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RESEARCH ARTICLE

Smallholder land-use decisions in a tropical agro-forest frontier in Southern Mexico

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Abstract
Context Agricultural expansion has significantly diminished tropical forests. Understanding how social-ecological processes impact local smallholder land-use decisions is critical for assessing the effectiveness of land-use policy initiatives and shaping long-term socio-environmental futures.
Objectives Through a comparative analysis of two neighboring communities this research examines: 1) the land-use composition at farm-level, and 2) the social-ecological variables at three different scales: local (household factors), regional (biophysical factors), and national (institutional factors) that shape smallholders land-use decisions in an agro-forest frontier in Southern Mexico.
Methods Drawing on farm-level data from semi-structured interviews we tested for differences in land-use composition across farms per community. Using a combination of qualitative analysis from ethnographic research, and generalized linear models we assessed the variables that influence smallholder land-use decisions.
Results Seven distinct land-use types were identified: agriculture, pasture, primary forest, secondary forest, rubber, oil palm, and reforestation. The two communities differ in on-farm primary forest cover. We found that the following variables influence smallholders' land-use decisions: 1) local-level: farm size, off-farm income, and diversity of income sources; 2) regional-level: soil quality; 3) institutional-level: some programs (Rubber, Oil palm, Reforestation) influence certain land-use decisions, while the relationship between some programs (PROCAMPO, PROGAN, PES) and certain land-use decisions was harder to evaluate.
Conclusions We conclude that while making local land-use decisions, smallholders evaluate a number of social-ecological factors at various scales. This has important implications for the formulation of more tailored and contextual-based agricultural development and conservation policies that aim not only to accomplish specified land-use outcomes but also to improve farmers' livelihoods.

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Keywords Agricultural landscape · Social-ecological variables · Land-use change · Smallholder decision-making · Qualitative analysis · Mixed-methods

Introduction

Tropical forests harbor much of the world's biodiversity and supply vital ecosystem services at different scales (Laurance et al. 2014). Since the 1960s, forest landscapes in the tropics have diminished substantially as a result of agricultural expansion (Rudel et al. 2009), jeopardizing planetary integrity (IPBES 2019). Understanding the social-ecological drivers of land-use decisions in tropical landscapes is thus critical to formulate policies that might halt deforestation and shape sustainable socio-environmental futures. Scholars from several domains have addressed the critical subject of the role of socio-ecological drivers of land-use change. In land system science, many meta-analyses of hundreds of case studies indicated that diverse pressures at the political, economic, and social levels have driven much of the land-use change in the forested tropics over the last 50 years. Keys and McConnell (2005), for example, discovered that the most common variables driving land-use change were related to markets, population pressure, and institutional factors such as governmental policies and programs. Rudel (2007) concluded that, between 1970 and 2000, drivers of land-use change in the tropics shifted from state-initiated (e.g., colonization and road building projects) to enterprise-initiated processes such as agricultural extensification and agri-business. Hettig et al. (2016), in turn, found that household endowments and internal household characteristics accounted for more than 40% of land-use drivers, followed by markets (14%) and infrastructure (13%), while demography, technology, policies, and institutional drivers appeared to play a lesser role in household land-use decisions.

The endeavor in land system science to identify the social, political, and economic drivers of land-use changes has come, to some extent, at the cost of examining the role of biophysical elements as drivers of these changes. To address this, some local-scale studies have, in addition to social drivers, included in their multivariate analyses the examination of biophysical factors as potential drivers of land-use change. For instance, Roy Chowdhury (2006) found that in southeast Mexico, elevation and soil composition were major predictors of plot-scale deforestation. Chavez and Perz (2012) learned that, in the Peruvian Amazon, smallholders' perceptions of biophysical conditions were critical in decisions to assign significant areas for forest regrowth. While these local-level studies highlight the importance of biophysical factors in land-use change, others challenge their significance. Ravnborg and Rubiano (2001) examined the impact of farmers' perceptions of soil conditions on land-use decision making in southwest Colombia, and suggest that the importance of soil conditions in explaining farmers' land-use choices is nominal when compared to other variables such as farm size and market opportunities.

As the above studies demonstrate, it is difficult to isolate specific social, political, economic, or biophysical factors as drivers of land-use change in the tropics. Thus, changes in land-use have been argued to be the result of dynamic interactions of biophysical, socioeconomic, and political forces operating across multiple spatial and temporal scales, influencing decision-making by local-level land users (Klepeis and Vance 2003). These so-called social-ecological land systems are characterized by their particular contextual factors, such as unique configurations of social and ecological conditions, settlement histories, and land-use dynamics, which can be evaluated from the small to the medium to the large scale (Boillat et al. 2017).

Recent advancements in land system science open the door to the significance of particularity and difference in the study of land-use change. Our research contributes to this by revealing how local smallholder land-use decisions are affected by social-ecological dynamics on three scales. We do this through an interdisciplinary mixed-methods analysis of two neighboring communities in the humid tropics of Mexico, and draw on a unique combination of ethnographic research and farm-level data to evaluate the importance of social-ecological variables at three different scales: 1) local (household factors), 2) regional (biophysical factors), and 3) national (institutional factors), for smallholder land-use decision-making. Our specific research questions are: (Q1) What is the land-use composition across farms in the two communities? (Q2) What household, biophysical, and institutional variables influence land-use decisions at the farm level in each community? We hypothesize that locally, household variables such as farm size and off-farm income have played an important role in farm land-use composition, i.e., owners of larger farms have diversified their land-use portfolios while simultaneously conserving more forest, and smallholders who receive off-farm income have also conserved forest because they rely less on agricultural activities for their livelihoods. In terms of biophysical factors, we hypothesize that soil quality also influences smallholder's land-use decisions. For example, that farmers with access to more high-quality soils on their farms choose to concentrate agriculture on those soils, whereas farmers without access to high productive soils opt to invest in alternative land-uses such as pastures, oil palm, rubber, small-scale reforestation with valuable timber species, or just leaving the forest undisturbed. Finally, at the national level, we hypothesize that smallholders' decisions on adopting (or not) agricultural and conservation policies also influence the allocation of certain land-uses on their farms.

Materials and methods

Study site and historical context

Our case study was conducted in the adjacent communities of Loma Bonita and Boca de Chajul (Loma and Chajul hereafter) in the Marqués de Comillas region (MdC hereafter), Chiapas, Mexico (Fig. 1). The two villages lie within the Lacandona Rainforest, the largest remaining tropical rainforest in North America (Fernández-Montes de Oca et al. 2015), and a hotspot of deforestation (Vaca et al. 2012). The Lacandona Rainforest has been designated as a priority conservation area because it provides vital ecosystem services to the region (Hernández-Ruedas et al. 2014). In the early 1970s, the MdC region underwent a colonization effort, which triggered a rapid process of forest and ecosystem loss (de Vos 2002; Cano Castellanos 2018). The region's rapid forest conversion has resulted in an agro-forest frontier (i.e., areas with particular dynamic borders between forested and agricultural land) where agriculture with a variety of crops, pastures, primary and secondary forest patches are intermingled in a highly dynamic

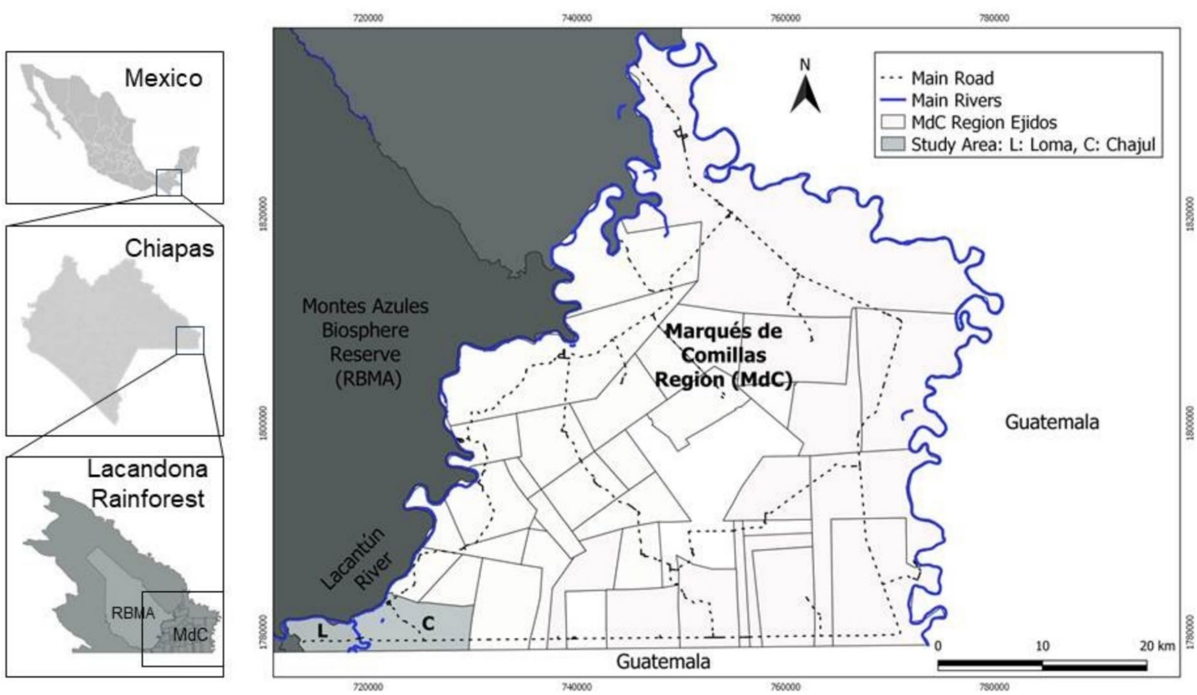

Fig. 1 Map of the study area: Loma and Chajul, Marqués de Comillas, Lacandona Rainforest, Chiapas, Mexico

landscape (De Jong et al. 2000; Zermeño-Hernández et al. 2016). This rural region represents a characteristic multifunctional agricultural landscape (Baudron et al. 2019), which exhibits high levels of biodiversity (it is part of the Mesoamerican biodiversity hotspot, Myers et al. 2000), and provides multiple ecosystem services to the local communities, primarily agricultural, provisioning, regulating, and cultural services (Pingarroni et al. 2022). The region's primary vegetation type is tropical rainforest, which varies in structure and composition across distinct geomorphological units. The region's most common unit consists of small hills and valleys (100–200 m.a.s.l.) with sandy and limestone soils of low pH (<5.5) (Siebe et al. 1996). The region's climate is humid tropical, with a relatively brief dry season from February to March, with an average annual precipitation ranging from 2,000 to 3,500 mm (de la Maza 2015).

Until the 1970s, the Lacandona Rainforest was inhabited mostly by the Lacandón indigenous community, which had largely maintained the forested cover.[1] During the colonization process between 1970–1976, land in the region was granted to farmers from several Mexican states (de Vos 2002). In 1976, the first settler families coming from the southwest state of Guerrero arrived to Chajul. In 1981, the government officially recognized Chajul as an *ejido*.[2] The first settler families from the northwest of the state of Chiapas came to Loma in 1980; however, the *ejido* was not officially established until 2005, after a land title dispute with the original landowners, the Lacandón peoples, was resolved.

Loma and Chajul vary substantially in terms of total *ejido* area and the amount of land owned by households. Because there was extensive land (4,838 ha) and not many inhabitants in Chajul – besides the men who were already enlisted as *ejidatarios* (members of the *ejido* with land tenure rights) – wives and children were also elegible to enroll as *ejidatarios*. Therefore, in Chajul, there is typically more than one *ejidatario* per household, however, usually the oldest male *ejidatario* is the head-of-household. The average size of Chajul households' landholdings is approximately 65 ha. In contrast, in Loma, the *ejido*'s 1,731 ha were distributed among 80 households, who on average possess roughly just 20 ha each. Land in Loma has historically been limited, and in general, there is only one *ejidatario* per household, who is usually the male head-of-household. Repordetdly, the differences in farm size between the two villages have had a significant impact on the landscape composition of each *ejido* (for details refer to Berget et al. 2021). Thus, in Loma, where each *ejidatario* has smaller landholdings, the landscape is dominated by pastures, intermingled with small patches of agriculture and secondary forest, and little old-growth forest. Because of the larger landholdings in Chajul, and because households did not have enough labor to cut-down the forest and keep it clear, the landscape is a mosaic of large tracts of conserved forest, with patches of pastures, agriculture, and some agro-industrial crops like oil palm and rubber (part of a Productive Reconversion program) (Berget et al. 2021). As a result, when the federal Payment for Environmental Services (PES) program entered the MdC region in 2008, Chajul's *ejidatarios* could collectively enroll approximately 2,000 ha of forest. In contrast, Loma had too little forest area to be able to participate in the program. The PES is a subsidy that offers a specific amount of cash annually to *ejidatarios* based on the hectares of forest they registered to conserve. Another difference is that, unlike Loma, from 2008, some farmers in Chajul planted part of their farms in oil palm and rubber using subsidies from federal and state programs – the amount paid depending on the number of hectares inscribed in either program (Berget et al. 2021).

Aside from these differences, a variety of institutional programs operate in both *ejidos* including the federal Program for the Direct Support to Agriculture (PROCAMPO) which transfers cash to farmers based on the amount of hectares under maize production (launched in 1994); the federal Stimulus Program for Livestock Activity (PROGAN/Credit), which incentivizes cattle-ranching with predetermined amounts of cash per head of cattle (started in 2004); the federal Credit Program offered through the National

[1] This brief reconstruction of the recent history of the researched villages is based on the findings from Berget et al. (2021).

[2] One of the main kinds of land tenure in Mexico, which consists of communal land rights by a group of people who manage the use of the land and natural resources collectively; see Harvey (2005). After reforms to Article 27 of the Mexican Constitution were made in 1992–1993, the privatization of communal resources within the *ejido* were allowed. Under this new reform individuals can pursue ownership of titles of the farm-plot they work (Harvey 1995).

Financial Institution for Agricultural, Rural, Forestry and Fisheries Development (FND), which is available for *ejidatarios* wanting to engage in calve-fattening projects requiring larger capital investments (*ejidatarios* in general, engage in either the PROGAN or the Credit program); and the Special Program for the Conservation, Restoration, and Sustainable Use of the Lacandona Rainforest (PESL), a subsidy program established in 2010 for farmers interested in reforesting (parts of) their pasture fields with commercially valuable tree species and administered by the National Forest Commission (CONAFOR).

Chajul is almost three times larger than Loma (Table 1). After they adhered to the federal Program for National *Ejidal* Rights Titling (PROCEDE), the majority of both *ejidos'* total surface it titled land (RAN 2020). There are no communal lands in Loma, and 4% of the *ejido* is earmarked for human settlement/housing. In Chajul, 6% belongs to human settlement/housing and communal lands (RAN 2020). Chajul's population is 2.4 times larger than Loma's (INEGI 2010). There are 80 *ejidatarios* in Loma (RAN 2020), each being the head-of-household of one of the 80 households holding land-tenure rights in the *ejido* (i.e., typically one (male) *ejidatario* per household). There are also five *posesionarios* (those who do not possess land, which are often the non-inheriting descendants of *ejidatarios*), and 25 *avecindados* (those who settle in the *ejido* and farm but do not have any legal land tenure rights) (RAN 2020). Loma livelihoods are based primarily on subsistence agriculture, being cattle-ranching the predominant economic activity. In Chajul, there are 145 *ejidatarios*, eight *avecindados*, and two *posesionarios* (RAN 2020). There are around 72 households having land-tenure rights, each typically with two *ejidatarios* (the male head-of-household and his female spouse). Livelihoods are based on agriculture, mainly for self-consumption (though some is sold for cash), and, the main economic activities include cattle-ranching, PES payments, some oil palm cultivation, dump trucks, and a few small businesses (e.g., eateries, a couple of lodges, miscellaneous stores, basic drugstore, bicycle and car repair shops, etc.). Both *ejidos* share the following characteristics: riverine villages along the Lacantún river; population is predominantly *mestizo* (a mix of indigenous and Spanish descent); access to the main road – the Southern Border Highway – via an internal village road; similar distance to markets; and similar population density.

Data collection

We used a mixed-methods approach as our methodological framework. This approach is increasingly common in human–environment research and integrates qualitative and quantitative data (Newing 2010; Biggs et al. 2021). We used a qualitative ethnographic method, and conducted semi-structured household interviews with open-ended questions to obtain both quantitative and qualitative data. Semi-structured interviews focus on individual smallholders, whereas the ethnographic research focuses on the community level: "The farmers are part of their rural communities, so their individual opinions can be understood in the context of the community-level diversity of views" (p. 1663, Root-Bernstein et al. 2020). We used quantitative data (the semi-structured interviews) to contextualize and understand qualitative data (i.e., individual behavior obtained via ethnographic methods). From our interdisciplinary viewpoint, articulating the qualitative and quantitative methods, is an innovative methodological approach to strengthen our understanding of smallholder land-use decisions in socio-ecological multifunctional landscapes.

Between 2016 and 2017, the lead author conducted eight months of ethnographic research while living in the two communities. Ethnographic methods included participant observation, informal interviews, in-depth life histories with original settlers, interviews with

Table 1 Characteristics regarding population, territorial extension, and household's landownership in two studied communities (*ejidos*) in southern Mexico

Ejido	Total population	Density pers/ha	*Ejidatarios*	Households with land-tenure rights	*Ejidatarios*/household average	Total area ha	Titled land ha	Farm size/household average ha
Loma	164	0.09	80	~80	~1	1,731	1,674	~20
Chajul	398	0.08	145	~72	~2	4,838	4,557	~65

local key informants, archival research, and secondary data analysis, among others. These methods yielded data on agricultural activities, land-use decision-making, institutional programs, *ejido* rules on natural resource management, and land tenure maps. We used these data as a framework to design and fine-tune household interviews, farm visits, and as a backdrop to understanding farmers' land-use decisions.

Between March–May 2017, 39 semi-structured interviews with head-of-household *ejidatarios* (2 women and 37 men), who are usually the ones operating the farms, were conducted in Loma ($n = 19$) and Chajul ($n = 20$). Interviews were complemented by farm visits (see below). The total area of sampled farms in Loma represents approximately 27% of the *ejido*'s titled land (458 ha out of 1,674 ha), and sampled farms in Chajul represent around 25% of the total titled land (1,123 ha out of 4,557 ha). The two interviewed women were widows, and interviews were done with the presence of the son in charge of working the farm, who also guided the farm tour. We refer to farm as the household's production unit, which may consist of one or more plots positioned in different parts within the territory (in total, 76 plots were sampled: 32 in Loma and 44 in Chajul). At the same time, a plot could have one or more land-uses, which we refer to as fields (in total, 144 fields were surveyed: 67 in Loma and 77 in Chajul). The semi-structured interview was used to elicit information on socioeconomic and land-use data from participants. The open-ended questions focused on household characteristics such as demographics, productive and economic strategies, off-farm economic activities and sources, and enrollment in agricultural and conservation programs. The interview also covered the farm's history, characteristics, land-use composition and area allocated to each land-use, management practices, and land-use perceptions. Interviews were performed in Spanish with prior informed consent, lasted between 1–2 h, and were recorded with the permission of the interviewees. Guided farm visits with land managers lasted between 2–5 h (depending on accessibility and farm size) and included: 1) asking interviewees to sketch a map of their farm, delimiting each plot and respective fields (land-uses) (Supplementary Information (SI) 1); 2) making field observations and asking questions while surveying each farm; 3) taking GPS coordinates (when this was not possible due to farm inaccessibility, *ejidatarios* provided land titles with coordinates). Biophysical soil data for each farm was derived from a geopedologic land units map with accompanied soil quality measurements. This was first published by Navarrete-Segueda et al. (2018) and then expanded in a version by Lohbeck et al. (2022); see Fig. 1 in SI 2 for the portion of the geopedologic map that underlies the two communities of this study.

Variables

In this study, we assess the influence of 13 social-ecological variables (independent variables) on seven farm-scale land-uses (agriculture; pasture; primary forest; secondary forest; rubber; oil palm; reforestation) (dependent variables). The independent variables are classified on three different scales: 1) local-household factors (age-of-head; farm size; off-farm income; diversity of income sources); 2) regional-biophysical factors (soil potential to produce food (SPP); topsoil phosphorous (P_{ex})); and 3) national-institutional factors (PROCAMPO; PROGAN/Credit; PES; Oil Palm program; Rubber program; Reforestation program; diversity of subsidies). We divided our independent variables in two categories: binary and non-binary. The binary variables we used were: off-farm income; PROCAMPO; PROGAN/credit, PES; Oil palm program; Rubber program; Reforestation program. The non-binary variables were: age-of-head; farm size; diversity of income sources; SPP; P_{ex}; and diversity of subsidies. The variables were selected based on data obtained during our ethnographic fieldwork and from relevant empirical studies performed in Latin America (Roy Chowdhury and Turner 2006; Chavez and Perz 2012; Hettig et al. 2016; Garrett et al. 2017; Bopp et al. 2020)**.** A more detailed description of the variables used is found in SI 3.

Analyses

We tested for differences in land-use composition across the sampled farms per community (Q1) using T-tests on the number of hectares under each of the seven land-uses. We also made use of T-tests to determine whether the two *ejidos* differed in terms of the independent variables. To evaluate which household, biophysical, and institutional variables influence land-use decisions at the farm level in each community (Q2) we used a mix-methods approach using qualitative and quantitative analysis methods. Qualitative analysis is a suitable approach since the narrative, based on many months of fieldwork and ethnographic research, provided a rich source of information. All data obtained through ethnographic methods were carefully recorded in fieldwork diaries. We then transcribed all household semi-structured interviews, and the responses were systematized and coded in a Microsoft Excel database. Next, to analyze the qualitative data, we used the qualitative content analysis method, which entailed identifying themes (related to the variables assessed in our study) within the dataset and then analyzing the data by coding participants' responses according to the identified themes that arose from their answers (Schreier 2014; Preiser et al. 2021). The qualitative analysis of the interviews was enriched with the information from the ethnographic work. To illustrate the results, we used direct quotes from respondents.

We then used quantitative data and statistical analyses to support the qualitative results in response to Q2. We approached the binary independent variables (off-farm income; PROCAMPO; PROGAN/credit; PES; Oil palm program; Rubber program; Reforestation program) by testing for differences between the *ejidos* using T-tests. To evaluate which household characteristics (age-of-head; farm size; diversity of income sources), biophysical (SPP; P_{ex}), and institutional (diversity of subsidies) non-binary independent variables might influence land-use decisions at the farm level in each community, we performed generalized linear models (GLM's) for each of the seven land-use types[3] using the number of hectares (for common land-uses: agriculture, pasture, primary forest, secondary forest) and presence (for rare land-uses: rubber, oil palm, reforestation) as the dependent variable, and the household, biophysical, and institutional factors as independent variables. For the common land-uses, we used presence/absence on each farm as the dependent variable, and instead fitted binomial models. Separate models were tested for each of the seven land-uses as dependent variables. Given our limited sample size, we also created separate models for each of the independent variables (three local-level household factors, two regional-level biophysical factors, and one national-level institutional factor). For each combination of independent and land-use variable we tested both a simple model, and a slightly more complex model where the *ejido* is included in interaction with the independent variable. This resulted in a total of 84 generalized linear models. We then selected the best model based on the following: overall model performance as indicated by p-values, significance of the driver, in cases where both simple (independent driver without interaction with *ejido*) and complex model (including interaction with *ejido*) were significant, the model with lowest Akaike Information Criterion (AIC) was chosen as the best model (unless less than Δ2 AIC; in that case the most parsimonious model was chosen). Spearman's rank correlation coefficients were tested for all independent variables. All statistical tests were performed using R version 3.5.3 (R Core Team 2024).

[3] For the common land-uses agriculture, pasture, primary forest, and secondary forest we used the number of hectares of land under those land-uses for each farm as an indicator of land-use composition. The land-uses rubber, oil palm, and reforestation appeared to be rare which made their variation across the farms zero-inflated. To this end we used the presence of these land-uses as a binary dependent variable, and not their absolute areas like in the common land-uses.

Results and discussion

Farm land-use composition (Q1)

The 39 farm semi-structured interviews revealed seven distinct land-use types: agriculture, pasture, primary forest, secondary forest (natural forest regrowth), rubber plantations, oil palm plantations, and reforestation. In general, all land-use types were present in both communities, except for oil palm and rubber plantations, which were only present in Chajul (Table 2). Of the five land-use types found in Loma farms, the dominating one is pasture (an average of 16.4 ha), whereas (in descending order) secondary forest, agriculture, primary forest, and reforestation, occupy on average a much smaller area of the farms. Primary forest dominates the seven land-use types found in Chajul farms (an average of 27.5 ha), followed by pasture (15.5 ha on average), and, to a lesser extent, secondary forest, oil palm, agriculture, rubber, and reforestation.

The results of the T-test for differences in farm composition show that the two communities significantly differ only in primary forest, where Chajul

Table 2 Descriptive statistics for dependent and independent variables used in two studied communities (Chajul and Loma) in southern Mexico. P-values for the T-test (2 groups-test): P < 0.001***, P < 0.01**, P < 0.05*, P > 0.05 NS (not significant)

Variable		Chajul ($n=20$)		Loma ($n=19$)			
Dependent	Description	Mean	SD	Mean	SD	T-val	P-val
Farm Land-use Type							
Agriculture	Farm area allocated to agriculture (ha)	2.4	3.9	2.2	2.2	0.2	NS
Pasture	Farm area allocated to pasture for cattle (ha)	15.5	18.0	16.4	14.3	-0.2	NS
Primary Forest	Farm area allocated to old-growth forest (ha)	27.5	23.6	1.7	2.2	4.9	***
Secondary Forest	Farm area allocated to natural forest re-growth (ha)	4.8	8.4	3.7	4.1	0.5	NS
Rubber	Farm area allocated to rubber plantation (ha)	1.6	4.8	0.0	0.0	1.4	NS
Oil Palm	Farm area allocated to oil palm plantation (ha)	3.7	11.4	0.0	0.0	1.5	NS
Reforestation	Farm area allocated to reforestation (ha)	0.7	1.4	0.1	0.2	2.0	NS
Independent							
Local-level Household (HH) Factors							
HH Endowments							
Age-of-head	Age of household head (years)	56.7	17.1	43.2	13.5	2.7	**
Farm Size	Total production unit area (ha)	56.2	37.7	24.1	14.1	3.6	**
HH Economic Strategies							
Off-farm Income	Receive income from other sources than the farm (0/1)	0.9	0.4	0.3	0.5	4.4	***
Diversity of Income Sources	Number of income sources (max 4: agriculture, cattle, oil palm, off-farm)	2.0	1.0	1.3	0.8	2.4	*
Regional-level Biophysical Factors							
Soil Potential to Produce Food (SPP)	SPP index includes: soil organic carbon, total nitrogen, clay content, aluminum and stoniness (values between 0 and 1)	0.4	0.1	0.6	0.0	-10.0	***
Topsoil Phosphorous (P_{ex})	Topsoil extractable phosphorous (mg kg^{-1})	2.3	0.2	2.7	0.3	-5.2	***
National-level Institutional Factors							
PROCAMPO Program	Receive subsidy for agriculture (0/1)	0.6	0.5	0.6	0.5	-0.5	NS
PROGAN/Credit Program	Receive subsidy/credit for cattle-ranching (0/1)	0.5	0.5	0.7	0.5	-1.5	NS
PES Program	Receive subsidy for forest conservation (0/1)	0.9	0.3	0.0	0.0	13.1	***
Oil Palm Program	Receive subsidy to plant oil palm (0/1)	0.2	0.4	0.0	0.0	1.8	NS
Rubber Program	Receive subsidy to plant rubber (0/1)	0.1	0.3	0.0	0.0	1.5	NS
Reforestation Program	Receive subsidy to reforest (0/1)	0.3	0.4	0.1	0.3	1.2	NS
Diversity of Subsidies	Number of subsidies received (max 6: all of the above)	2.4	1.2	1.4	0.6	3.3	**

farms have significantly more primary forest than Loma farms (Table 2). Differences in the other land-use variables are not significant. Despite the significant difference in primary forest, our qualitative findings show that there are commonalities in how smallholders in both *ejidos* perceive forests and trees. Farmers value forests and trees because they provide key ecosystem services from which they benefit, such as food, shade, timber, fuelwood, biodiversity, hunting spaces, and scenic beauty; similarly to what Pingarroni et al. (2022) reported for the MdC region. However, the most cited ecosystem service that smallholders perceive from forests is climate regulation, mainly that the forest "supplies" rain, which is congruent with regional findings (Meli et al. 2015c). The following observation from an 88-year-old original Loma settler reflects this widely held belief in both *ejidos*:

"…here we see that it rains there [in the Biosphere Reserve across the river; see Fig. 1] *but heavily, and here* [in Loma] *sometimes it drizzles*, *sometimes it crosses* [meaning that the rain crosses to the ejido from the Reserve], *but otherwise we only see that it rains there* [in the Reserve]. *So, it's clear and you can see it. That's what can attract water* [the forest vegetation], *it attracts water. But it's only now that we realize its usefulness* [of the forest], *because it's an experience. Before, we didn't realize it because there was so much of it* [meaning that when they settled, the ejido/region was covered in forest]".

Variables that influence smallholder land-use decisions (Q2)

Below, we describe our findings and discuss the influence of the different independent variables at different scales on smallholders' land-use allocations and decisions for each of the seven land-use types analyzed. We first explain land-use decisions based on qualitative data from the ethnographic research and household interviews, and then support our findings with quantitative analyses for the non-binary independent variables. The results of the T-tests for all independent variables show that households in the two *ejidos* differ in all household characteristics and soil variables tested, as well as in their participation in the PES program, and the diversity of subsidies they receive (Table 2).

Local-level: household variables influencing land-use decisions

According to our ethnographic research, farmers in Chajul and Loma typically allocate between 15–16 ha on average to pasture (Table 2; reportedly due to labor constraints, see below), holding a mean of two head-of-cattle/ha, suggesting that having a much larger farm does not necessarily translate into forest conversion to pasture, but to simply leaving the "surplus" forest untouched, as seen in Chajul. Cattle-ranching is practiced extensively in the MdC region, and the typical size of a pasture field is between 15–20 ha (Carabias et al. 2015). Historically, Chajul households' have owned larger farms than they could work due to labor constraints (Berget et al. 2021). Vegetation re-growth in the MdC region is quite fast (Chazdon et al. 2007; Lohbeck et al. 2012), as is typical in tropical regions (Bongers et al. 2015; Poorter et al. 2016), and so cutting forest and maintaining it clear in the study area is a challenging undertaking, requiring significant labor inputs. Therefore, as the results of the ethnographic work and interviews evidence, Chajul farmers only cleared enough forest area for subsistence agriculture (~2 ha) and a feasible pasture area for extensive cattle-raising (~15 ha), which could be kept clear of re-growing vegetation through available family labor. The remaining acreage in Chajul farms – usually located in more distant, remote and inaccessible areas – were essentially left intact and thus remained under primary forest.

On the contrary, historically, households in Loma had smaller farms that they could manage to work with the available family labor (Berget et al. 2021). In Loma, smallholders typically designate roughly 16 ha for pasture, which accounts for more than half of a household's farm, leaving just some land for subsistence agriculture (~2 ha) and limited land for primary and secondary forest. The ethnographic work and interviews demonstrate that the predominant source of labor in the study site is family labor. Also, household size (a proxy for family labor) is on average five persons in the sampled households in both *ejidos*. Households rely on family labor and hence are labor constrained, because hiring labor from landless farmers (e.g., *avecindados*) is costly and thus is only done occasionally for agriculture or pasture related activities. Exceptionally, in Chajul, the sole land-use practice that requires hiring labor is the harvesting of the oil palm fruit bunches, especially during the peak season. In such cases, Guatemalan Mayas furnish the majority of agricultural labor at low costs (Castellanos-Navarrete 2015; Castellanos-Navarrete et al. 2019). During fieldwork, the few rubber plantations in Chajul were still quite young (~2-year-old), therefore labor for rubber tapping was not required.

The qualitative interview results indicate that there does not appear to be a clear relationship between the age of the head-of-household and their land-use decisions, and that smallholders of all ages engage (or not) in various land-uses (SI 4). Our qualitative results highlight that regardless of age, smallholders in Loma allocate on average a larger amount of the farm to pasture than to primary forest, whereas in Chajul the opposite occurs. This trend may be explained by the size of the farm, a variable in which both communities differ (Table 2). Our qualitative findings are supported by the GLM's results which show that farm size had a significant effect on pasture and primary forest (Table 3). The number of hectares of pasture in farms in both *ejidos* was positively affected by farm size (although the effect is stronger in Loma; SI 5, Fig. 1a). The number of hectares of primary forest was positively affected by farm size, and this effect is particularly strong for Chajul, showing limited effect in Loma (SI 5, Fig. 1b).

Our results support our hypothesis that smallholders with larger farms have the tendency to conserve larger shares of primary forest, especially in Chajul, as similar studies on farm size and forest area demonstrated for the Yucatán Peninsula in southern Mexico (Klepeis and Vance 2003; Schmook and Vance 2009), and the Peruvian and Brazilian Amazon (D'Antona et al. 2006; Chavez and Perz 2012). In terms of the influence of farm size on land-use decisions about pasture, we found similar results to those of primary forest: smallholders with larger farms in both *ejidos* tend to decide to allocate higher shares of pasture on their farms, which is also consistent with findings from Klepeis and Vance (2003), Schmook and Vance (2009), and Chavez and Perz (2012) in Yucatán and the Amazon.

Furthermore, we contend that our qualitative findings support our hypothesis that smallholders with larger farms have more diversified land-use portfolios, but only in Chajul where farms are larger, and some farmers have engaged in agro-industrial crops cultivation (oil palm and rubber), expanding the diversity of land-uses in this *ejido*. In contrast, in Loma, where smallholders are constrained by small farm sizes, land-use diversification has been limited. These results are supported by other research carried out in these communities (Berget et al. 2021, 2024), and elsewhere in the Lacandona Rainforest (Christman et al. 2015).

When calculating the odds ratio, interviewees in Chajul who get off-farm income are 32% more likely to also have primary forest (SI 6). These results appear to support our hypothesis that smallholders who receive off-farm income tend to have conserved forest because they rely less on agricultural activities for their livelihoods, as corroborated by research carried out in the study site (Berget et al. 2021). In Loma, in contrast, the odds of having primary forest did not differ between farmers who get off-farm income and those who do not. This appears to indicate that receiving off-farm income in Loma does not necessarily translate in having conserved forest. Instead, as our ethnographic fieldwork revealed, off-farm income may be invested in other land-use practices, such as cattle pasture, which is the primary livelihood strategy in Loma.

Our qualitative findings reveal that smallholders with higher diversity of income sources have more means to, for example, invest in the cattle-ranching enterprise (e.g., acquiring livestock, fencing material, etc.). This finding is supported by the model results which shows that the diversity of income sources variable was a significant driver for pasture in both *ejidos* (Table 3; SI 5, Fig. 1c). Furthermore, our qualitative results show that oil palm production requires considerable costs to purchase fertilizers, hire labor for the harvest, among others. Similar findings were discovered by Castellanos-Navarrete (2015) and Castellanos-Navarrete and Jansen (2018) in the MdC region and elsewhere in Chiapas where oil palm is grown. Thus, we argue that smallholders with a wider diversity of income sources may have more capital to engage in oil palm farming, like is the case in Chajul. This is supported by the GLM results, where the probability of having oil palm increased with the diversity of income sources across farms (Table 3; SI 5, Fig. 1d).

Our qualitative research suggests that agriculture is one of the most important land-use practices in the study area. In the two *ejidos*, agriculture is primarily done and preferred for self-consumption rather than for market output (in general, only surplus—if any—is sold). This non-market, self-provisioning logic smallholders follow may explain why farmers in Loma and Chajul devote only a handful of hectares to grow *milpa* (traditional agricultural system characterized by a combination of crops, one of them – and often the most important one – being maize) (Table 2), regardless of household variables such as age-of-head, farm size, and/or having multiple income sources, including off-farm income. Our ethnographic work demonstrated how household members prefer to consume their own *milpa*, rather than purchasing commercial corn flour. This reflection from a Chajul farmer represents a general perception of self-provisioning agriculture at the study site: "[milpa agriculture] *is something that directly*

Table 3 Test results for the 84 land-use generalized linear models for seven land-use types as dependent variables, and three household, two biophysical, and one institutional factor as non-binary independent variables, for two communities (Chajul and Loma) in southern Mexico. Total sample size is n=39 farms (Chajul=20 and Loma=19). Significance for each model is $P<0.001$***, $P<0.01$**, $P<0.05$*

	Agriculture (ha)					Pasture (ha)					Primary Forest (ha)				
	P-val	AIC	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]	P-val	AIC	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]	P-val	AIC	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]
Local-level Household Factors															
Age-of-head	0.482		-0.12	NA	NA	0.873		0.03	NA	NA	0.068		0.3	NA	NA
Age-of-head * *Ejido*	0.330		-0.38	-0.10	0.61	0.519		-0.16	0.16	0.55	0.001**[3]	339.2	0.08	-1.18	-0.08
Farm Size	0.211		0.2	NA	NA	0.000***	316.8	0.57	NA	NA	0.000***	320.7	0.76	NA	NA
Farm Size * *Ejido*	0.603		0.27	0.16	-0.11	**0.000*****	**301.6**	0.63	1.33	1.28	**0.000*****	**313.8**	0.67	-0.86	-0.60
Diversity of Income Sources	0.219		0.2	NA	NA	**0.009****	**325.2**	0.41	NA	NA	0.103		0.26	NA	NA
Diversity of Income Sources * *Ejido*	0.663		0.24	0.11	-0.04	0.010*	323.9	0.72	0.36	-0.58	0.001**[3]	339.0	0.11	-1.19	-0.15
Regional-level Biophysical Factors															
SPP	0.611		0.08	NA	NA	0.656		0.07	NA	NA	**0.001****	**341.2**	-0.53	NA	NA
SPP * *Ejido*	0.631		0.32	-1.20	0.73	0.500		0.28	1.14	-1.81	0.001**	339.4	-0.03	-1.06	-0.13
P_{ex}	0.059		0.3	NA	NA	0.618		-0.08	NA	NA	0.026*	348.8	-0.36	NA	NA
P_{ex} * *Ejido*	**0.005****	**194.4**	1.23	-0.97	-1.00	0.778		0.03	0.22	-0.30	0.000***[3]	338.3	0.31	-1.39	-0.34
National-level Institutional Factors															
Diversity of Subsidies	0.429		0.13	NA	NA	**0.001****	**319.6**	0.53	NA	NA	0.039*	349.5	0.33	NA	NA
Diversity of Subsidies * *Ejido*	0.842		0.19	0.04	-0.19	0.001**	317.7	0.71	0.68	-0.07	0.001**[3]	339.1	0.09	-1.21	-0.16

Table 3 (continued)

	Secondary Forest (ha)				Rubber (0/1)				Oil Palm (0/1)					Reforestation (0/1)				
	P-val	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]	P-val	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]	P-val	AIC	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]	P-val	AIC	Std Coef Predict[1]	Std Coef *Ejido*	Std Coef Interact[2]
Local-level Household Factors																		
Age-of-head	0.556	0.1	NA	NA	0.701	0.26	NA	NA	0.381		0.48	NA	NA	0.894		0.06	NA	NA
Age-of-head * *Ejido*	0.731	-0.05	-0.05	0.35	0.845	-0.15	-18.42	0.15	0.855		0.11	-18.78	-0.11	0.282		-0.74	-1.05	1.84
Farm Size	0.634	-0.08	NA	NA	0.052	1.16	NA	NA	0.064		1.32	NA	NA	0.920		-0.04	NA	NA
Farm Size * *Ejido*	0.810	-0.18	-0.25	0.16	0.104	0.97	-17.44	-0.97	0.121		1.03	-18.03	-1.03	0.604		-0.30	-4.41	-4.63
Diversity of Income Sources	0.574	-0.09	NA	NA	0.223	0.84	NA	NA	**0.022***	**15.2**	2.24	NA	NA	0.557		0.24	NA	NA
Diversity of Income Sources * *Ejido*	0.841	-0.14	-0.26	-0.01	0.440	0.56	-18.05	-0.56	0.038*	17.4	2.12	-16.99	-2.12	0.291		0.57	-2.64	-2.91
Regional-level Bio-physical Factors																		
SPP	0.523	-0.11	NA	NA	0.264	-3.46	NA	NA	0.224		-0.78	NA	NA	0.862		-0.07	NA	NA
SPP * *Ejido*	0.503	-0.24	-1.26	1.76	0.285	-3.42	-14.11	3.42	0.795		0.22	-19.00	-0.22	0.280		0.79	-9.38	7.32
P_{ex}	0.785	-0.05	NA	NA	0.217	-3.83	NA	NA	0.948		-0.04	NA	NA	0.904		-0.05	NA	NA
P_{ex} * *Ejido*	0.164	-0.67	0.04	1.01	0.351	-3.06	-15.68	3.06	0.101		1.66	-19.54	-1.66	0.853		-0.17	-2.61	1.7
National-level Institutional Factors																		
Diversity of Subsidies	0.914	-0.02	NA	NA	0.067	1.10	NA	NA	**0.014***	**15.4**	1.76	NA	NA	**0.016***	**32.6**	1.22	NA	NA
Diversity of Subsidies * *Ejido*	0.770	-0.15	-0.10	0.41	0.196	0.82	-17.66	-0.82	0.041*	18.7	1.51	-17.35	-1.51	0.056		1.11	-0.79	18.01

For all significant models the AIC is given. Standardized coefficients show the direction of the relationship. Standardized coefficients are reflected by standardized beta coefficients in case of linear models, and by standardized odds ratios in case of binomial models. In case of predictor '*Ejido*' it is compared to Loma, so when the value is negative, Chajul is lower compared to Loma. Bold values represent the best models chosen (see also Fig. 1 in SI 5)

[1]Standard coefficient predictor; [2]Standard coefficient interaction; [3] The model was significant but the driver was not significant, thus the model was not selected

feeds us; when we cultivate ourselves, we avoid buying corn, buying beans, buying all that; we have always done it like that. Now, what do I think about agriculture? Well, agriculture is very good, so, without agriculture, where the hell are we going to go? We're very used to eating tortillitas de maicito [corn tortillas], *not from maseca* [commercial corn flour]." As research from Berget et al. (2024) confirms, we contend that smallholders also consider values, preferences, and perceptions when making land-use decisions, such as in the case of agriculture.

Regional-level: biophysical variables influencing land-use decisions

Our ethnographic research and qualitative interview data support our hypothesis that farmers in both *ejidos* with access to high-quality soils on their farms choose to concentrate agriculture on those soils. Our qualitative findings indicate that smallholders in Loma and Chajul choose the more fertile soils on their farms primarily for *milpa* agriculture, which are usually located close to the river. This is exemplified by one of the interviewees from Loma who explains the quality of the soil:

> "*The soil quality is better the closer it is to the river. In this plot, the quality is good from the middle towards the river, because from the middle "upwards" the cattle become thinner even if there is good pasture. However, the closer you are to the river…the soil is black and loose, because there are more minerals in the soil, and the soil is clayey with pebbles*".

Farmers have done this historically since they settled the region because they perceive that the best lands for agricultural (crop) production in the study area are those along to the riverine area (de Vos 2002; Cano Castellanos 2018; Berget et al. 2021). The model results support our hypothesis given that farm-level P_{ex} had a positive effect on the area dedicated to agriculture, although the effect is stronger in Chajul (Table 3; SI 5, Fig. 1f). The qualitative data also supports our hypothesis that smallholders with farms with poorer soil quality tend to invest in other land-uses (other than agriculture) such as pastures, because farmers in both *ejidos* claim that, in general, they assign pasturelands in less productive lands further away from riverine fertile areas. Additionally, smallholders mentioned that many of the sites where primary forests are located are of poor soil quality for agricultural (crop) production, and are better suited for forest conservation areas or for other land-uses such as pastures. This hypothesis was also statistically supported in the case of primary forest (in both *ejidos*), where farms with a lower SPP tend to have a larger share of primary forest (Table 3; SI 5, Fig. 1e).

Concerning the oil palm and rubber land-uses, informants mentioned during the ethnographic research that according to the Oil palm and Rubber programs' requirements, conserved forest should not be converted to either of these agro-industrial crops, and ideally these should be planted in pasturelands, as part of the overall goal of productive reconversion of these programs. Notwithstanding, the three oil palm growers interviewed in Chajul chose to plant their oil palm crops on the *ejido's* most fertile lands. The following quote from a Chajul interviewee illustrates issues related to this:

> "*…in the two hectares up near Chajulillo* [river], *there is more* [agricultural] *production and that is why I plant my maize and beans there. But the neighbor planted oil palm trees* [in his field] *and the palm branches are shading part of my crop, affecting it. I believe the palm is drying out the land, also affecting my crop*".

Regarding the rubber land-use, of the two interviewees who grow this crop, one planted rubber in his pasture, and the other one (who is also one of the oil palm grower interviewees) in a secondary forest that was previously used for occasional *milpa* production, thus an area with good soil quality according to farmers' knowledge. Based on this evidence, we argue that biophysical factors are therefore important variables that smallholders take into account when making land-use decisions. Nevertheless, these biophysical variables may sometimes only be understood when other social factors are also considered.

National-level: institutional variables influencing land-use decisions

After the so-called 4T (4th Transformation) of former Mexican President Andrés Manuel López Obrador, which began in 2018, the majority of our analyzed subsidies, especially those concerned with agricultural development (PROCAMPO, PROGAN/Credit, Oil palm, and Rubber) have continued until today as part of the 4T focus on agrarian programs in rural Mexico (Cano Castellanos 2022, 2024; Mendoza Solís 2024; Izquierdo-Tort et al. 2024). In contrast, subsidies for environmental conservation have been susceptible to budget cuts and adjustments. For example, the PES program continues to run in the region, yet the subsidy amount has been significantly reduced (Izquierdo-Tort et al. 2024). The PESL which operated the Reforestation program was discontinued. Instead, the 4T administration created the *Sembrando Vida* (Sowing Life) program, which promotes reforestation through agroforestry production systems in the region (Mendoza Solís 2024).

Each of the six national-level institutional programs we examined targets a distinct land-use. Participation in these agricultural and conservation programs is voluntary. In Chajul, all six programs were adopted at time of fieldwork, however in Loma, only three (i.e., PROCAMPO, PROGAN/Credit, and Reforestation program). This implies that for various reasons, policy interventions are not universally adopted by farmers living in the same region. Our hypothesis that smallholder decisions to engage (or not) in agricultural and conservation programs influence the allocation of certain land-uses on their farms was only partially supported. The land-uses agriculture, pasture, primary forest, and secondary forest were already present in the studied *ejidos* when the corresponding program arrived, making it difficult to establish a causal relationship between policy and land-use. In contrast, the land-uses rubber, oil palm, and reforestation were only adopted when the respective program arrived. Meaning that the availability of the Rubber, Oil palm, and Reforestation programs caused (some) smallholders to adopt the land-use each subsidy targets, which supports our hypothesis. This outcome is consistent with other research in Latin America, where it has been found that land-use policies are effective at driving land-use decision-making when smallholders participate in those policies, such as in Chiapas (Ramírez-Mejía et al. 2017; Kolb and Galicia 2018); the Yucatán Peninsula in southeast Mexico (Klepeis and Vance 2003; Roy Chowdhury 2006, 2010; Roy Chowdhury and Turner 2006; Schmook and Vance 2009); Peru (Chavez and Perz 2012); and Chile (Bopp et al. 2020). Although land-use policy can enable land-use decisions at the farm level, no driver acts in isolation, therefore understanding smallholder land-use decisions requires to address other variables at different scales to understand the context in which these decisions are made (López-Carr 2021). As a result, we will analyze each of the national-level institutional variables below.

PROCAMPO and PROGAN/Credit programs Our qualitative results found that in our case study, some farmers do not participate in specific programs but nevertheless have the land-use connected with the subsidy. This is the case for smallholders in both *ejidos* who have agriculture and pasture fields but are not enrolled in PROCAMPO or PROGRAN/Credit programs, respectively (Table 4), and farmers in Chajul who enroll only parts of their qualifying forests in PES, as our ethnographic work revealed. This suggests that farmers have autonomy (agency) to make their own land-use decisions independent of exogenous institutional forces.

NAFTA's (North American Free Trade Agreement) introduction in 1994 opened the Mexican market to corn imports from the United States (U.S.), causing maize prices to fall, significantly disadvantaging Mexican maize farmers who were forced to compete with the influx of cheaper corn from the U.S. (Keleman et al. 2009; Galemba 2012). The PROCAMPO national-federal cash-transfer program was developed to compensate maize producers for the adverse consequences of NAFTA (Keleman et al. 2009). Farmers in Loma and Chajul receive annually approximately $1,000MX/pesos per enrolled hectare in PROCAMPO. However, because the price of maize in the study area is very low (during fieldwork, the price was around $3-4MX/pesos per kg; cf. beans' price was around $9-10MX/pesos per kg), smallholders prefer to continue producing *milpa* mostly for self-provisioning and not for the market, while also benefiting from the cash-transfer from PROCAMPO; as demonstrated by the high enrollment of farmers with agriculture fields in this program (92% in Chajul and 71% in Loma; Table 4). Moreover, *milpa* agriculture in the study site, as previously stated, has historically been a traditional manner of staple-crop production. Thus, the agriculture land-use has been present in these *ejidos* since their settlement, long before PROCAMPO arrived in the region (or farmers were eligible to enroll, as in Loma's case; see Berget et al. 2021). One of the respondents in Loma reflected about practicing agriculture: "*it's a little bit difficult because it requires a lot of investment, but as we always use it* [the milpa] *for self-consumption, we have to do it*". Smallholders in the study area would most likely continue producing self-consumption *milpa* regardless of the subsidy, because the practice of *milpa* agriculture is ingrained in Mesoamerican and Mexican culture, and in general, *milpa* is the main means of subsistence and livelihoods for rural families (Rodríguez-Robayo et al. 2020). Hence, it is difficult to establish a direct causal relationship between the PROCAMPO program and the share of agriculture land-use in the studied *ejidos*. Nevertheless, other studies on the Yucatán Peninsula in southern Mexico found that the PROCAMPO subsidy is an important driver of farm area cultivated for agriculture and forest loss (Klepeis and Vance 2003; Schmook and Vance 2009).

Cattle-ranching is the primary economic activity in the MdC region in general (Carabias et al. 2015), and in the study site, in particular, as our ethnographic research revealed. This is exemplified by the significant number of interviewees who have cattle-raising pastures: 14 (70%) in Chajul and 17 (89%) in Loma. The qualitative results of the semi-structured interviews demonstrate that all of these smallholders, state that cattle raising is the most reliable and secure economic activity that historically has supported them financially in any need, particularly in health emergencies. Narratives like these illustrate how important livestock are to respondents in both *ejidos*:

"[cattle is the only option] *to get* [you] *out of a problem"*;
"is an easy way to have an investment…it's money saved there";
"the money is there safe and fast";
"a cow is a walking piggy bank";
"is the only thing [activity] *that gives you more* [money]".

The PROGAN/Credit program seeks to stimulate cattle-ranching productivity at the national level (Castro et al. 2015; Álvarez-Macías and Santos-Chávez 2019). Although there is high enrollment in the PROGAN/Credit program among the interviewees who have pasture (64% in Chajul and 76% in Loma; Table 4), not all *ejidatarios* enroll since there are certain requirements that not everyone can or is willing to meet. For example, possessing a certain number of cattle (calves do not count) is required to receive the approximately $300MX/pesos per head-of-cattle from PROGAN annually; or being willing to commit to a substantial loan through the Credit program for cattle-fattening projects (which is risky because of the fluctuating calves' prices). Similarly to *milpa*, farmers in both *ejidos* had pastures for cattle-raising long before the PROGAN/Credit program arrived (Berget et al. 2021). Notwithstanding, prior to the PROGAN/Credit program, farmers in Chajul had access to numerous different cattle-ranching initiatives through the *ejido's* union (Unión de Ejidos Julio Sabines, UEJS) since the 1980s; whereas in Loma because of its "unofficial" status as *ejido* until 2005,

Table 4 Number of smallholders who have the land-use associated to each of the six national-level institutional programs, and percentage of those who have the land-use and receive the associated subsidy in two studied communities (Chajul and Loma) in southern Mexico

	Chajul		Loma	
	Farmers who have the associated land-use (#)	Farmers who receive the subsidy* (%)	Farmers who have the associated land-use (#)	Farmers who receive the subsidy* (%)
PROCAMPO	12	92	17	71
PROGAN/Credit	14	64	17	76
PES	19	95	NA	NA
Oil palm program	3	100	NA	NA
Rubber program	2	100	NA	NA
Reforestation program	5	100	2	100

*Percentage of those who have the associated land-use. Note: there are no farmers receiving the subsidy that do not have the associate land-use farmers practiced cattle-ranching and expanded their pasture fields without governmental support but with own resources. According to Berget et al. (2021), there was a 15% increase in pasture/agriculture area in Loma between 2005 and 2015, which could be attributed to Loma farmers' eligibility to engage in programs such as PROCAMPO and PROGAN after acquiring land titles and becoming *ejidatarios* in 2005. Nevertheless, as with PROCAMPO, it is difficult to demonstrate a direct causal relationship between the PROGAN/Credit program and the share of farm under pasture in the study site, especially since the pasture land-use was already there before the program started. However, the subsidy certainly provides an incentive for cattle-ranchers to own cattle. Regional research has linked MdC's high deforestation rate (5.6%) between 2003 and 2007 to program subsidies for cattle-ranching and agriculture (Meli et al. 2015b). Elsewhere in Chiapas, other studies have revealed that the PROGAN subsidy incentivizes farmers to have pasture for cattle production (Ramírez-Mejía et al. 2017; Kolb and Galicia 2018).

PES program Our ethnographic research and qualitative findings show that the PES program is only available in Chajul, not because Loma smallholders refused to participate, but because Loma did not meet the minimal criterion of 100 ha of continuous conserved forest to be eligible to enroll in this conservation scheme. Among the 20 interviewees in Chajul, 19 (95%) have primary and/or secondary forests on their farms, and 18 (95%) are enrolled in the PES program (Table 4). However, like with PROCAMPO and PROGAN, a causal relationship between the forest land-use and PES is difficult to determine because the forest existed prior to the establishment of PES. Thus, this relationship needs to be investigated more closely to the historical context in which it has arisen. As discussed earlier, historically, the large tracts of conserved forest in Chajul farms have been "surplus" land that smallholders did not convert to other more productive land-uses, mostly due to family labor constraints. Consequently, when PES arrived in the region in 2008, Chajul farmers took advantage of this annual payment and enrolled their forested lands because they saw an opportunity to collect cash that they would not have received from these unexploited forested lands. The following comment from a Chajul smallholder illustrates why farmers registered in the PES in the first place: "[I enrolled] *because I had forest; I wasn't getting any type of benefit from it, so I said, as long as it is possible,* [and] *they are giving me that* [payment], *it is something, and then, we will see*". The historical context then questions the PES program as a driver of higher shares of conserved forest in Chajul farms. Clear linkages between PES and conservation outcomes are difficult to measure (Ruggiero et al. 2019), and program success is mediated by various factors. For example, based on her findings in two MdC *ejidos* including Chajul, Stolwijk (2016) questions the effectiveness of the PES subsidy in encouraging smallholders to maintain the forested cover. Stolwijk argues that *ejidatarios* have resided in the villages for the preceding 40 years and have not had the intention of tearing down the forest, mainly because conserved forests are usually located too far away.

During fieldwork, PES subsidiaries received $1,000MX/pesos per enrolled hectare annually. On average, Chajul farmers have 27 ha of conserved forest enrolled in PES. This amounts to an average annual income of $27,000MX/pesos per household. This is a significant income for the average family in the study site (cf. the average yearly household income from *milpa* agriculture, cattle, and governmental subsidies is roughly $20,000MX/pesos; see Ortiz et al. 2015). According to the local narratives gathered during our ethnographic research, some *ejidatarios* in the region who already have their own forested lands enrolled in PES have taken advantage and even purchased extra forested land from other *ejidatarios* to reap the benefits of this stable annual income, as was the case with one of the interviewees from Chajul. Nevertheless, interestingly, our findings show that farmers do not always enroll all of their eligible forest in PES, preferring to leave some hectares aside for different reasons and objectives. For instance, timber extraction is not allowed in PES-enrolled forests, thus not registering some of the forest allows the farmers to extract timber, mainly for household needs; or having available land for any other use just in case.

Furthermore, 16 (89%) of the Chajul farmers enrolled in PES claim that the payments they have received from PES have helped them economically to satisfy some of their household's needs (for example to: buy a tractor, invest in cattle-ranching, build/improve the house, pay for higher education, travel, etc.). Nevertheless, these farmers were dissatisfied with the stricter requirements that the PES program was implementing at the time of fieldwork (i.e., that 50% or more of the collected payment must be re-invested in conservation efforts in the enrolled forested lands); and with rumors that PES payments would be significantly reduced by 50% (Berget et al. 2021). Thus, when asked if they would continue enrolling their forests in PES with these changes beyond 2018, when the five-year contract would finish, 15 (83%) Chajul farmers stated they would not renew their PES contract. Of these 15 smallholders, nine (60%) said they would continue conserving the forest, five (33%) mentioned they would cut down the forest and turn it to pasture for cattle-ranching, and one (7%) was unsure what he would do. For example, one of these farmers who enrolled 30 ha of forest in PES said: "*if the PES continues like this,* [my son] *will cut all* [the forest] *down and sow grass* [for cattle pasture]". This demonstrates that, while some smallholders believe they would continue conserving the forest without the PES subsidy, there are also farmers who would probably not continue conserving because, now that they have accumulated some capital, they would rather convert the forest to cattle-ranching pastures, which they consider more lucrative. One of the farmers illustrated this with an example: if ranchers sell the two head-of-cattle that may be produced in one hectare, farmers could potentially make $20,000MX/pesos per hectare, annually.

It is difficult to establish a direct causal relationship between the PES program and higher shares of conserved forest in Chajul farms. However, the qualitative findings reveal that some farmers who had not cut down their forest in the last 40 years are willing to do so now if the PES continues with stricter requirements and decreases its annual payments, which puts them in a disadvantaged economic situation. Furthermore, forest area in Chajul decreased by 18% in the period 1996–2005, but only 7% and 2% in the period 2005–2015 and 2015–2019, respectively (Berget et al. 2021). The low percentages of forest loss of the latter two periods may be related to the PES implementation in 2008. According to Costedoat et al. (2015) and Izquierdo-Tort et al. (2019), the loss of forest cover on smallholder holdings in Chajul and other MdC *ejidos* registered in PES has been less compared to non-enrolled lands. Rodríguez Silva's (2018) study in three *ejidos* in MdC, including Chajul, concluded that farmers prefer to convert forests to more profitable land-uses like cattle-ranching if there are no incentives for conservation, such as PES. Furthermore, at the MdC regional level, Ortiz et al. (2015) contend that: "the PES has contributed to curbing the accelerated deforestation rate facing the region" (p. 328; own translation), which peaked at 5.6% from 2003 to 2007. Similar to our results in Chajul, these authors also argue that the requirement to reinvest between 50 and 70% of the PES payments *ejidatarios* receive, will most likely induce many farmers to abandon the program and convert the forested lands to other profitable land-uses. Elsewhere in the tropics, such as Costa Rica, reduced forest loss has also been linked to the implementation of PES policies (Morse et al. 2009).

Finally, the PES program is strongly positively correlated to the household variables farm size and off-farm income, but negatively to the two biophysical variables (SI 7). These strong across-scale correlations may indicate that in Chajul, smallholders with larger farms and who receive off-farm income have greater forest area enrolled in PES, as there is likely more "surplus" forest in the former and less reliance on the land for income in the latter. The negative correlation between PES and the soil variables supports our hypothesis and findings that smallholders with low quality soils on their farms tend to have larger shares of primary forest (SI 5, Fig. 1e), and hence much of the forest under PES in Chajul's case.

Oil palm, Rubber, and Reforestation programs Our results show that oil palm and rubber land-uses are only found in Chajul. Only three of the 20 respondents in Chajul owned oil palm and two had rubber plantations (one of these farmers grows both crops). All of these farmers receive the subsidies associated to oil palm and rubber plantations (Table 4). Our qualitative findings reveal that Chajul smallholders began adopting the agro-industrial crops oil palm and rubber in 2008 (one started ~ 2012) and ~ 2015, respectively. The oil palm program offers registered farmers free oil palm seedlings and an initial subsidy of $1,000MX/pesos per inscribed hectare. One of the interviewed Chajul oil palm entrepreneurs, who started planting oil palm in 2008 and during fieldwork had 43 ha, reflected on why he became interested in experimenting with this agro-industrial crop:

> "…*because we sowed chili,* [and] *we lost; we sowed maize and it was worth* [only] *around*

one peso per kilo at that time, it was not a business. Precisely for that reason, because we have no other ways out, other than looking to see what [else] *can be done, and one of the solutions was the* [oil] *palm…the producers* [of oil palm in other ejidos] *told us that it* [oil palm] *was even better than cattle-raising."*

There are approximately 3,288 ha of rubber plantations in the MdC region (Pingarroni et al. 2022). The Rubber program provides farmers an initial incentive of $10,500MX/pesos per enrolled hectare to get started (to purchase and plant the seedlings). *Ejidatarios* then receive a $2,000MX/pesos annual subsidy for plantation maintenance, which requires approximately three *limpias* (weeding) per year to remove fast growing (unwanted) vegetation. One of the rubber entrepreneurs in Chajul, who had 18 ha of this crop, explained that he started planting rubber because, according to him, 1) the government supports this crop more than oil palm, and 2) rubber is a "timber" species (whereas, he mentions, oil palm is not) which he could also harvest and profit from in the future. For these reasons, he opted to cultivate rubber rather than oil palm on what was once his pasture.

Our ethnographic work revealed that all of the oil palm and rubber growers in Chajul (aside from those interviewed) receive the corresponding subsidy program. Because producing oil palm and rubber crops involve substantial investments (particularly labor for weeding, and in the case of oil palm for fertilizers and labor for harvest), smallholders are highly unlikely to adopt these land-uses without the subsidy that encourages them. Therefore, the Oil palm and Rubber programs are regarded drivers of their targeted land-use in Chajul. The state of Chiapas is one of the largest oil palm producers in Mexico, reaching 43,200 ha in 2016 (Castellanos Navarrete 2018). In the MdC region, oil palm covered an area of approximately 9,843 ha by 2020 (Pingarroni et al. 2022). In his extensive research on oil palm in the MdC region and elsewhere in Chiapas, Castellanos-Navarrete concludes that smallholder oil palm farming has been actively supported by official incentives and support (Castellanos-Navarrete 2015; Castellanos-Navarrete and Jansen 2018; Castellanos Navarrete 2018). Our case study findings align with previous research on smallholder oil palm expansion in Latin America led by government policies, including the Amazon in Peru (Bennett et al. 2018), Brazil (Brandão et al. 2019), and elsewhere in Latin America (Meijaard et al. 2020; Castellanos-Navarrete et al. 2021), as well as smallholder rubber expansion in Southeast Asia, such as in Laos (Junquera et al. 2020), and Thailand (Sakayarote and Shrestha 2017). In contrast, whereas initial adoption of oil palm among smallholders was done through government backing in Indonesia, this has lost importance, and recently the majority of the oil palm adoption occurs independently by farmers (Euler et al. 2016). Loma farmers have not participated in either of these two agro-industrial crops programs, nor do they have any of these plantations independently. Not because they do not qualify to participate (as with PES), but because based on their perceptions, needs, values, and beliefs, they do not want to, demonstrating their agency in deciding whether or not to engage in voluntary policy programs (Castellanos-Navarrete 2015; Berget et al. 2021, 2024).

Lastly, seven farmers in the study *ejidos* have the reforestation land-use type, and they are all engaged in the Reforestation program (Table 4), which has incentivized them to reforest parts of their farms with valuable tree species like mahogany (*Swietenia*) and cedar (*Cedrela*) for future timber exploitation. One of the Chajul farmers who has 5 ha of reforestation indicated that sustaining the reforestation requires a minimum of two *limpias* annually, which is a costly task. The Reforestation program consisted of supplying farmers with seedlings, an initial payment of $1,200MX/pesos for planting, and subsequently $400MX/pesos per year for upkeep (weeding). We conclude that the Reforestation subsidy promotes the reforestation land-use in the study site, because reforestation is a costly activity that, according to smallholders, they are highly unlikely to engage in unless they get financial support for it. Meli et al. (2015a) also argue that without the Reforestation subsidy, smallholders in the MdC region are unlikely to invest their resources in reforestation efforts.

Diversity of subsidies The diversity of subsidies variable appears to influence smallholder decisions concerning pasture and oil palm, similarly to the influence of diversity of income sources on these land-uses (see earlier discussion). According to our ethnographic fieldwork, smallholders consider agricultural development and conservation subsidies as a source of cash – even if it is not much, as in the case of the reforestation program – that if not enrolled, would not receive. Cano Castellanos (2022, 2024) reported similar findings in the MdC region, where subsidies are regarded by smallholders as a form of "help" to invest in various market-oriented agricultural activities and associated land-use types. This is especially evident in Chajul where farmers are not land-constrained and tend to enroll in more land-use subsidies compared to Loma farmers. We found that in Loma, smallholders invest any cash they get in their cattle-ranching enterprises, including left-over money from subsidies because, as mentioned, their livelihoods depend on cattle-raising. The GLM results support our findings given that the models show that the diversity of subsidies a smallholder receives tended to increase the area under pasture, as well as the probability of adopting the oil palm, and reforestation land-uses (Table 3; SI 5, Fig. 1g–i). Finally, there is a strong positive correlation between the diversity of subsidies and the farm size variable (SI 7), which as we argue based on our findings for Chajul, smallholders with larger farms have more farm area to allocate land to diverse land-uses and hence likely to enroll in more land-use subsidies.

Finally, both *ejidos* feature a complex mosaic of diverse land-uses that provide multiple subsistence, economic and environmental benefits to smallholders, representing a typical multifunctional landscape (Hölting et al. 2020). This landscape multifunctionality may be undermined by these competing national-level subsidies, because of the six programs we analyzed, the majority (four) are directed toward rural development, targeting specific productive land-uses, while only two target forest conservation. However, Loma does not have access to PES, therefore the opportunities for forest conservation are unequal in both *ejidos*. To support landscape multifunctionality in the study *ejidos* and the MdC region, policy programs that target rural development should also incorporate the environmental dimension in their objectives, and take into account the livelihoods and needs of the farmers who rely on these landscapes (Meli et al. 2015c). Improving policy design would maintain landscape multifunctionality and the continuous provision of crucial ecological services locally and regionally (Mastrangelo et al. 2014).

Limitations

Limitations to our study include the small sample size (two villages and 39 household interviews). We were also constrained by time and resources to conduct more semi-structured household interviews in more *ejidos*. Adding more communities, especially those that are very different from Chajul and Loma, would have been enriching, such as villages that are not riverine but located inland in the region, and/or including indigenous communities. Nevertheless, the ethnographic approach, participant observation, and farm visits provided rich qualitative data to conduct the comparative analysis.

Conclusions

Through a comparative analysis, we demonstrated that neighboring communities in a tropical agro-forest frontier with multifunctional landscapes share commonalities, yet also show differences in terms of land-uses and the variables that influence smallholders land-use decision-making. In our case study, the *ejidos* differ in terms of primary forest, with the larger village having significantly more forest than the smaller village. Our empirical case study findings support several of our hypotheses and reveal that when making land-use decisions, smallholders evaluate and take into consideration multiple variables at different scales. For example, at the local-level, household variables such as farm size, off-farm income, and diversity of income sources are important factors influencing land-use decisions. At the regional level, soil conditions are also important: farmers with access to high-quality soils on their farms choose to concentrate agriculture on those soils; in contrast, smallholders with farms with poorer soil quality tend to invest in other land-uses (other than agriculture), such as pasture. Lastly, our findings on the national-level institutional factors, partially supported our hypothesis that farmers' decisions to participate (or not) in agricultural and conservation policies influence the allocation of particular land-uses on their farms. The results of the Rubber, Oil palm and, Reforestation programs supported the hypothesis. In contrast, a direct causal relationship between the PROCAMPO, PROGAN/Credit, and

PES programs and their targeted land-uses was difficult to establish.

We conclude that smallholder land-use decision-making is a complex process that consists of considering not only one but several social-ecological factors at different levels when making decisions on their farm land-use allocations. Furthermore, historical context is critical for understanding farmers' land-use decisions in the present. Finally, we contend that smallholders play a fundamental role in the conversion and/or conservation of frontier landscapes, and their decisions are mediated by endogenous and exogenous social-ecological factors at local, regional, and national scales. Thus, we recommend policy and decision makers to consider the intricacies and diverse realities of smallholders' land-use decision-making process. The contextual social-ecological factors that influence these decisions in agro-forest frontiers and multifunctional landscapes must be addressed, in order to formulate more effective and tailored agricultural development and conservation policies that not only aim to achieve specific land-use outcomes but simultaneously to improve farmers' livelihoods.

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Author contributions CB, ML, GV, EG-F, and FB contributed to the study conception and design. Data collection was performed by CB. Geopedologic data, soil methods, and soil data was provided by AN-S. Analyses were performed by CB and ML. The first draft of the manuscript was written by CB. CB, ML, GV, EG-F, and FB commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability Data will be made available on request.

Declarations

Conflicts of interest The authors declare no competing interests.

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