor, per frontier stage.

Finally, to explore how local-urban people perceive the impact of land-use changes on their welfare (specific objective #4), we analyzed the arguments favoring and opposing to recent (i.e. since ~1990) and local land-use changes. Since no categories were imposed in the questionnaire, the arguments emerged from the respondents' discourses and were qualitatively grouped according to their similarity *a posteriori*. To warranty no-biased trends in our results across the three educational levels reported by the respondents, we calculated the percentages of negative and positive arguments. We then calculated the C coefficient between arguments and the drivers of land uses, by using the Atlas Ti software. The C-coefficient is a qualitative measure of the strength or intensity in the co-occurrence between two codes. The values of the coefficient range between 0 and 1 (where 0 represents the absence of co-occurrence and a value of 1 means co-occurrence between two codes in 100% of cases). The C-coefficient is suitable for big datasets of interviews, as in this case (Atlas ti v7 instructions manual). We arbitrarily decided to highlight values of the C-coefficient higher than 0.05 in the table, with the simple goal of easing the finding of the higher C-values.

Results

Agricultural-frontier stages in Dry Chaco

Cluster analysis based on %CLA_{00} and %CLA_{00-13} grouped four classes of agricultural-frontier stages, with a cophenetic coefficient (i.e. an index for measuring the correlation between the Euclidean distance of points in feature space and distance on the dendrogram; Romesburg, 2004) of 0.845. The groups reflect different stages in the frontier establishment. We define the following classes of agricultural-frontier stages and their cut off thresholds values: (*i*) *new frontier*, n = 7, characterized by a low level of

transformation and large remaining forest area (%CLA_{00} < 10.8; % CLA_{00-13} < 6.28); (*ii*) *active-incipient frontier*, n = 9, characterized by an important land-use change, but still large remaining forest area (% CLA_{00-13} = 6.28–22.96); (*iii*) *active frontier*, n = 8, also characterized by strong land-use change (% CLA_{00-13} > 22.96); and finally (*iv*) *mature frontier*, n = 5, characterized by large area converted before our study period, and low conversion during it (% CLA_{00} > 28.57, % CLA_{00-13} < 25). For both the active-incipient and the active frontiers, the values of %CLA_{00} did not influence the classification, and thus the analysis did not include them in the criteria. The list of localities included in the analysis and their class of agriculture-frontier stage, as well as their different-land cover area, is reported in Table S.2 in Supplementary Material.

The new frontier stage is integrated by localities with a high proportion of forest, where land conversion is negligible (Fig. 1). In the year 2000, the forest still represented $\bar{x}$ = 88% of the area in new frontiers, while croplands and grazing area were the $\bar{x}$ = 0.46% and $\bar{x}$ = 1.39% of the area. During 2000–2013, deforestation was mostly for conversion into grazing areas, and intensification processes were almost inexistent. The *active-incipient frontier* stage for localities starting their forest conversion into croplands and grazing areas. In the year 2000, forest area was high ($\bar{x}$ = 86%), and grazing area and croplands ($\bar{x}$ = 5% and $\bar{x}$ = 3% respectively) were higher than in the new frontier localities. During the 2000–2013 period, forest loss was $\bar{x}$ = 12% (94,200 ha), which was mostly destined for grazing area (less than 2% was converted into croplands). Intensification during this stage was still a weak process, with only $\bar{x}$ = 1% of the grazing area turned into croplands. Therefore, the increase in croplands was lower than in grazing areas ($\bar{x}$ = 3% and $\bar{x}$ = 10% respectively). *Active-frontier* localities had an average forest area of 62%. The area of croplands and grazing in this class was higher than in the active-incipient frontier, with percentages of $\bar{x}$ = 18% and $\bar{x}$ = 15%, respectively. Forest conversion during 2000–2013 was $\bar{x}$ = 21.6% (169,560 ha), similarly distributed across grazing areas and croplands. In this class, intensification sharpened, and an average of 10% of the grazing area was turned into croplands. While much forest area was converted into grazing area, also large grazing area was turned into croplands; thus resulting in a low net increase in the grazing area. Thus, the croplands increased by $\bar{x}$ = 21%, while the grazing area increased 0.75% on average. Finally, *mature frontier* localities started in the year 2000 with a forest area of $\bar{x}$ = 30%, while croplands represented $\bar{x}$ = 53% of the buffer area. In contrast, grazing area only represented $\bar{x}$ = 12% of the area. During the period 2000–2013, the predominant land-cover change in mature-frontier localities was the loss of forest area, but also the conversion of grazing area into croplands. Intensification characterizes this frontier-stage class since the croplands increased around 13%. Even when the grazing area replaced the forest area, $\bar{x}$ = 9% of the grazing area turned into croplands; thereby the net change into grazing area resulted negative for localities of mature frontier (Fig. 1).

Local-urban people's perception

A total of 254 people were interviewed across 20 of the 29 localities under study. Their distribution among agricultural frontiers was n = 62 across *5 'new frontier'* localities; n = 76 across 6 *'active-incipient frontier'* localities; n = 92 across 6 *'active frontier'* localities, and n = 24 across 3 *'mature frontier'* localities (number of interviews per locality is shown in Table S.2). The imbalanced number of interviews among agricultural frontiers is because the classification of agricultural frontiers was posterior to fieldwork. Along with those interviews, 60 mentions (19.74%) did not perceive deforestation, either as a local or a remote phenomenon. When inquiring about land-use changes occurring around in their town, some of the interviewees said that deforestation is processes taking place in distant places, as in the Brazilian Amazon. In other cases, interviewees

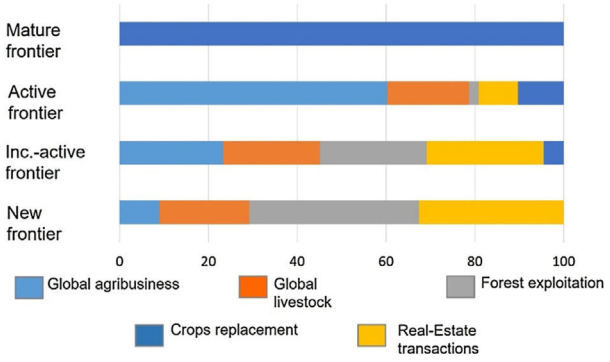

Fig. 2. Percentages of purposes perceived by local-urban people as drivers of land-use changes, per agricultural-frontier class.

talked about deforestation as discrete events which took place in their childhood, for example, associated with the railroad arrival. However, when we asked them what is currently happening in their area, some of them said that they do not know, and others even neglected deforestation or any other important land-use changes occurring in their town. Other 244 mentions recognized deforestation as follows: 209 (the 68.75%) perceived deforestation as a recent and local phenomenon, while 35 mentions (11.51%) perceived it as a recent but distant phenomenon. Mentions are in higher number than interviews, since the same person could report more than one option.

Main drivers of land-use changes in the study area, as perceived by local-urban people, emerged from the interviews. Five main drivers emerged along 379 mentions: 'global agribusiness', 'global livestock', 'forest exploitation', 'real-estate transactions', and 'crops replacement'. Percentages of mentions per driver were quite variable across agricultural-deforestation stages (Fig. 2). In *'new frontiers'*, 89 mentions of drivers of land-use change emerged, being 'forest exploitation' perceived as the dominant one (38.20%), while 'real-estate transaction' seconded it (32.58%). In the incipient-active frontier, 133 mentions were recorded as follows: 'Crops replacement' was mentioned but in a very low percentage (4.51%), while the remaining four drivers were mentioned in very similar percentages (values between 21.80% and 26.32%). Active frontiers recorded 136 mentions of drivers and were highly dominated by 'global agribusiness' (60.29%), while the drivers 'global livestock' and 'crops replacement' seconded it with very lower percentages (18.38% and 10.29%, respectively). 'Real-estate transactions' and 'forest exploitation' were scarcely mentioned as responsible drivers of land-use change in this frontier. Finally, the mature frontiers only recorded 21 mentions of drivers, and all of them pointed at 'crops replacement' as the unique driver of land-use change (Fig. 2).

A total of 388 mentions about the responsibility of different actors on land-use changes, as perceived by local-urban people were recorded during our interviews (Fig. 3A). Across the four agricultural-frontier stages, the highest percentage of mentions was for the extra-regional actor (65.98%). Also across all mentions, government (19.33%) was perceived as the actor seconding extra-regional actors, while local-rural and regional actors were the least pointed (10.31% and 4.38% respectively). In *'new frontiers'* and *'incipient-active frontiers'*, local-rural actors were perceived as the third ones in order of responsibility, and regional actors as the last ones. In the *'active frontiers'*, however, those orders were inverted but were very similar to each other. Lastly, in the *'mature frontiers'*, 100% of responsibility was assigned to extra-regional actors (Fig. 3A).

When looking at the mentions on the responsibility of actors on the different drivers of land-use change, independently from the agricultural-frontier class, we observed very heterogeneous values

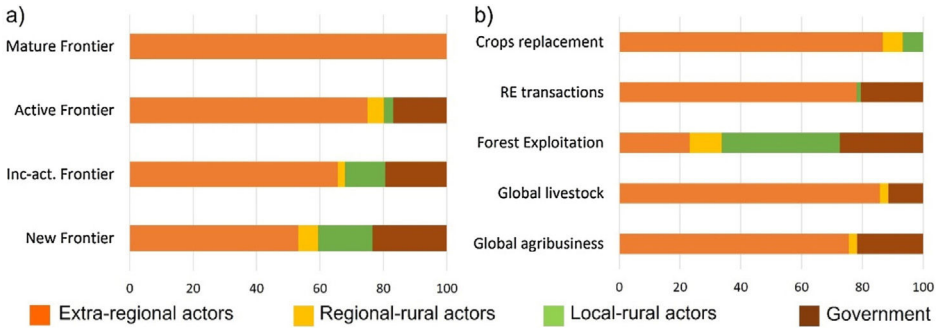

Fig. 3. Percentages of actors mentioned, by local-urban people, as responsible for land-use changes per (a) class of agricultural frontier, and per (b) driver of land-use change.

across drivers (Fig. 3B). Of the 115 times that 'global agribusiness' was mentioned as the driver responsible for land-use changes in the study area, the most times extra-regional actors were pointed as responsible for it (75.65%), followed by governmental actors (21.74%). The driver 'global livestock' was named 70 times, and 85.71% of the time was associated with the extra-regional actors, seconded by governmental actors (11.43%). In both, global agribusiness and global livestock drivers, local actors were never named as responsible, while regional actors were scarcely mentioned (<than 3% of times). The driver 'forest exploitation' was the most weakly associated with one particular actor; It had 95 mentions and most times local actors were pointed as the responsible ones (38.95% of times), followed by governmental and extra-regional actors in similar percentages (27.37% and 23.16% respectively). This is the only driver in which local inhabitants are pointed as the responsible actors. The driver 'real-estate transactions' was mentioned 78 times, almost exclusively associated with extra-regional (78.21%) and governmental (20.51% of times) actors. Finally, the driver 'crops replacement' was mentioned 30 times, and it was associated with extra-regional actors 86.67% of the time, while the remaining mentions were equally distributed between regional and local actors (Fig. 3B).

During the interviews, 17 categories of arguments favoring (6) and opposing (11 arguments) land-use changes in the study area were mentioned (Table S.3 in Supplementary material, Fig. 4). Broadly, there were 994 mentions regarding the impact of land-use changes, 76.26% of which were negative (758 mentions). Along those, negative mentions were predominant from people with the three educational levels (i.e. 83.82%, 66.43%, and 78.30% of the answers from respondents with primary, secondary, and higher education, respectively, were negative).

The driver of land-use change 'forest exploitation' was only scarcely mentioned by local-urban people as having an impact on their welfare. Therefore, values of the C-coefficient were too low and thus are not presented in Fig. 4. The highest C-coefficient values associating drivers and arguments, considering separately the positive and negative arguments, emerged both from the association of the driver 'global agribusiness'; with the positive argument 'benefits in a general way' (C-value = 0.10), and with the negative argument 'no-rural employment' (C-value = 0.20) (Table S.3). Among the positive arguments of land-use changes, the highest values of the C-coefficient emerged from the association of the driver 'global agribusiness' with the arguments 'benefits in general', 'rural employment', and 'direct' and 'indirect-urban employment' (C-values = 0.10, 0.08, 0.07 and 0.07, respectively); and of the driver 'crops replacement' with the argument 'indirect-urban employment' (C-value = 0.05). Among the negative arguments, on the other hand, many associations between drivers and arguments reached high values of the C-coefficient (Table S.3, Fig. 4). The same arguments with high C-value among the positive arguments were also detected as negative arguments for the drivers 'global agribusiness', 'global livestock', 'real-estate transactions', and 'crops replacement'. It means, the negative arguments 'no-benefits in general', 'no-rural employment', 'no-direct urban employment' and 'no-indirect urban employment' also reached the highest values of the C-coefficient for those four drivers (Table S.3, Fig. 4).

Discussion

Agricultural frontiers in Dry Chaco

The classification of localities into agricultural frontiers in the Dry Chaco ecoregion described a sequential pathway of land-cover changes between the years 2000 and 2013, in a gradient from a mostly forest-covered to a fully deforested area. Our results suggest a sequential trajectory, starting with an area with a prevalence of forest and negligible croplands and grazing area. At the early stage, which we named as *a new-frontier* class, forest area is still predominant and land conversion is mostly into grazing area. Afterward, deforestation increases and land-cover changes from forest to (mostly) grazing areas are the daily scenarios. We named this stage an *active-incipient frontier*. In a later stage, forest cover still is high, but much has been removed, and deforestation is highly active. During this stage, named as *active frontier*, main-land cover is croplands, because of deforestation but also of the replacement of grazing area into croplands. Finally, in the latest stage named *mature frontier*, deforestation turns a comparatively slower process since forest area is significantly lost. Instead, key processes are intensification and crops replacement, in a scenario of mostly croplands directly resulting from deforestation, and indirectly from grazing area's replacement into crops.

Based on our results, we conclude that the classification of localities into agricultural-frontier stages was helpful to better understand land-cover changes in the Dry Chaco ecoregion. Such classification can be attained by using available and reliable data, in a simple and non-arbitrary way. Though our data only represent a sample of the entire study area, our approach could be useful for predicting future social-ecological trajectories in agricultural expansion, in other moments and regions of the most active hotspot of deforestation of Neotropical dry forests.

Actors and drivers of deforestation according to local-urban people's perception

Drivers perceived by local-urban people as the main responsible of land-use changes differed among agricultural-frontier classes, in a way coherent with the revealed sequence of classes. The story behind our results, built from the local-urban people's perception, tells that during an early stage of deforestation (new-frontiers class), forest exploitation is the principal driver of land-use changes, seconded by real-estate transactions. This result makes sense with a stage in which forest area is high, deforestation is perceived as

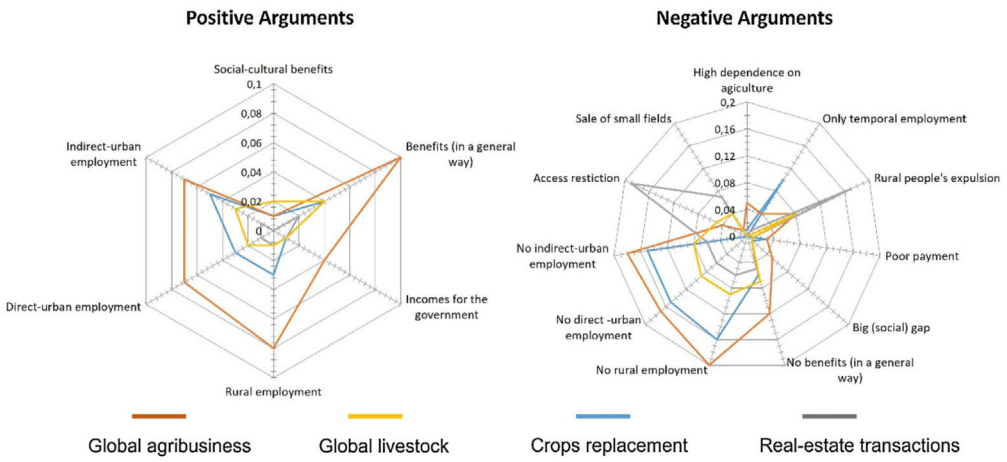

Fig. 4. Values of C-coefficient between (positive and negative) arguments and drivers of land-use changes, as perceived by local-urban people in Dry Chaco ecoregion.

the forest's fate, and real transactions are daily. Besides, the generalized local-urban perception of forest exploitation as an important driver of deforestation may likely be tied to the historical process taking place with the arrival of the railroad around 1880s, which heightened forest exploitation as a main activity in the region and opened roads widely (Bucher and Huszar, 1999). It allowed local inhabitants to work on their own, or to be hired by technician logging companies. Since the government is the actor responsible for forest extraction regulation at national and provincial levels (Marinaro et al., 2020), both the government and logging companies were the actors pointed out as responsible for deforestation. This converges in a generalized discourse among the local-urban population, of weakness in control and common corruption as ever-present factors. Meanwhile, native communities and criollos were also associated with logging by local-urban people, but not pointed them out as 'responsible' for deforestation, due *'they sell out of necessity'*. This perception denotes the unavoidable subjectivity underlying social perceptions since local-urban discourse reflects they associate *'responsibility'* with *'non-necessity'*. Therefore, local-rural people are *'innocent'* in the local-rural collective perception. In this context, we interpret that local-rural people could likely have increased their use of forest resources before fences' erection and deforestation would take place.

In the next stage (incipient-active frontier), all drivers excepting for crops' replacement would simultaneously be responsible for land-use changes. In face of the land-use changes observed all around, the replacement of local land tenure ownership by extra-regional actors would become frequent, here detected into the driver 'real-estate transactions'. Our results agree with previous research reporting that in the region, mean farm sizes increased from the arrival of extra-regional medium and large farmers (Mastrangelo et al., 2019). This farm-size increase would be a consequence of a farm type replacement from small farmers without land titles, to extra-regional actors with production strategies based on forest clearing and farm expansion (Le Polain de Waroux et al., 2018; Mastrangelo et al., 2019). Our results detected, besides, the local-urban perception that these land-use changes are also the responsibility of local and/or provincial governments by enabling them. Meanwhile, people selling their fields were sometimes motivated by the economic compensation, but other times forced to do it through intimidation and violent situations, ranging from verbal threats to the use of weapons (Burkart, 2009; Sili and Soumolou, 2011; Cáceres, 2015), in a context of legal vulnerability by their lack of land formal titles (Mastrangelo et al., 2019). These processes are reflected in the increase of social conflicts for the land since the year 2000, in coincidence with the highest agricultural expansion (REDAF, 2013). Independently of the trajectory in which real-estate transactions occur, it is often followed by local-rural people displacement into diminishing portions of marginal lands (Cáceres, 2015), or by their outmigration towards urban settlements. The last outcome commonly involves the settlement of rural people in the periphery of the cities, under highly vulnerable conditions (Krapovickas, 2016).

During the active frontier class, real-estate transactions and forest exploitation were perceived as sharply decreasing. At this stage, global agribusiness is perceived as the main driver of land-use changes, and crops replacement begins to acquire importance in local-urban people's perception. Finally, in the last stage of the agricultural-frontier advance (i.e. the mature-frontier class), only crop replacement is perceived to occur. Since there is almost no forest remaining at this stage, nor forest exploitation or deforestation may take place. Also, global livestock would have been almost fully converted into global agribusiness. Thereby local-urban people only perceived crops replacement around, though is possible that real-estate transactions were still taking place.

Broadly, extra-regional actors are the ones mostly perceived as responsible for land-use changes, across the four agricultural-frontier stages, and all the drivers of land-use change, except for forest exploitation. That last driver is the most different from the others since is the only one for which local-urban people pointed out mostly local-rural people as responsible for land-use changes, while also government and regional actors have a significant responsibility according to their narrative. Whereas local and regional people were only scarcely perceived as responsible for other drivers of land-use changes, and almost exclusively in new and incipient-active frontiers (with a negligible percentage in active frontiers). Meanwhile, the government was perceived in the first three frontiers' classes as a highly responsible actor for land-use changes, but much less so than extra-regional actors. Furthermore, extra-regional actors were the only ones pointed by local-urban people as responsible for land-use changes in the mature frontiers, where only crops replacement was mentioned to occur. However, when asking *'who is then responsible for crops replacement?'*, a few answers pointed to also local and regional actors.

Drivers impact on the welfare

Questions exploring the impact of drivers as perceived by local-urban people revealed two arguments diametrically opposite and similarly intense regarding global agribusiness. On the one hand, a part of the local-urban people frequently argued that global

agribusiness generates benefits in general, for instance, improvements to parks, access roads, and public lighting, as well as rural and urban employment. Nevertheless, there was interestingly a low generalized perception of the links between the agricultural practices and the state tax revenues. On the other hand, another large part of the population argued exactly the opposite, that is, that agribusiness does not generate benefits at all, nor rural or urban employment. Besides, people supporting the second discourse associated this driver with the expulsion of the rural people, high economic dependence on the activity, and the enlargement of a social-economic gap. This result is interesting since the coexistence of such opposing perceptions could show a potential factor of social conflict within localities. Future research deepening the typology of the interviewees could be insightful to better understand this dichotomy.

Of the other four drivers analyzed, only the "crops replacement" was significantly associated with a positive argument, specifically with the indirect generation of urban employment. Global livestock and real-estate transactions were deforestation's drivers perceived as lacking benefits at all. More particularly, they were negatively mentioned as generators of rural expulsion and restrictions on resources' access, and no generators of urban employment. The real-estate transactions driver was perceived as responsible for the displacement of small fields, and its substitution by medium and large-sized farms, owned by extra-regional people. This is consistent with previous research reporting this process in the region (Mastrangelo et al., 2019). Finally, it was broadly argued that crops replacement only generates temporary work, but no rural or urban permanent jobs.

Telling the story

Summing up, which is the story behind deforestation, as told by local-urban people? From whom and for what is the forest area being lost? According to the local-urban perception, local-rural people live surrounded by forest, from where they use to take natural resources which were historically perceived as common-pool resources (i.e. forest exploitation). That discourse coincides with previous research for the region (e.g. Bucher and Huszar, 1999; Altrichter and Basurto, 2008). Up to here, the locality is yet in the stage of a new agricultural frontier. On a certain day, a company arrives in the town, purchases land, wires it, and sells it at a higher price (i.e. real-estate transactions). Itself, fences' establishment implies a restriction to the access to the natural resources from forests (Marinaro et al., 2020). Since agricultural expansion commonly involves fences, it may boost outmigration of several rural families (Cáceres, 2015), with a consequent decrease of the rural population, as previously reported by other authors (López-Carr et al., 2009). After some cycles like this, livestock appears in those fields recently bought from extra-regional people. Neither the livestock nor the real-estate transactions bring, according to local-urban people discourse, improvements to the town nor economic benefits. At this point, the locality is already in the stage of the incipient-active frontier. Those responsible are extra-regional actors and the government, the last one as the stakeholder with power enough to regulate all those land-use changes. After this, the locality begins the stage of the active frontier, where forest conversion into croplands is daily. Besides, grazing fields are re-converted into crop fields. Along most of the answers, extra-regional actors are the people pointed out as responsible for these land-use changes. With this boom of companies and machinery arriving in the area, services begin to increase in the town, sometimes bringing infrastructure improvements, and new jobs. Finally, the novelty ends, and the town is in the mature-frontier stage. At this moment, many rural people have out-migrated to the town or even to larger cities, land-use changes are limited to exclusively crop replacement, and jobs' offering stops, as previously stated by Sacchi and Gasparri (2015).

The Dry Chaco scenario of frontiers' advances depicted in this work, over areas initially open by small farmers, combining corporate actors and a relative absence of state planning, is typical of the so-called neoliberal frontiers (Brannstrom, 2009; Le Polain de Waroux et al., 2018). Besides, since the land-use changes taking place pursue to increase the provisioning of agricultural commodities, mostly for soybean and livestock, these frontiers are 'commodity frontiers' (Le Polain de Waroux et al., 2018). Among the local-urban perceptions, it was synthesized in the discourse that deforestation driven by extra-regional actors promotes rural displacement and no major benefits (Fig. 4). Meanwhile, the cost of the advance of the frontier is non-provisioning local services, and a substantial loss of native vegetation and biodiversity (Piquer-Rodríguez et al., 2018).

Far from representing an isolated study case, the NADC area is one piece of a systematic and accelerated wider advance of deforestation across South America (Fehlenberg et al., 2017), where many expanding agricultural frontiers are simultaneously taking place (Le Polain de Waroux et al., 2018). Besides the ecological damage that deforestation itself represents, Latin America remains one of the most unequal places in the world (De Ferranti et al., 2004). Thereby, the social dimension tied to those frontiers is as much threatened as the ecological one, and as such deserves equal attention from the academic sector.

With this work, we expect to bring the perspective of the people living within the social-ecological systems on which the agricultural frontiers advance, in this case, the urban centers of commodity frontiers. We consider that their perspective contributes to a better understanding of the social impact of deforestation, and represents a basis for generating some new research questions in this line, as: (1) are the local land-use changes perceived as a local-scale process, or in turn, as a small piece of larger-scale processes, i.e. regional or global? (2) If real-estate transactions are perceived as having only negative impacts, would the solution, for local communities, be not selling land? And if that is the case, would agricultural-frontier advance be positively perceived if agribusiness and livestock would be implemented by local/regional owners? (3) Why is global livestock production perceived as having a secondary role, without major negative or positive impact, despite grazing area occupying the biggest portion of the area deforested, especially in active-agricultural frontiers?

Aligned to previous research, our results suggest that a higher governmental and societal engagement is needed to meet the rising demand for agricultural commodities, and simultaneous alleviate poverty and ecosystems degradation (Gardner et al., 2014). A stronger government involvement, with land use policies that recognize the actors' diversity, may have a significant impact on the well-being of socio-ecological systems built on different land use and ownership regimes, with mosaics of traditional land use and communal properties of indigenous people (Marinaro et al., 2020). Concretely, governments need to recover their role of planning agents for land-use changing, despite the facilitation or non-intervention role (Rudel, 2007) they currently play, as perceived by local-urban people in the NADC. The results here presented may be helpful as a diagnosis of the local-urban people perception, and contribute to more "actors' diversity-centered" policies, pursuing social and environmental justice.

Concluding remarks

Considering our results and the summary of the local perceptions, we suggest some conclusions from our work. The classification of localities into agriculture-frontier stages was a

simple and rigorous way to understand, organize and differentiate several social-ecological processes and perceptions, in this case, from local-urban people. Their perceptions regarding which are the drivers of deforestation differed across the agricultural-frontier stages. On the one hand, in the earlier-stage frontiers, i.e. new and incipient-active frontiers, drivers perceived were forest exploitation and real-estate transactions. On the other hand, in the active-frontier stage, global agribusiness and livestock emerged as drivers of deforestation. Whereas, the only driver perceived as responsible for deforestation in mature-frontier stages was crops replacement.

Extra-regional actors were the most frequently pointed out as responsible for deforestation, mainly due their investment capacity and production strategy, based on forest clearing and farm expansion. It resulted across all agricultural-frontier stages, and all drivers, excepting for forest exploitation. The government was also recurrently labeled as responsible for enabling deforestation, among all agricultural-frontier stages excepting for mature frontiers, and for all drivers excepting for crops replacement. This result highlighted a generalized local-urban perception of the State's inefficiency by omission related to weak policies and lacking plans.

Finally, concerning the impact of different land-use change drivers on local-urban people's welfare, global agribusiness was the most mentioned among the positive and negative arguments of deforestation. Mostly, this driver was related to rural and urban job opportunities. This suggests that the real impact of the global agribusiness expansion on the local development is on discussion and setting conflicts among people involved and facing the process. This likely reflects that not all the population can take part in the economy boosted by commodity production.

As a general conclusion, we suggest that the deforestation and agricultural-frontier expansion in Dry Chaco have not a clear consensus about its impact (positive or negative) on the local-urban population. However, this process is identified as imposed from out of the region. Additionally, real-estate transactions are perceived as having a negative impact that generates access restriction and rural people's expulsion. Surprisingly, livestock is perceived as generating benefits in general, but none particularly remarkable (e.g. rural employment), despite sown pastures being the largest land cover substituting forests and the most generator of job opportunities (Riethmuller, 2003).

Conflict of interest

None declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2021.12.003.

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