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DEFORESTATION AND REFORESTATION IN THE SIERRA DE GUADALUPE, STATE OF MEXICO, AS A NETWORKED SOCIAL SYSTEM

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ABSTRACT

Deforestation is a complex and multifactorial problem. In Mexico, this phenomenon is exacerbated by urbanization in metropolitan areas. The Sierra de Guadalupe is situated in the Valley of Mexico and is a Protected Natural Area (PNA) that has been continually devastated by encroaching human settlement. In the area of mountain range located in the State of Mexico, attempts have been made to counteract deforestation with reforestation in degraded areas. However, these activities have been modified by the social, economic and political realities of this area. Our aim was to analyze the reforestation process in the Sierra de Guadalupe in the State of Mexico, during the period 2009-2020, by analyzing the social network and the structural phenomenon generated between social actors, reforested places and species used. Results indicated that 416.9 hectares have been reforested, affecting 75 localities, with participation of around 300 social actors, using 50 species, of which only 15 are native to the Sierra de Guadalupe ecosystem. Unequal distribution of resources used for reforestation was apparent, when comparing the municipalities analyzed (Coacalco, Ecatepec, Tlalnepantla and Tultitlán), despite being part of the same ecological corridor.

Keywords: peri-urban, protected natural area, social networks.

INTRODUCTION

There are 4,060 million hectares of forests in the world, corresponding to 31% of total land area (Food and Agriculture Organization-FAO, 2020). The environmental services provided by these ecosystems are: I) Supply (water, food and raw materials, etc.), II) Regulation (air quality and water flows, carbon capture, conservation of soil fertility, III) Support (conservation of the biodiversity of flora and fauna) and IV) Cultural (recreational activities, tourism, cultural identity, aesthetic and spiritual inspiration from the natural environment), Environmental and Natural Resources Secretary (Secretaría de Medio Ambiente y Recursos Naturales-SEMARNAT, 2021). However, forests have suffered a drastic reduction in space and volume, due to various causes and factors that cause their fragmentation and deterioration. A loss of 420 million hectares of forests has been estimated worldwide between 1990 and 2020. As of 2015, an average loss of 10 million hectares per year is estimated (Food and Agriculture Organization of the United Nations -FAO, 2022). For its part, the World Wildlife Fund (WWF) reported a loss of 370 million hectares of forests between 2001 and 2018, equivalent to an average loss of 21.8 million hectares per year, double the figure estimated by FAO (WWF), 2021).

The FAO defines these processes as deforestation, that is the conversion of forests to another land use (agriculture, livestock, mining, urban areas, water reserves or infrastructure) or the reduction of canopy cover to below a minimum threshold of 10% (FAO, 2020; Cubillollos, 2012). This phenomenon, caused by human activity, is characterized as a much more complex process than the mere removal of the forest layer (this is its ultimate manifestation). Some of the intervention processes to try to reverse these trends are through reforestation practices and activities, however, these activities are limited by local social and economic conditions, National Commission for the Assessment and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad-CONABIO, 2020).

In Mexico, forest loss between 2001 and 2021 was 4,385,837 hectares, averaging 208,850 hectares per year (National Forest Monitoring System -SNMF, 2023); this is due to multifactorial causes, among which are included: demographic dynamics, poverty, lack of forest governance, absence of social organization for the care of forests and the increased cultivation of certain agricultural products, for example, avocados, National Forestry Commission (Comisión Nacional Forestal-CONAFOR, 2020).

Currently, the highest incidence of deforestation is concentrated in the states of Campeche, Chiapas, Guerrero, Jalisco, Michoacán, Oaxaca, Quintana Roo, San Luis Potosí, Veracruz and Yucatán (SNMF, 2023). However, given the historical process of development, urbanization and expansion of the agricultural frontier in Mexico, deforestation has been changing, depending on these determinants. Furthermore, a "historical failure" is apparent concerning the calculation of the loss of forest area in previous decades, because in these calculations, those areas that lost their forested areas and that now have only secondary vegetation are not considered as deforested, which is expressed as a degradation process of the forest mass (Rosete-Vegés *et al.*, 2014). In this case, although the states in the central area of the country do not feature predominantly in the current deforestation rates in Mexico (SNMF, 2023); this may be only nominal, as the alterations have been constant, preventing forest recovery. In the case of the historically populated and urbanized regions of Mexico, forest systems have been modified to the point of reducing them to areas with secondary vegetation, over and over again, (Rzedowski, 1978; González, 1992).

In this context, the Valley of Mexico is located in the central area of the country, a regional socio-ecological system of 9,560 km2 that includes the Metropolitan Zone of the Valley of Mexico, with approximately 22 million inhabitants; National Institute of Statistics and Geography, (Instituto Nacional de Estadística y Geografía-INEGI, 2020); Environmental and Territorial Planning Office of Mexico City, (Procuraduría Ambiental y del Ordenamiento Territorial de la Ciudad de México-PAOT, 2002) and historically, this has been one of the areas, whose forest masses have been most affected by growing urbanization. Among the principal strategies that have been implemented to counteract deforestation in this area, the following stand out: reforestation campaigns (CONABIO, 2020) and the declaration of Protected Natural Areas (PNA), both federal and state

(Chamber of Deputies, 2022). The first are administered by the National Commission of Protected Natural Areas (Comisión Nacional de Áreas Naturales Protegidas-CONANP); in the State of Mexico, the state PNAs are run by the Environmental secretary of the State of Mexico, through the General Coordination of Ecological Conservation (Coordinación General de Conservación Ecológica-CGCE) which is in charge of 10 PNAs, among which stand out Sierra of Tepotzotlán, Sierra Hermosa, Sierra Patlachique, Cerro Gordo and Sierra de Guadalupe, located in the Metropolitan Zone of the Valley of Mexico, Environmental Secretary, (Secretaría del Medio Ambiente, 2018). For its part, in Mexico City, there are currently 25 PNAs (10 are managed by CONANP and 15 by the Mexico City Environmental secretary (Secretaría del Medio Ambiente de la Ciudad de Mexico-SEDEMA), grouped into six categories: National Park, Community Ecological Reserve, Ecological Conservation Zone, Hydrological and Ecological Protection Zone, Ecological and Cultural Zone and Zone dedicated to Ecological Conservation (SEDEMA, 2022).

These forest management strategies form part of the environmental and forest protection policy in Mexico, which began with the promulgation of the General Law of Ecological Balance and Environmental Projection (Ley General de Equilibrio Ecológico y la Proyección al Ambiente-LGEEPA) in 1988, and the Forestry Law of 1992, with which responsibilities for forest resources are decentralized, under direction of the Agricultural and Hydraulic Resources Secretary, today the Agriculture and Rural Development Secretary (Secretaría de Agricultura y Desarrollo Rural-SADER). Subsequently, SEMARNAT (created in 1994), established CONAFOR (in April 2001) to manage Mexico's forest resources. With the promulgation of the General Law of Sustainable Forestry Development, power was conferred to delimit the national territory into "Forestry Management Units" (Unidades de Manejo Forestal-UMAFOR).

However in this law, the way resources were to be managed was not defined, which would have integrated a wide diversity of social actors and consequently their relational heterogeneity (Rodríguez-Aguilar and Trench, 2020). This caused an ongoing methodological disparity, concerning the monitoring of deforestation, degradation, afforestation, forest management and inventory, as well as lack of comparison of data obtained; insufficient personnel were assigned to generate forest inventories and geomatics, centralize functions; likewise technological capacity to monitor forest degradation, using high-resolution remote sensors has been inadequate (Leyva, 2016; Merino *et al*., 2011).

Consequently, this has become a recurring problem in public organizations, responsible for forest resources at national and state levels. For example, despite the work of CONAFOR involving the management of national forestry abundance (Del Ángel-Mobarak, 2012), there is a continuous decline in forests, due to "A discontinuity… between conservation, surveillance and sanctions on one side and the promotion policy, with similar negative impacts on productive and management capacities of communities" (Merino *et al*., 2011).

In the case of the State of Mexico, CONAFOR cooperates with the Forest Protector of the State of Mexico (Protectora de Bosques del Estado de México, PROBOSQUE) and the General Coordinator of Ecological Conservation, which form part of the State

Reforestation Committee (PROBOSQUE, 2023). PROBOSQUE operates by means of reforestation programs, sustainable forest management, payment for hydrological environmental services, carbon storage and commercial forest plantations on ejidal, communal and privately owned lands; Rural Secretariat (Secretaría del Campo, 2023).

However, reforestation programs carried out with the help of PROBOSQUE have had unpromising results, because the percentage of survival of the plants in various regions of the State of Mexico has been 38% (Torres, 2021), a lower percentage than the acceptable range of 50-60%, among most commonly used pine species, such as Gregg's pine (Muñoz *et al*., 2012). Currently, PROBOSQUE seeks to increase survival rates, implementing economic incentive programs for reforested properties that achieve more than 40% survival (PROBOSQUE, 2023b). For its part, administration of reforestation activities in combination with the General Coordination of Ecological Conservation is limited to the implementation of policies and actions for the conservation of the PNA, ecological parks and green urban areas, among other projects Ministry of the Environment (Secretaría del Medio Ambiente, 2023). However, these programs have not benefited the mountain range.

According to this, forest degradation processes have been addressed institutionally, from different perspectives. In spite of this, they do share a growing level of uncertainty, regarding the state of the forest resource in Mexico, as well as complex interaction with the social environments where the forest resource exists. An example of is evident in the socio-ecological system located in the Valley of Mexico, Sierra de Guadalupe, where some of the strategies established by public, state and municipal institutions, to alleviate the impact of urbanization in this mountain range, have been promoting and also participating in variety of reforestation processes.

However, the complexity of present contradictions and socio-political and economic structures, have generated dynamics that have a contrary effect. Paradoxically, the execution of public policies in Mexico opens a broad panorama of "inclusion" of political-economic actors who, depending on the resources they have and the interests they promote, even reformulate these policies to fulfill differential objectives (Agudo, 2015; Trench *et al*., 2018). Based on the above, this research intended to analyze the reforestation process in the Sierra de Guadalupe in the State of Mexico, as a socially constructed process, analyzing the socio-structural dynamics generated between social actors, reforested places and species.

THEORETICAL FRAMEWORK

Deforestation and reforestation

Every reforestation activity implies a certain management, planning and organization of economic, technical, forestry resources, etc., in order to have impact on deforested areas. However, in Mexico, these activities have not managed to stop the decomposition of forest ecosystems, so deforestation has become a system driven by the interweaving of variables, both natural and anthropic (including institutional). Some socio-institutional subsystems, responsible for reforestation activities are not exempt from particular dynamics, such as: varied methodological approach/gaps in forest analysis and monitoring, unsuitable technological innovation for analyzing forest degradation, insufficient technical resources, dismantling of conservation procedures, in addition to the fact that these activities interact with the complexity and social and economic diversity of the communities, resulting in the modification (radical) in terms of the objectives of reforestation (Trench *et al.*, 2018; Leyva , 2016; Agudo, 2015; Consequently, the loss of forest resources has not been arrested; on the contrary, growing skepticism has been generated about the real state of forests in Mexico.

Deforestation is a multifactorial phenomenon, composed of a diversity of causes and consequences that feed off each other, depending on the type of human activities that intervene or intersect, directly or indirectly, with this phenomenon. And its initial impact is the loss of environmental services, mainly affecting the localities that depend on these resources (Ogundele *et al.*, 2016). This undermines nutrition by interrupting pollination processes, reducing the availability of forest foods and harming human health, because forests are the largest reservoir of medicinal plants and inputs for the production of medicines (Lawrence *et al.*, 2007; Acharya *et al.*, 2020). These health risks are exacerbated, as deforestation creates ideal environments for reservoirs and vectors of diseases, for example, malaria, dengue, Zika, chikungunya, Ebola virus, Nipah virus, Chagas disease, zoonotic diseases, diarrheal diseases, respiratory infections and pandemic diseases, such as COVID-19 (Codeço *et al.*, 2021; Acharya *et al.*, 2020).

Besides this, deforestation also generates economic losses by increasing the severity of natural disasters, such as forest fires and floods (Bradshaw *et al.*, 2007). Additionally, population density correlates with the rate of deforestation: due to the need for more spaces for human settlements and the fact that these spaces cause deforestation (Guojing *et a*l., 2021). Evidently, deforestation is a process that is not random, but a product of biogeochemical and energy imbalance, linked to processes of socioeconomic vulnerability of (and in) human communities. In this sense, one of the main vulnerabilities that drive these biotope decomposition processes is generated as a direct product of deficiencies in public organizations and institutions (United Nations Development Program-UNDP-, 2014).

In Mexico, this institutional vulnerability is shown to relate directly to a historical decline in confidence in public institutions, Organization for Economic Cooperation and Development/Development Bank of Latin America and the Caribbean/Economic Commission for Latin America and the Caribbean-OECD/CAF/ECLAC 2018 (Organización para la Cooperación y el Desarrollo Económicos/ Banco de Desarrollo de América Latina y el Caribe/ Comisión Económica para América Latina y el Caribe). In this sense, the decomposition of anthropic variables (socioeconomic conditions and sociopolitical systems) intervenes directly with societies' degree of vulnerability, meaning that degree of vulnerability is directly proportional to the degree of institutional decomposition (Nuñez, 2020). In this context, the FAO (2012) suggests that the social construction of the vulnerability of communities occurs at the intersection of: a) the disequilibrium between supply and demand for services, b) insufficient infrastructure to meet the needs of the population and c) institutional incapacity to guarantee safe and equitable access to resources required by communities. And in the case of this analysis, it is not reckless to establish as a premise, the link between a multifactorial phenomenon, such as deforestation, with the institutional decomposition of the forestry sector and the management of participating social diversity, in an area like the Sierra de Guadalupe. Given this, we implemented a social network analysis.

Social network analysis

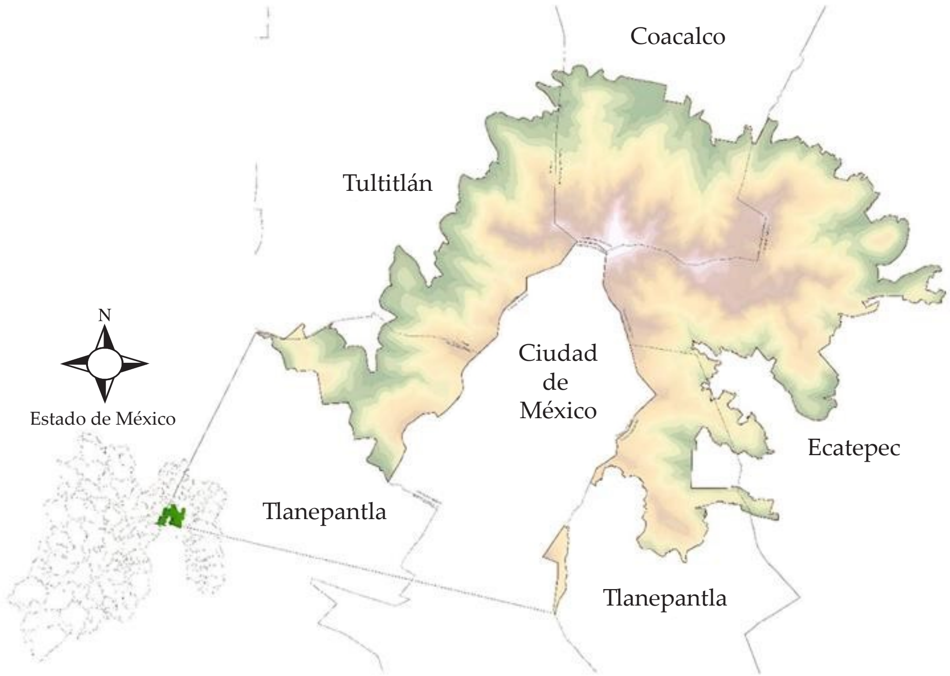
Social network analysis (SNA) is a structural tool that, by means of matrix mathematics: makes it possible to represent social agglomerations in the form of graphs, in order to examine the way each of the social actors are integrated (Ramos-Vidal, 2015), and also how relevant they are within these organizational structures. To address problems related to the management of natural resources (application and compliance with environmental regulations and implementation of conservation strategies, among others), and to improve the goods and services provided by them, taking into consideration the diversity of public and private actors involved in this management, the SNA attempts to identify the relationships between the interested parties in the participatory processes and adjust the distorted perceptions, which on numerous occasions occur between social actors, (Bodin and Crona, 2009).

We must not forget that the management of natural resources operates in a socio-ecological system that directly influences resource management decisions themselves; meaning that the SNA allows us to characterize the behaviors of the social structures responsible for this management (Groce *et al*., 2019). It thus also facilitates intervention, in terms of the relationships established for the management of forest resources that can influence coalitions and/or decision-making (Paletto *et al*., 2016). In this sense, the notion of networks, applied to the management of natural resources, is associated with the possibility of generating capacities for the transmission of information, deliberation and collective construction of knowledge and resilience, that is, the most optimal network governance models for the management of natural resources (Kyriakopoulou and Xepapadeas, 2021; Newig *et al*., 2010). However, this must take into account that these social structures are constantly changing, and likewise the structural qualities of the actors, hence the need to constantly update these analyses (Scott, 2015).

METHODOLOGY

The Sierra de Guadalupe, located in the Valley of Mexico, to the north of Mexico City, is delimited by the Gustavo A. Madero mayor's office and by four municipalities of the State of Mexico: Coacalco, Ecatepec, Tlalnepantla and Tultitlán, so it is completely surrounded by areas of urban growth (Figure 1).

This mountain range is a Protected Natural Area covering a total area of 5,927.1 hectares (Table 1). In the State of Mexico, it consists of an area of 5,293.4 hectares and is categorized as a "State Park" (CGCE, 2021a). In Mexico City, it covers an area of 633.7 hectares and



Source: modified from the map showing locations of meteorological stations in the Sierra de Guadalupe (scale 1:26000) contained in (CGCE, 2021a).
Figure 1. Map of the Sierra de Guadalupe.

is classified as a "Zone Subject to Ecological Conservation" (SEDEMA, 2022).

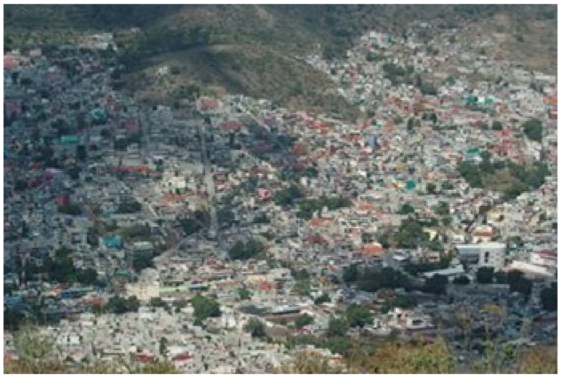
Large-scale ongoing urbanization is the third cause of loss of forested area at the national level (CONAFOR, 2020). Human settlements have affected biotic and environmental composition, creating a social and historical process of transformation. In the case of the Sierra de Guadalupe, this area has been subjected to a continuous and accelerated process of deforestation, mainly due to the change in land use from forest to urban (Alcérreca *et al*., 2009) (Figure 2).

Urbanization in this mountain range is directly linked to forest loss, pollution with solid waste, the introduction of non-native species of flora and fauna, the proliferation of

Table 1. Distribution of the Sierra de Guadalupe Protected Natural Area.

Federal entity	Mayor's Office or Municipality	Land area (ha)
Mexico City	Gustavo A. Madero	633.7
State of Mexico	Coacalco	1,242.8
	Ecatepec	1,835.3
	Tlalnepantla	1,222.2
	Tultitlán	993.1

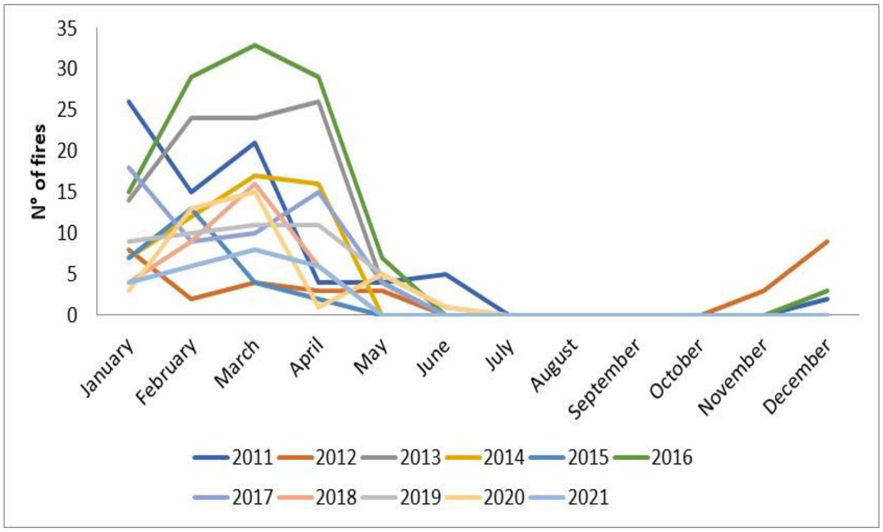
Source: self-elaborated with data from (CGCE, 2021a) and (SEDEMA, 2022).



Source: credits, Nuñez J., 2022. Valleys of Santa María Tulpetlac and San Andrés de la Cañada.
Figure 2. Urban expansion in the Sierra de Guadalupe in the State of Mexico.

feral fauna, the clandestine extraction of species, disorderly recreational activities and an increase in forest fires (Alberto, 2007; Cueto, 2007). During the period 2011-2021, 596 fires were recorded in the mountains, impacting 2,331.7 hectares (CGCE, 2022); Most of the damage (71.3%) tends to occur during the first half of the year (Figure 3).

The number of fires per municipality was concentrated in the territory of Ecatepec (36.3%), followed by Tlanepantla (30.3%), Tultitlán (17.7%) and Coacalco (15.7%) (CGCE, 2022). The distribution of damaged areas was similarly differentiated, predominantly in Tlanepantla and Tultitlán (Table 2).



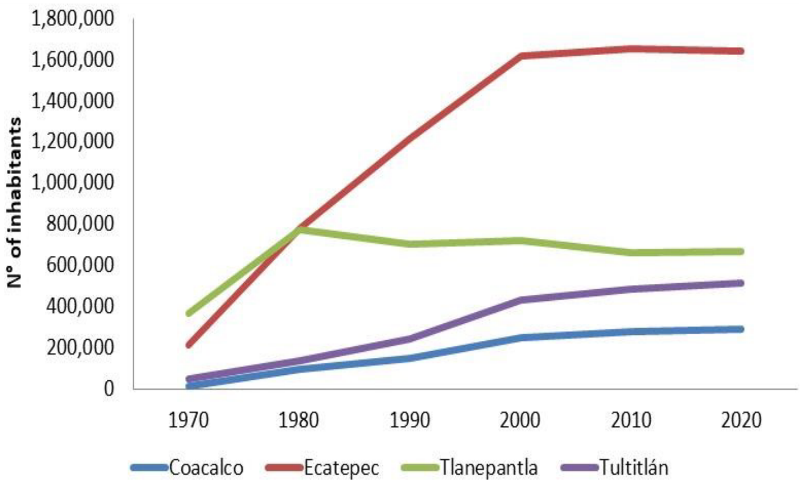
Source: self-elaborated with data from (CGCE, 2022).
Figure 3. Monthly distribution of fires in the Sierra de Guadalupe in the State of Mexico, 2011-2021.

Table 2. Surface area damaged by fires in the Sierra de Guadalupe, State of Mexico.

Municipality	Burnt area (ha)
Tlalnepantla	644.2
Tultitlán	600.6
Ecatepec	595.7
Coacalco	491.2

Source: self-elaborated with data from (CGCE, 2022).

The Sierra de Guadalupe is an area that has been impacted since pre-Hispanic and colonial times (National Institute for Federalism and Municipal Development, 2010; El mexiquense, 2018). Besides this, in the first half of the 20th century, technological, economic and social changes were accentuated and from the 1940s onwards, an industrial and population boom occurred (National Institute for Federalism and Municipal Development -INAFED, 2010; Martínez-López *et al.*, 1998). However, rapid and disorderly population growth in the area began at the end of the 20th century, leading to the elimination of a large part of the forest cover in the mountains; degrading the forest, impeding the restoration of aquifers, deteriorating soil quality and encouraging the creation of open-air solid waste tips in the area (Cueto, 2007). From 1980 onwards, the municipalities of the State of Mexico, adjacent to the Guadalupe mountain range, experienced an increase in their population dynamics (Figure 4) and human settlements in the mountains intensified due to the subdivision of ejidal lands (Alberto, 2007).



Source: elaborated with data from INEGI (1970, 1980, 1990, 2000, 2013, 2021).
Figure 4. Population growth in municipalities of the State of Mexico, where the Sierra de Guadalupe is located (1970-2020).

These processes of degradation of the territory of the Sierra de Guadalupe, in the State of Mexico, have contributed to constraining and determining reforestation activities in the area, to such a degree that it was necessary to conceptualize reforestation itself in the Sierra of Guadalupe, State of Mexico, as a social system. For this, the following procedure was implemented:

1-Data on reforestation activities in the Sierra de Guadalupe, in the municipalities of Coacalco, Ecatepec, Tlalnepantla and Tultitlan in the State of Mexico, during the period 2009-2020 were analyzed. These were obtained from the review by the Plantation Registration Certificates of the General Coordination of Ecological Conservation, the entity in charge of managing the Sierra de Guadalupe State Park. The information was captured and systematized in a database that included the following variables: locations, areas, dates, participating social actors, and species used for reforestation. The criteria selected for the analysis were the municipalities, the social actors and the species. The information was organized into bimodal adjacency matrices in the following order: a) Actor-Municipality and b) Species-Municipality (CGCE, 2021b).

2-This enabled the use of SNAs in the reforestation process in the Sierra de Guadalupe, considering in combination: spaces where reforestation activities were implemented at the municipal level, type of species used and the diversity and number of social actors involved in reforestation, during the period 2009-2020. The measures used in the present study corresponded to the conceptual group of centrality, such as nodal degree and degree of closeness. The nodal degree enables identifying those nodes that, depending on their number of links, have a better possibility of strategically accessing the information inputs that are being distributed, throughout the social structure (Freeman, 1978). For its part, the degree of closeness identifies nodes that can potentially influence the composition of the social structure, simply by being linked to prominent nodes (Molina, 2001).

For this research, Latour's (2008) Actor Network Theory was taken into consideration, conceiving each node as a neutral node. Thus; actors, forest species and municipalities were all considered nodes, linked together by reforestation activities. This allowed us to assume a flow of information (reforestation) between nodes, therefore, identifying the breadth and diversity of the network structure analyzed, as well as the mutual distribution network of social prominence (Hanneman and Riddle, 2005). Each of the databases were captured in the Microsoft Excel® program and processed with the Visone® program, which made it possible to recreate reticular models to analyze and visualize structures in the form of social networks (Brandes and Wagner, 2004).

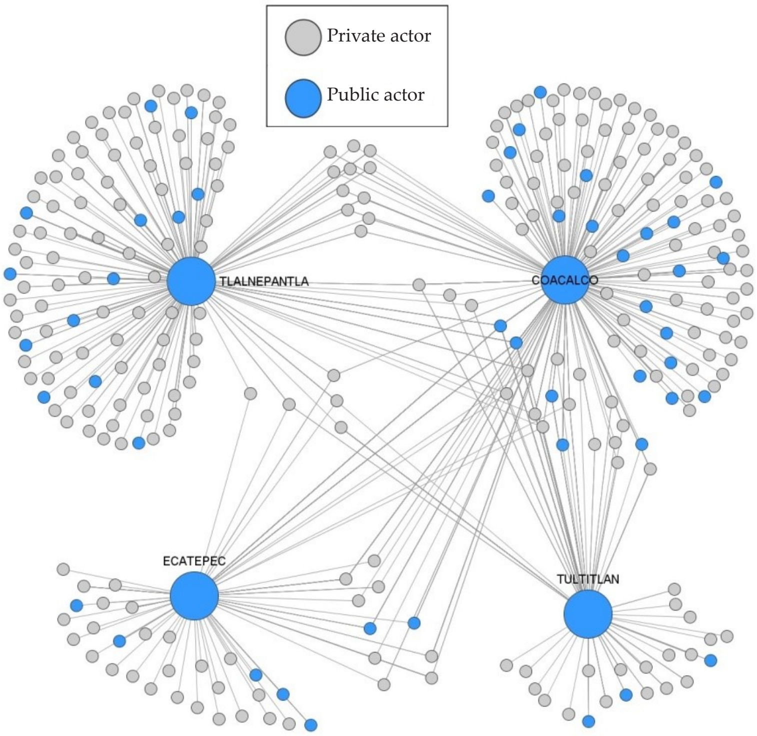
RESULTS

Social participation

The reforestation process in the Sierra de Guadalupe in the State of Mexico has been complex and variable; a number of locations have been reforested in the municipalities of Coacalco, Ecatepec, Tlalnepantla and Tultitlán. The General Coordination of Ecological Conservation has inegrated a total of 967 data from 2009 to 2020, with participation on the part of about 300 actors, in 75 locations, in the four municipalities of the mountain range. Although each municipality is an independent administrative entity, they may coincide on some issues, for example, in terms of appealing to various social actors for their participation in reforestation. The trend for support can be seen among the staff of adjacent City Councils, but barely, among those further away (Figure 5). For example, Coacalco and Tultitlán share the largest number of public and private actors who participate in reforestation, and likewise they share territorial borders.

Distribution of species in reforestation

The reforestation process is accompanied by a distribution of technical, economic, human resources, etc.; and in the indicated municipalities, this distribution is uneven and tends to be concentrated in Coacalco. The slopes where these four municipalities meet are in a socio-ecological "continuum", however, the disproportionate distribution of resources dedicated to reforestation is apparent, in terms of the amount of reforested surface and by the number of social actors, localities and species involved (Table 3). For example, Coacalco has the most extensive reforested area, with more social actors involved and a greater diversity of species used. Although Tlalnepantla comes next, in terms of reforested



Source: self-elaborated in Visone® with data from (CGCE, 2021b).
Figure 5. Network of social actors involved in reforestation of the Sierra de Guadalupe in the State of Mexico.

Table 3. Number of social actors, localities, species and reforested area in the Sierra de Guadalupe, State of Mexico.

Municipalities	No. of Actors	No. of Locations	No. of Species	Reforested area (ha)
Coacalco	145	26	36	165.9
Ecatepec	51	21	35	36.1
Tlalnepantla	123	12	29	161.3
Tultitlán	46	16	23	53.6

Source: self-elaborated with data from (CGCE, 2021b).

hectares and number of social actors involved, there are fewer locations. In contrast, the municipality of Ecatepec has a similar number of worked locations to the municipality of Coacalco, but the reforested area is significantly smaller.

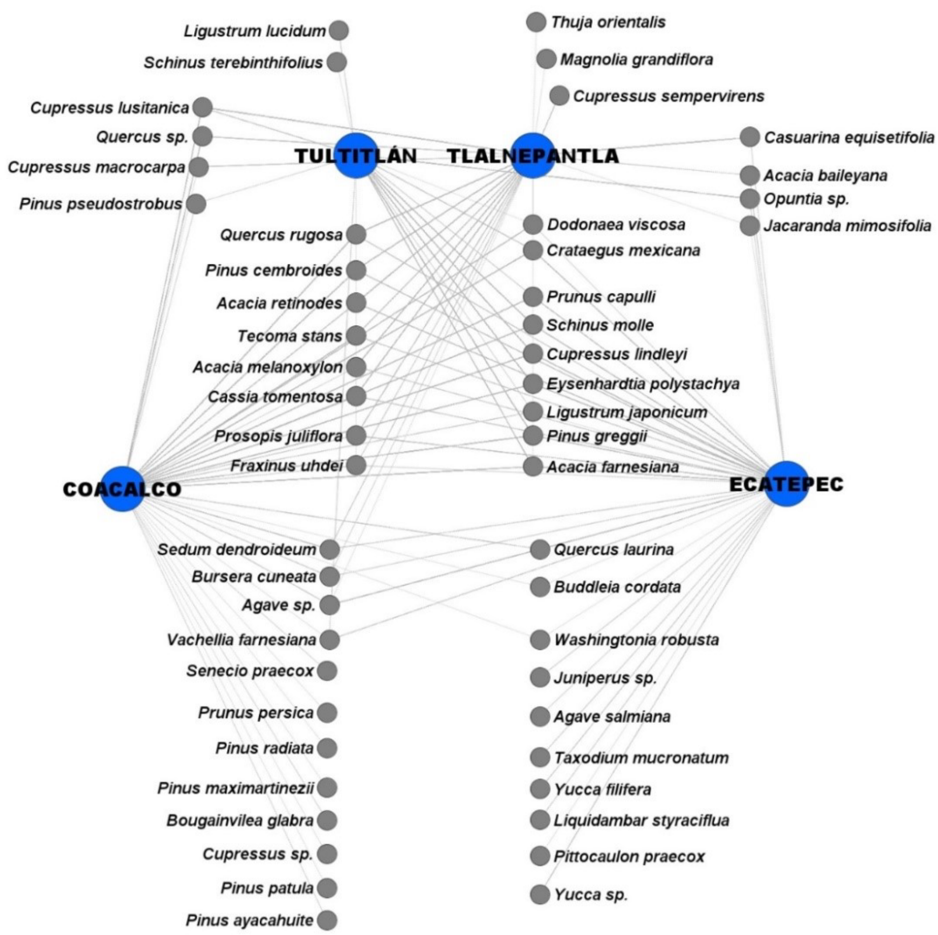
50 species were used to reforest the Sierra de Guadalupe in the State of Mexico, during the period 2009-2020: Silver wattle (*Acacia retinodes*), Bailey's wattle (*Acacia baileyana*), Australian Blackwood (*Acacia melanoxylon*), Montezuma bald cypress (*Taxodium mucronatum*), Bouganvilea (*Bougainvilea glabra*), Capulin (*Prunus capulli*), Coastal she-oak (*Casuarina equisetifolia*), Mexican cypress (*Cupressus lusitanica*), Monterey cypress (*Cupressus macrocarpa*), Broadleaf hopbush (*Dodonaea viscosa*), Cupressus (*Cupressus sp*.), Leyland Cupress (*Cupressus lindleyi*), Mediterranean cypress (*Cupressus sempervirens*), Copal (*Bursera cuneata*), Peach (*Prunus persica*), Oak (*Quercus sp.*), Netleaf oak (*Quercus rugosa*), Oak (*Quercus laurina*), Common juniper (*Juniperus sp.*), Evergreen ash (*Fraxinus uhdei*), Sweet acacia (*Acacia farnesiana*) (*Vachellia farnesiana*), Jacaranda (*Jacaranda mimosifolia*), Amercian sweetgum (*Liquidambar styraciflua*), Magnolia (*Magnolia grandiflora*), Maguey (*Agave sp.*), Maguey pulquero (*Agave salmiana*), Mezquite (*Prosopis juliflora*), Nopal (*Opuntia sp.*), Mexican fan palm (*Washingtonia robusta*), Kidneywood tree (*Eysenhardtia polystachya*), Broomstick tree (*Pittocaulon praecox*) (*Senecio praecox*), Big cone pinyon (*Pinus maximartinezii*), Mexican white pine (*Pinus ayacahuite*), Monterey pine (*Pinus radiata*), Smooth-bark Mexican pine (*Pinus pseudostrobus*), Mexican pinyon (*Pinus cembroides*), Gregg's pine (*Pinus greggii*), Mexican weeping pine (*Pinus patula*), False pepper tree (*Schinus molle*), Brazilian peppertree (*Schinus terebinthifolius*), Glandular senna (*Cassia tomentosa*) (*Senna multiglandulosa*), Stonecrop tree (*Sedum dendroideum*), Tejocote (*Crataegus mexicana*), Tepozán (*Buddleia cordata*), Tecoma stan*s* (*Tecoma stans*), Japanese privet (*Ligustrum japonicum*), Chinese privet (*Ligustrum lucidum*), Chinese thuja (*Thuja orientalis*), Yuca (*Yucca sp*.) and Yuca filfera (*Yucca filifera*) (CGCE, 2021b).

Coacalco and Tlalnepantla have used the largest number of these species in their reforestations, 36 and 35 respectively. However, of all the species used, only 15 are native: Capulin, Copal, Broadleaf hopbush, Cupressus, Leyland Cupress, Sweet acacia, Maguey, Maguey pulquero, Mesquite, Nopal, Kidneywood tree, Broomstick tree, Tejocote, Tepozan and Yellow elder (CGCE , 2021a). Furthermore, the species used in reforestation were not uniformly distributed; only 17 were established in the four municipalities:

Mimosa, Australian Blackwood, Capulin, Broadleaf hopbush, Leyland cypress, Netleaf oak, Evergreen ash, Sweet acacia, Mesquite, Kidneywood tree, Stone pine, Gregg's pine, False pepper, Retama broom, Tejocote, Tecoma stans and Japanese privet (Figure 6).

Network of social actors involved in reforestation

When analyzing the network of social actors involved in the reforestation process in the Sierra de Guadalupe, measurements of nodal degree centrality and degree of closeness were applied to assess the point of view of key social actors in the reforestation process. Regarding nodal degree, the City Councils of Coacalco, Ecatepec, Tlalnepantla and Tultitlán were the social actors with the greatest number of connections, with the process remaining constant during the 2009-2020 period. The point of view of staff from the General Coordination of Ecological Conservation (Park Rangers and staff members) is clear, because this is the institution in charge of managing and reporting on the Sierra de



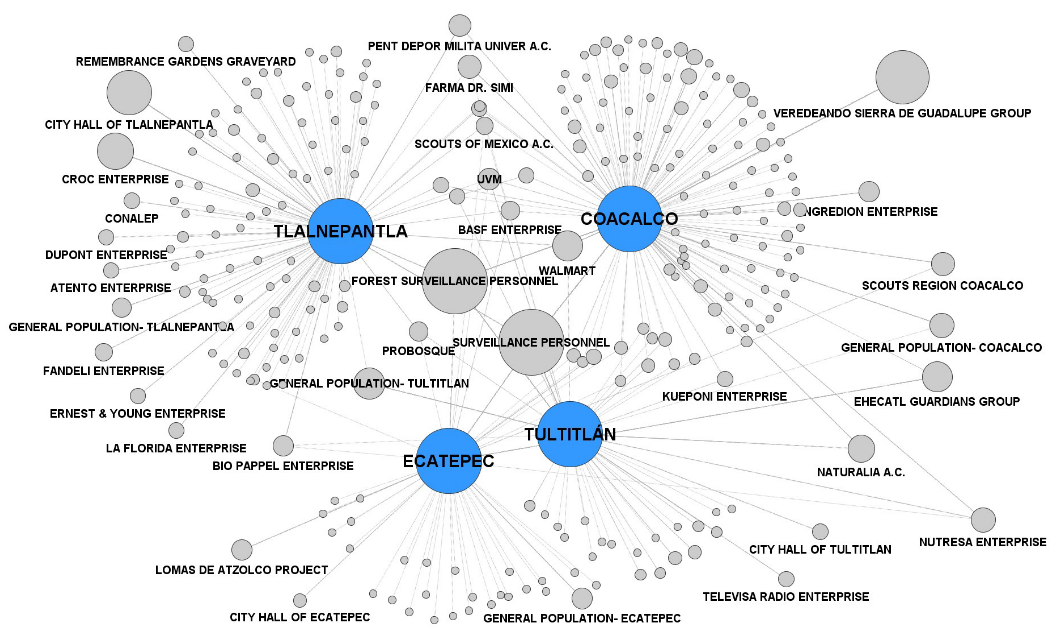
Source: self-elaborated in Visone® with data from (CGCE, 2021b).
Figure 6. Network of species used in reforestation of the Sierra de Guadalupe in the State of Mexico.

Guadalupe State Park Protected Natural Area. In this analysis, the prominence of social actors as companies is evident; however, their work is limited to the municipality where they are located: greatest participation was in Tlalnepantla and Coacalco. With respect to educational centers, the participation of secondary schools, high schools and universities is notable, although generally, they only participate for one or two consecutive years. Regarding the groups, the environmental group "Veredeando Sierra de Guadalupe" is prominent and has presence in Coacalco and Tultitlán, whereas "Guardianes del Ehécatl" is in Ecatepec and Coacalco (Figure 7).

Considering the degree of closeness, as well as the extent of power that each social actor has for influencing the network, the staff of the General Coordination of Ecological Conservation represent the most significant social actors; the park rangers. Then there are the collectives with certain relevance, for example, the environmental groups "Veredeando Sierra de Guadalupe", "Guardianes del Ehécatl" and the civil association FRANATURE (Figure 8).

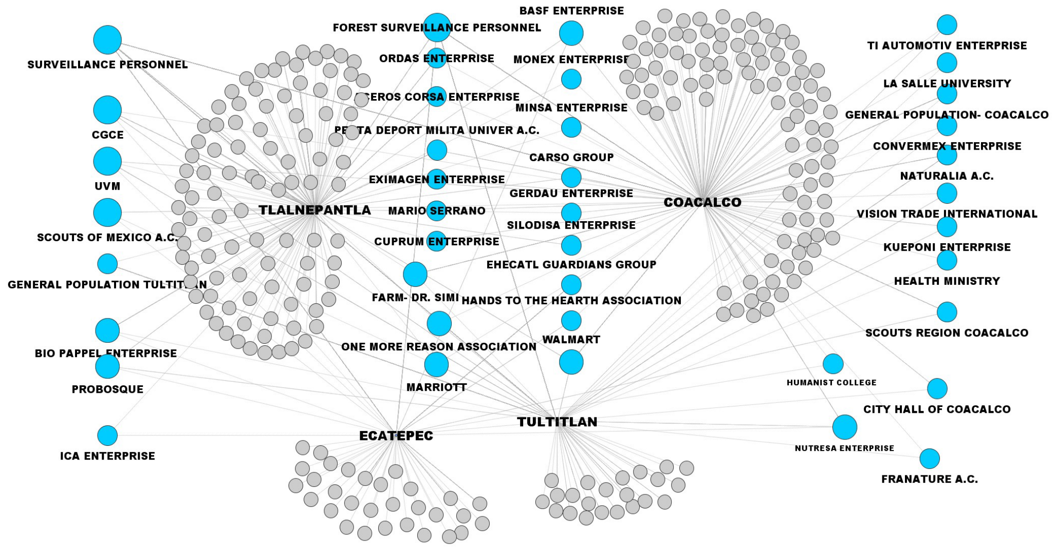
DISCUSSION

The social actors who have participated in the reforestation process of the Sierra de Guadalupe in the State of Mexico are heterogeneously distributed throughout the four municipalities; although there was greater participation of social actors from Coacalco, and likewise there is greater diversity of social actors from here, who have participated in



Source: self-elaborated in Visone® with data from (CGCE, 2021b).

Figure 7. Nodal degree network of social actors involved in the reforestation of the Sierra de Guadalupe in the State of Mexico.



Source: self-elaborated in Visone® with data from (CGCE, 2021b).

Figure 8. Network for degree of closeness of the social actors involved in the reforestation of the Sierra de Guadalupe in the State of Mexico.

the three remaining municipalities of the mountain range. Coacalco and Tultitlán share the largest number of social actors who have participated in two municipalities, implying that this is due to the fact that they share territorial borders. The tendency to participate in reforestation in more than one of the municipalities, predominantly concerns social actors from public institutions, and on occasion a number of companies, although the overall population from each municipality does not participate; this may be due to the fact that attending reforestation in a neighboring or more distant municipality involves more economic resources and time. Thus, an alternative, which might encourage a greater number of social actors to care for the Sierra de Guadalupe, would be to invite them to participate in reforestation near the town where they live.

There is differential concentration of resources for the care of the mountains in each of the municipalities; it might be contended that this phenomenon is governed by the proportion of the Sierra de Guadalupe State Park Protected Natural Area that is located in each municipality; the greater number of hectares, the greater the number of social actors and species used to reforest the area; but this is not the case. Ecatepec has the largest proportion of mountainous territory (34.7%), followed by Coacalco (23.5%), Tlalnepantla (23.1%) and Tultitlán (18.7%) (CGCE, 2021a). However, these proportions do not correspond to the reforested area per municipality: in Coacalco this was 165.9 hectares, contrasting with Ecatepec with 36.1 hectares. This indicates that care of the mountains through reforestation processes does not depend on the extent or damage, but on the way in which social actors organize themselves to carry out this activity, as well as the type of resources that they have for this. For example, one of the limitations of reforestation strategies is that the propagation of species in nurseries for reforestation is limited to only a small range of native species (CONABIO, 2020), usually the most commercial ones.

Analysis of social networks enables certain understanding and explanation of the problems concerning the management and diversity of resources (Calvet-Mir and Salpeteur, 2016). Similarly, considering the number of species used for reforestation of the mountain range by municipality, notably, diversity manifests a weak structure, because a greater number of species does not create a more biodiverse network, but rather a network made up of the indiscriminate use of species, without being a program based on the needs and characteristics of the ecosystem. Of the 17 common species that were established in the reforestations in Coacalco, Ecatepec, Tlalnepantla and Tultitlán, only seven are native to the mountains (broadleaf hopbush, Mexican cupressus, sweet acacia, mesquite, kidneywood tree, tejocote and tecoma stans), so these might be priority species for propagation and establishment in reforestation areas in the Sierra de Guadalupe.

In fact, it would be pertinent to analyze the benefits that these species can provide for the restoration of ecosystems in the mountains: sweet acacia and mesquite adapt to degraded, saline and compacted soils, and they also have the capacity to improve soil fertility due to their association with nitrogen-fixing bacteria (CONAFOR, 2023a; CONAFOR, 2023d). Broadleaf hopbush, kidneywood tree and tejocote, have the capacity to develop in eroded soils and adapt to terrain with steep slopes (CONAFOR, 2023c; CONABIO, 2023; CONAFOR, 2023b). Mexican cupressus contributes to the infiltration of water into aquifers and when the tree is adult, it is tolerant to droughts, frosts and environmental pollution (CONAFOR, 2023e). Likewise tecoma stans is a useful species for soil restoration, due to the dense root system it develops (Becerril-Navarrete *et al*., 2022).

In the analysis of degree of closeness, the City Councils of Coacalco, Ecatepec, Tlalnepantla and Tultitlán are organizations that do not stand out for their communication dynamics with the population, which is a critical point and possible subject for exploration. Due to their proximity to the population (compared to the state and federal government), these social actors could exercise their power to convoke in order to establish more assertive reforestation campaigns that are easily accessible to the population in each municipality.

The behavior of this social network could be defined as centralized, with predominant presence on the part of public bodies, followed by some environmental groups that reiterate their participation in municipalities that share territorial borders. According to Matous and Todo (2015), networks with a centralized structure can be reinforced, if the predominant social actors share positive experiences of their activities with other members on the network. Thus, the implication is that the conservation of the Sierra de Guadalupe could have more homogeneous and widespread management, if the social actors involved share the results of their experiences and strategies with others.

CONCLUSIONS

Reforestation processes are organized and carried out in diverse communities, using a variety of inputs and species and bringing together different social actors, which allows them to be scrutinized with structural tools, such as social network analysis. In the case of the Sierra de Guadalupe in the State of Mexico, the main interconnecting component was the species used in reforestation in the municipalities of Coacalco, Ecatepec, Tlalnepantla and Tultitlán, while recognizing the social actors involved and the prominence they assume in the process, which depends on recurrence and/or diversification in the localities of one or more municipalities. Additionally, a concentration of resources was observed in Coacalco. The above made it possible to identify deficiencies in the reforestation process itself, which has not created homogeneous management of the territory of the Sierra de Guadalupe in the State of Mexico.

This analysis enabled us to identify a forest resource in better condition in Coacalco, because constant reforestation processes have been maintained and has suffered less forest fires. This municipality could represent a resource management model in reforestation for the neighboring municipalities and make possible more assertive management of the mountainous territory. We should keep in mind that the efficient management of natural resources should not be bound by territorial borders and that a successful program for the preservation of the mountains and maintain the environmental services it provides, requires the combined efforts of the public and private actors from each of the municipalities.

In order to increase citizen participation, the City Councils of Coacalco, Ecatepec, Tlalnepantla and Tultitlán could play an active role as relevant social actors in the reforestation process of the mountains, as they have significant power to convoke citizens and could organize reforestation campaigns with greater assistance from communities near the mountains.

The establishment of mutual cooperation and support for the care of the Sierra de Guadalupe by public organizations by means of reforestation, requires defining which species should be used. It is imperative to increase the production of native species from the mountains and dispense with the exotic species that have been used in recent years. An alternative would be to considerably increase the production of the seven native species that have already established themselves in the four municipalities of the State of Mexico, where the Sierra de Guadalupe is located.

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