Livestock in the sustainability of changing livelihoods in high mountain communities in a Natural Protected Area in Central Mexico

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ABSTRACT

Objective: Livelihoods of communities within the high mountain Natural Protected Area for Flora and Fauna 'Nevado de Toluca' (NPAFFNT) in the central highlands of Mexico have changed due to statuary limitations established in management program respect to agro-silvopastoral activities. In these communities, the small scale farmers who still rely on livestock, mainly sheep production. There is no knowledge on the sustainability, strengths and weaknesses of these systems and the influence of seasons in this area of marked bioclimatic seasonality.

Methodology: The IDEA method to assess sustainability was applied in a small village within NPAFFNT in the dry as in the rainy season.

Results: Sustainability is limited by the economic scale while their main strengths were in the agroecological scale in both seasons. Indicators show deficiencies in farmer education, lack of technical assistance, poor local infrastructures, lack of access to institutional support programmes, and the revision of norms for the natural protected area.

Conclusions and implications: Results are useful for improving the sustainability of these systems that may improve que quality of life of high-mountain communities and provide ecosystemic services relevant for society. Diversification of income sources are of needed given the limitations that the new statute create on livestock and agricultural activities. It is advisable to increase the educational level of the inhabitants and farmers receive specialized technical training in agricultural and sustainable livestock production.

Keywords: Sustainability; seasonality; IDEA method; high mountain systems; indicators.

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INTRODUCTION

The future of society is jeopardized by patterns of consumption and exploitation of natural resources that threaten the diversity and resilience of human communities and the ecosystems they inhabit. Therefore, there is a need to redirect production systems and livelihoods towards more sustainable strategies (FAO, 2018).

The relationships between the agricultural field and the environment in mountainous territories are usually approached from the point of view that the negative effects that may occur due to these practices affect natural resources as little as possible, allowing sustainable use to be given to these on the part of the population, especially those who are dedicated to livestock, taking charge of giving an adequate use to the grasslands that are destined for grazing to protect the biodiversity in this type of areas (Lasseur, 2005).

Mountain agricultural systems are characterized by their biological diversity, in addition, they are considered as forms of family livelihood conditioned mainly by the scarcity of arable land and the difficulties of access to such territories (Martínez y Rosser, 2012; Kohler Y Romeo, 2014); these are generally dynamic and imbalances occur over time, given by the interactions that pass between each of its components (Calvente, 2007); allowing them to be sustainable but not stable, since they are in a construction process that is based on past experiences and future projections (Fuentes y Marchant, 2016). Under those high mountain conditions, some crops and livestock rearing constitute the basis for the livelihoods and subsistence of those communities (Lasanta, 2010), who at the same time exert a strong activity that shapes rural landscapes (González *et al.*, 2019). Among mountain territories, there is a special interest in the development sustainable livestock strategies for those systems located in protected areas, because there the objectives for the use of natural resources must be strongly aligned to the parallel efforts of environmental conservation. A mountain natural protected zone with singular characteristics is the Natural Protected Area for Flora and Fauna 'Nevado de Toluca' (NPAFFNT) in the central highlands of Mexico, since it not only holds an important natural heritage, but has moved from the status of National Park decreed in 1936 to that of a protected natural area in 2013 (CONANP, 2013), with the objective of conciliating the socio-economic interests of communities living within the area, and the environmental protection objective (Lasanta,2010; González *et al.*, 2019).

The volcano 'Nevado de Toluca' (Snowed Mountain of Toluca) or *Xinantecatl* in the native nahuatl language, is the fourth highest peak in Mexico at an altitude of 4,660 m, and the protected area comprises 53,590 ha of which 1,941 ha are the totally protected nucleus and 51,649 ha comprise the buffer zone, where 16 small rural villages are located with a population of 5,297 people live (CONANP, 2016).

A source of knowledge on the current situation and the evolution of the natural and cultural heritage are the local communities since they possess the ecological knowledge of their surroundings from their experience and adaptation to optimize the use of natural resources. This knowledge enables the inhabitants of the area to valorise changes from a holistic perspective attending socioeconomic and environmental components, as well as identifying causes for those changes and possible consequences (CONANP, 2016).

However, local ecological knowledge needs to be considered in actual times has received little attention by the scientific community, in spite of its potential to implement strategies better adapted to local conditions (Santana, 2012) and better valued by communities who inhabit those areas (Caro-Borrero *et al.*, 2017).

Several authors have analyzed the main factors that may jeopardize the sustainability of livestock rearing in Mexico (Fadul-Pacheco *et al.*, 2013; Salas-Reyes *et al.*, 2015; Vences *et al.*, 2015; Prospero *et al.*, 2017) and in NPAFFNT (Granados *et al.*, 2018; Santana, 2012; Santana-Medina *et al.*, 2013; Endara *et al.*, 2012).

However, available information on sustainable strategies to solve the challenges in this protected natural area is scarce, and not from a holistic assessment of current productive systems considering environmental, socioeconomic, and cultural factors including governance; and that integrates both scientific as well as local ecological knowledge.

The NPAFFNT represents a challenge for human settlements that have lived within the area for around a hundred years. The area was initially established as a national park in 1936, and although formally there should be no human settlements within the park, many small villages founded before the decree of national park remained. Their livelihoods were linked to a silvopastoral system based mainly on sheep rearing and some cattle that used to be grazed in the forest and in openings in the forest, complemented with crop residues during the dry season.

However, in 2013 the statute of the area changed and became a Natural Protected Area of Flora and Fauna, that enables human settlements within the buffer zone, and several productive activities as cropping, livestock rearing, and forestry, although with a strictly enforced new statute limiting many of these activities. Grazing has been banned in most of the forested area, severely limiting the traditional activities of the silvopastoral systems.

The objective was to assess the sustainability of the farms in a community located within the NPAFFNT that live under the new statute, in order to identify strengths and weaknesses, and if these are limited by season of the year. The objective was met by an integrated analysis of information from a battery of sustainability indicators together with that derived from de local ecological knowledge of the people that inhabit the area.

MATERIALS AND METHODS

Study area

Work was undertaken in the village of Agua Blanca (19° 04' 45" N and 99° 50' 25" W) in the municipality of Zinacantepec in the State of Mexico in the central highlands of the country. Altitude is 3200 m, and the village is located in the buffer zone, at 6.5 km from the nucleus protected area. Predominant climate is sub-humid semi-cold, with mean annual rainfall of 1300 mm and mean annual temperature of 12 °C (INEGI, 2018). The town is integrated with 17 family units. The grasslands have some grasses such as *Vulpia myuros* (L.) C. C. Gmel, *Nassella mucronata* (Kunth) Pohl, *Trisetum spicatum* (L.) K. Richt and *Muhlenbergia* sp.; there are also some species like *Astragalus tolucanus* Rob. & Seaton, *Cuphea procumbens* Ort., *Prunella vulgaris* L., *Salvia reptans* Jacq., *Loranthus greenm* (Jack) and *Senecio angulifolius* DC. (Martínez *et al.*, 2018).

Collection of information

Collection of information followed the case study methodology (Yin, 2018) in terms of agrosilvopastoral activities. The assessment of sustainability was from December 2017 to November 2018. All 17 families were invited to participate in the study. All households kept animals. All of them kept sheep as the main livestock species in these high mountain systems, and most keep poultry and some also kept cattle. Eventually, only 13 households accepted to participate in the study during the whole year. Despite new restrictions brought about by the new statute as a natural protected area, families keep relying on livestock, mainly sheep, as the basis for their livelihoods.

Farmers do not keep any records, so information was collected through monthly visits when semi-structured questionnaires were applied to collect detailed information of the family activities; which included the sowing of seasonal crops, such as oat (*Avena sativa* L.) and wild edible plants (*Chenopodium* spp. and *Amaranthus* spp.), sheep farming is practiced in extensive production systems, made up of common areas, paddocks and farmland. Another important activity is the collection of wild mushrooms in the forest in the rainy season, which are marketed in local tianguis, firewood is also collected which is used to cook their food. Another way to obtain income is that some heads of families are dedicated to construction worker or work as day laborers inside or outside the community.

Sustainability assessment

The IDEA method (Indicateurs de durabilité des exploitations agricoles) version 3.0 was used. The method enables the integral assessment of the sustainability at farm level through 42 indicators grouped in 10 components that comprise the three scales of sustainability: (agro-ecological, socio territorial, and economic (Zahm *et al.*, 2008; Vilain *et al.*, 2008).

The IDEA method establishes a scoring scale that goes from 0 to 100 to evaluate the sustainability of each the indicators that comprise it; the scale with the lowest score identified as the limiting scale for the overall sustainability scales (Vilain *et al.*, 2008). The method had to be adapted to local conditions before it could be applied, due to the difference between the original context of French agroecosystems and the study area (NPAFFNT) as a protected natural area (Table 1).

The study area does have a marked bioclimatic seasonality, with well-defined rainy (May to October) and dry (November to April) seasons (Figure 1), that may determine how farming systems function and the timing of activities. Therefore, information was collected and analysed for each season.

Statistical analysis

For analysis of scores of agroecological, socio-territorial and economic scale, the indicators were separated and grouped. Subsequently, the indicators were selected for each of criteria. The results of rainy and dry conditions for each of the criteria were analyzed through a chi square test ($P<0.05$).

Table 1. Summary of modified indicators to assess sustainability in Agua Blanca.

Scale	Component		Indicators
Agroecological	Organization of space	A9	Assessed according to the management plan for Natural Protected Areas (CONANP, 2016).
	Farming Practice	A15	The score was changed to 0-6 points, penalizing self-diagnostics and the application of treatments without veterinary advice, as well as lack of records.
	Quality of products and the land	B1	It was following state norms (40), with 3 pints if protected denomination of origin or green label.
Socio-territorial	Employment and services	B8	It was considered as services to the community (common work, road and water spring maintenance)
	Ethics and human development	B14	It was scored according to schooling of farmer. 0 = no schooling, 1 = primary education, 2 = secondary education, 3 = high school, and 4 = Children with university education.
Economic	Viability	C1	Assessed by Benefit/Cost Ratio (BCE) (22), and not in terms of minimum wage.

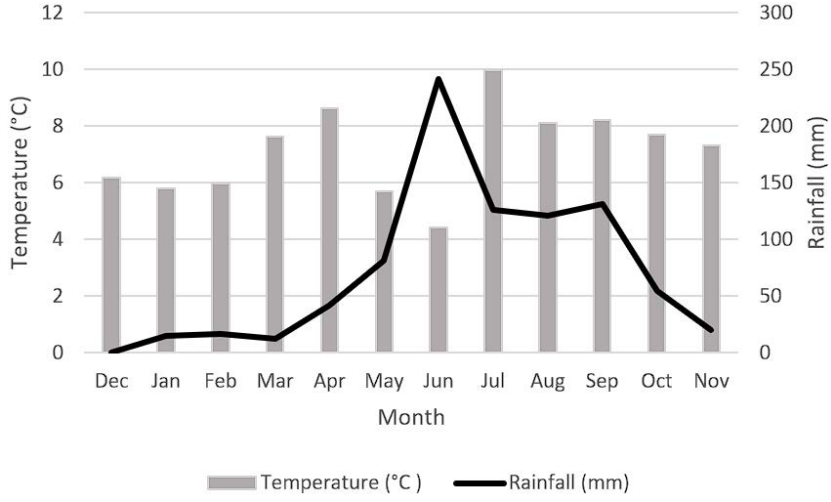

Figure 1. Temperature (°C) and rainfall (mm) since December 2017 to November 2018 (Fuente: CONAGUA, 2015).

RESULTS AND DISCUSSION

Although the total area for the village of Agua Blanca is 2,820 ha of pine (mainly *Pinus hartwegii*) - fir (*Abies religiosa*) forest, that used to be grazed by flocks and herds of the community, the area destined by the new statute for NPAFFNT to the village of Agua Blanca is only 48.5 ha for houses, crops, and livestock rearing with strict norms in place limiting the access of the community livestock to areas outside the village. Therefore, farms are very small, from 0.6 to 6.1 ha where 61% of land is destined for cropping maize and faba beans (*Vicia faba*) for self-consumption, and oats (and straws from maize and faba beans) as forage for livestock.

Grazing has been banned from most of the forest areas in the remaining 2,771.5 ha, so that the traditional silvopastoral management has been severely limited. Families can undertake approved activities in the forest area, mainly the collection and sale of wild mushrooms that are an important source of complementary income in the rainy season (Martínez *et al.*, 2019); but the ban on grazing has meant a need to reorganize their activities, although livestock rearing is still the basis of their livelihoods.

Table 2 shows the animal inventories of the 13 participating farms, who raised a total of 241 sheep, 30 cattle, and 156 diverse poultry (chickens, turkeys and one farm had quails). Sheep is the basis of the livestock system, although two farms sold their sheep during the study to meet economic needs. One farm also had one goat, and one farm kept one pig, but these species are not common in these high mountain systems.

The sheep are grazed during the day in pastures close to the family unit, in the dry season they are grazed inside the forest, an average of four and up to 7 hours a day. They are housed overnight in pens that are made with material from the region. Sometimes supplements such as tequesquite (mineral salts) or oatmeal are provided, in dry season, if they have economic resources to acquire them. Families in Agua Blanca have had to reorganise their livelihoods since they are now unable to graze their livestock outside the village boundaries imposed by the new statute.

The overall sustainability assessment for the three scales of the 13 farms is shown in Table 3 for both seasons. In the dry season, the economic scale with a score of 49 points determines the sustainability, having a large seasonal variation since the score for the economical scale was 74 in the rainy season. It is the socio-territorial scale that limits sustainability in the rainy season with a score of 59 points. The agroecological scale had the highest scores similar in both seasons with 79 in the dry season, and 82 points in the rainy season (Table 3).

Table 4 shown the scores obtained for each of the indicators belonging to the agroecological scale. It was possible to observe the strengths in the agricultural management practices that the inhabitants have, which are stable in both seasons, this was measured

Table 2. Animal inventories for 13 participating farms.

	Farm													
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Total**
Sheep	6	35	21	13	60	2	0	24	50	0	6	4	20	241
Cattle	0	0	0	1	11	0	0	0	7	0	0	0	11	30
Poultry	1	7	12	7	15	16	2	0	7	5	13	51	20	156

Table 3. Sustainability score by three scales per season.

Scale	**Season**		**Maximum possible score**
	Dry	**Rainy**	
Agroecological	79	82	100
Socio-territorial	60	59	100
Economic	49	74	100

Table 4. Scores for the agroecological scale of the locality Agua Blanca per season.

		Score		Maximum possible score	P<0.05
		Dry	Rainy		
Diversity	**Sub-total**	**25**	**25**	**48**	**7.81***
Diversity of annual and temporary crops	A1	2	2	14	
Diversity of perennial crops	A2	6	6	14	
Animal Diversity	A3	14	14	14	
Valorization and conservation of genetic resources	A4	3	3	6	
Organization of space	**Sub-total**	**21**	**24**	**43**	**12.59***
Crop rotation	A5	0	3	8	
Dimension of fields	A6	6	6	6	
Management of organic waste	A7	3	3	5	
Ecological buffer zones	A8	7	7	12	
Contribution to environmental issues of the territory	A9	1	1	4	
Improvement of the space	A10	2	2	5	
Fodder area management	A11	2	3	3	
Farming practices	**Sub-total**	**33**	**33**	**46**	**12.59***
Fertilization	A12	6	8	8	
Manure management	A13	3	3	3	
Pesticides	A14	11	10	13	
Veterinary products	A15	0	0	3	
Soil resource protection	A16	5	5	5	
Water resource management	A17	4	4	4	
Energy independence	A18	4	3	10	
Total		**79**	**82**	**137**	

through fertilization, which presented a slight increase in the rainy season, and the use of pesticides that is also bigger at the same season. The water management as a natural resource and the protection given to the soil to prevent its loss due to erosion and the management of manure in the production unit (indicators A12 to A18).

At the same scale, low values were found for the diversity of crops (A1 and A2) since oats and some edible plants are planted only in some production units. Crop rotation does not occur in the locality, nor does the veterinary management of livestock (A9 and A15), which is within this scale because it is the producers themselves who take care of their animals and sometimes, they self-medicate their animals. The statistical analysis showed significant differences between seasons ($p<0.05$).

The results obtained from the indicators of the socio-territorial scale are presented in Table 5. According to the quality of the products and the land, very homogeneous values were presented between seasons, importance is given to the use and management of manure, access to the spaces that make up the territory and the involvement of the inhabitants in the different social issues of the community (B1 to B5) which gave a total of

22 points at the time of rainy season and 21 points in the dry season; however, they only represent 60% of the total maximum points to be obtained in these indicators of the IDEA method. Among these indicators are areas for improvement which are related to manure management and accessibility to all spaces belonging to the locality that may be important for the inhabitants since they can be a way of obtaining extra income for the family.

Regarding the indicators related to employment and services in the locality (B6 to BII) where reference is made above all to the trade of products that takes place between localities (tianguis), to collective work, which gives way to self-employment and the improvement of sheep farming, sustainability in each of the production units and the way in which the inhabitants value the natural resources they have. The use of these resources is mainly intended for the houses building, (B18) although these are generally with dirt floors and have very few services, which is similar in the houses of almost the entire town.

In relation to indicators related to ethics and human development, scores were around 50% of maximum possible scores, although with important differences among indicators and between seasons, observing a 14% decrease in scores in the rainy season. Variations ranged from high scores for isolation (B17) to a null score for intensity of work (B15) and training and education (B14). The indicator on reliance of purchased concentrates (B12) also showed a large inter-seasonal variation with a higher dependence of purchased feeds in the dry season and lower in the rainy season, due to the low availability of forage in the forest in the dry season.

There are two indicators that may clearly be improved: animal welfare (B13) and training and education (B14). Significative differences were observed ($P<0.05$) among the criteria of the socio-territorial scale.

Incomes in the economic scale were from the sale of livestock (mainly sheep), manure (in the dry season), and wild mushrooms (in the rainy season). Some families have started to provide services to tourists, as eco-tourism is promoted as means to generate incomes and wellbeing in these poor mountain communities. One family rented a place to spend the night, and one family prepared and sold meals to visitors, although this activity is very incipient as Agua Blanca is away from the main areas visited by tourists and hikers.

Indicators for the economic scale showed large variation between seasons (Table 6). Indicators for economic viability were particularly low in the dry season (only 12 of 30 possible points), that increase in the rainy season (19 points). The indicator for transmissibility (C5) is slightly higher with 13 out of 20 possible points. Significative differences were observed ($P<0.05$) among the criteria of the economic scale.

Arriaga-Jordán *et al.* (2005) documented the livestock agrodiversity of small-holder *campesino* farms on hill-slope indigenous agricultural communities of the highlands, and the importance that livestock rearing has in the survival of these families. Hence the importance of evaluation in a high mountain area as in this case where sustainability dependent on the season, limited strongly by the economic scale (mainly in the dry season), with the socio-territorial scale limiting sustainability in the rainy season. The strengths of the system are in the agroecological scale.

These results are like those obtained in specialized market oriented small-scale dairy systems in temperate agricultural valleys (Fadul-Pacheco *et al.*, 2013; Prospero *et al.*, 2017),

Table 5. Scores for the socio-territorial scale of the locality Agua Blanca.

		Score		Maximum possible score	P<0.05
		Dry	Rainy		
Quality of the products and the land	**Sub-total**	**22**	**21**	**34**	**9.49***
Quality of manure	B1	7	7	10	
Enhancement of buildings and landscape heritage	B2	6	5	8	
Inorganic waste management	B3	2	2	5	
Space accessibility	B4	2	2	5	
Social involvement	B5	5	5	6	
Employment and services	**Sub-total**	**27**	**27**	**36**	**11.07***
Short trade	B6	7	7	7	
Autonomy and enhancement of local resources	B7	8	8	10	
Services, multi-activities	B8	5	5	5	
Contribution to employment	B9	3	3	6	
Collective work	B10	1	1	5	
Probable farm sustainability	B11	3	3	3	
Ethics and human development	**Sub-total**	**11**	**11**	**39**	**12.59***
Dependence on commercial concentrates	B12	0	1	10	
Animal welfare	B13	1	1	3	
Training-education	B14	2	1	6	
Labour intensity	B15	0	0	7	
Quality of life	B16	4	4	6	
Isolation	B17	3	3	3	
Quality of buildings	B18	1	1	4	
Total		**60**	**59**	**109**	

Table 6. Scores for the economic scale of the locality Agua Blanca.

		Score		Maximum possible score	P<0.05
		Dry	Rainy		
Viability	**Sub-total**	**12**	**19**	**30**	**3.84***
Economic viability	C1	2	9	20	
Economic specialization rate	C2	10	10	10	
Independence	**Sub-total**	**19**	**19**	**25**	**3.84***
Financial autonomy	C3	12	12	15	
Sensibility to government subsidies	C4	7	7	10	
Transferability and efficiency	**Sub-total**	**18**	**36**	**45**	**3.84***
Transferability	C5	13	13	20	
Efficiency of the productive process	C6	5	23	25	
Total		**49**	**74**	**100**	

as well as in dual-purpose silvopastoral cattle systems in sub-tropical areas (Salas-Reyes *et al.*, 2015; Vences *et al.*, 2015).

Scores obtained in the agroecological and socio-territorial scales in this study are higher than findings by Fadul-Pacheco *et al.* (Fadul-Pacheco *et al.*, 2013) in small-scale dairy systems in temperate agricultural valleys, or by Vences-Pérez *et al.* (2015). Higher agroecological scores herein reported may be since the studied farms are within a natural forested area in a silvopastoral system based on mainly sheep production that makes use of the natural vegetation of the area. Ross *et al.* (2016) found that resource economy and the ecological impacts of sheep grazing, showing that sustainability boundaries are most likely to be exceeded in fragile environments.

Currently, there is great interest in agrosilvopastoral systems that include livestock in ecosystems that integrate crops, grasses, shrubs and trees that offer a range of resources, and at the same time provide important environmental services (Godinho *et al.*, 2018). Agrosilvopastoral management enable multifunctional and more productive systems than if the activities they include were independent as in monocultures (Albarrán-Portillo *et al.*, 2019). Despite these benefits, it should be considered that this study was carried out within a protected natural area and agrosilvopastoral activity is restricted to limited areas.

Studies with sheep production in Morocco confirm higher sustainability scores for extensive and agro-silvopastoral systems, that showed higher strengths in the agroecological scale and the use of local breeds, as well as weakness in the economic scale (Araba and Boughalmi, 2016).

The high socre in animal diversity (A3) is because, although sheep is the dominant species, there are other domestic animal species in the farms as cattle, poulty (with one farm raising Japanese quails), (Table 2). Multispecies livestock systems enable a more efficient use of natural resources, particularly in comples agro-silvopastoral systems characterised by a range of varied resources (from crop residues to forest biomass) that may be valorised by the diverse selection of diets and grazing behaviour of different species (Fraser and Rosa, 2018).

In this study, the different stratified use of areas was observed in the height of grazed vegetation, such that sheep grazed the lower strata, while cattle the higher stratum. In the area, sheep consume at least six different plant species (Esquivel y Estrada, 2014).

It is the agrobiodiversity of both plant and animal species linked to agrosilvopastoral systems that may contribute to food self-sufficiency and productive diversification in farms that need to improve on the economic scale for which management options must be developed (Ochoa *et al.*, 2009), for example improving feeding systems and animal health.

Low scores for the cropping indicators (A1, A2, and A3) reflect the little crop production in the studied village, where families till an average of 0.11 ha of a limited number of plant species with low yields (Piñar, 2001; Méndez, 2021). Inter-season variability may be due to the presence and intensity of frosts, as well as by rainfall which is dependent on geographic latitude (Herrera *et al.*, 2015), which limits the possibility of crops in the dry season. Only one farmer sowed oats (*Avena sativa*) as forage, and faba beans (*Vicia faba*) for self consumption in the dry season, whilst in the rainy season most farmers sowed oats for

forage, and maize and faba beans for their family. Straw and residueds from these latter two are fed to livestock.

The indicator for the contribution to the environmental challenges (A9) is determined by the statute on the use and management of the protected area, in terms of approved activities in the two zones in the area according to the management plan of NPAFFNT (CONANP, 2016).

As mentioned, the area for agricultural activities is now severly limited to the 48.5 ha of the village, with most of the other land set off-limits to grazing in order to protect the forest since work previous to the change of statute from national park to natural protected area identified grazing and uncrontrolled fires (many due to burning grassland to promote regrowth) as two factors, together with illegal loging, that were hampering the renewal and conservation of the forests in the area (Endara *et al.*, 2012).

Now farmers have to face for the seasonality of available feed resources, and the low productivity of forages, particularly in the dry season (Martínez *et al.*, 2018), coupled with the very low land endowment per farm (1.3 ha on average). Extensive grazing in the forest is now banned and authorities promote confined rearing of their livestock even though these families have subsisted and come from a grazing tradition. According to the current statute, confining livestock could increase the risk of environmental damages from a high livestock density.

The statute for the NPAFFNT fails in its soecioeconomic objectives of providing sustainable livelihoods for communities that live within the area by severely limiting the size and growth possibilities of farms. There is no possibility of intensifying livestock rearing under total confinement as proposed, since that would require forage cropping which is not possible given the very small land endowment for crops in each farm, the low education and training level of farmers, and the impossibility to open new lands to cropping. In addition, the farmers do not agree on the confinement of the livestock.

It therefore calls for a revision of the current statute in order to take into consideration the activities and needs of the people in these communties, designing conservation strategies within the social context and the distribution of natural resources in time and space. The need for this revision has been pointed out by other authors (Santana-Medina *et al.*, 2013) that show the dire circumstances faced by the inhabitants in terms of pollution, lack of health services, transport, low levels of community participation, problems with animal health (Méndez, 2021), lack of secondary schools for children, and limited possibilities for income generation or employment.

Recent studies (Granados *et al.*, 2018) have highlighted these circunstances and show that the change in statute from national park to natural protected area have meant little changes in the poverty conditions of the people.

As observed by Santana-Medina *et al.* (Santana-Medina *et al.*, 2013), there is little management of animal health (A15) and veterinary assistance to farmers, although almost 50% vaccinate and 75% de-wormed their livestock. Survival rates of lambs are low (48%) and the incidence of respiratory problems is high 47.5% (Maldonado-Ferrucho *et al.*, 2014). Isolation, difficult access, and poor dirt roads limit the technical assistance farmers get, who treat their livestock with their own resources and from their experience. Animal health

issues linked to poor farm management and preventive strategies in poor communities is a worldwide problem that limits the prospects of a sustainable livestock production.

In regards to the socio-territorial scale, in terms of quality of products and the land, there were low scores in the management of inorganic residues (B3), since villagers just burn or bury their inorganic rubbish. Low scores for accesibility of space (B4) highlights the need to improve roads in the area.

High scores were obtained in the indicator on manure quality (B1), since farmers value sheep manure as the best organic fertiliser compared to manure from other species. This is local knowledge from observation, that coincides with what is established in the State standards for organic soil ammendments, reaffirming the role of traditional local knowledge in the development of sustainable systems (NTE-006-SMA-RS-2006).

Sheep manure is fundamental not only to improve soil fertility and fertilise crops, but for income generation through its sale, within a diversified subsistence economy that combines the sale of seasonal products as manure which is sold in the dry season, and wild mushrooms that are sold in the rainy season, toghether with livestock sales year round.

Among other items related to the conservation of their forests, and set in a participatory community action plan local, villagers mentioned the importance of wild animals for the environment, the provision of firewood for their households, the sale of wild mushrooms as an important source of income, and the collection of moss, sold by some young members of the community in December for Christmas decorations (Santana-Medina *et al.*, 2013).

Another indicator with high scores is related to short trade chains (B6), since the sale of their products is directly to consumers (mushrooms and manure) or to local diners and small roadside restaurants who sell lamb and mutton dishes (Martínez *et al.*, 2019). The obtaines score agrees with reports by Salas-Reyes *et al.* (Salas-Reyes *et al.*, 2015) in dual purpose cattle farms, and related to the low number of links in the trade chain of their produce.

The contribution to employment (B9) and collective work (B10) indicators are areas of improvement. The medium score for contribution to imployment (indicator B9 with 3 points out of 6) relates to the possibility of families to obtain a subsistence livelihood from their small farms and small flocks, although through precarious incomes. As is typical of smallholder farms in Mexico (Posadas-Domínguez *et al.*, 2014), studied farms rely on family labour.

In terms of collective work (B10), there is a tradition in Mexican rural communities to collaborate in work with other members of the community, be it in common tasks (*i.e.* road maintenance) or helping neighbours and family members on specific chores like harvest where help is rotated among participants (Ruíz, 2011; Vizcarra *et al.*, 2013). However, there was a low level of collective work in Agua Blanca, due to strong individualism that limits the potential for the development of productive activities and the capacity of local communities to defend their rights and preserve their cultural heritage (Santana-Medina *et al.*, 2013).

There is a high dependance on purchased concentrates and feeds for livestock (B12) with a strong seasonal variation, with high requirements of external inputs in the dry season. The ban on grazing in the forests has increase the need for purchased feeds.

The low scores in the economic scale, and the strong seasonal variation, are due to low scores in economic viability (C1) and productive efficiency (C6), closely related to the seasonal availability of forage resources. Sheep sales are the main source of income and essential for the family economy as a factor of financial security (Hernández-Valenzuela *et al.*, 2019).

Indicators for economic independence (C3 and C4) did not show seasonal variation, and although high scores according to the IDEA method, they mask the real precarious situation of poverty of households. The indicator for financial autonomy (C3) means farmers do not resort to loans, which makes them economically independent. Reality is that due to marginalisation and poverty, inhabitants of these communities do not meet requirements to be able to opt for loans.

Indicator C4 relates to dependance of government support programmes, but studied farms usually do not have all the legal documentation required (as legal deeds on their farms), which leaves them out of several government support programmes.

In terms of transferability of farms (C5) that relates to the permanence of farms in time, farms are inherited to the children similar to reports by Srour *et al.* (Srour *et al.*, 2009) in Lebannon, with lower scores than those reported by Benidir *et al.* (Benidir *et al.*, 2013) for sheep systems in Algeria probably due to the fact that farms in Agua Blanca do not have important infrastructure or equipement, since farms with high assets may be divided.

A common aspect that was not recorded are share framing agreements that has an effect on transferability. Share farming are oral agreements without any written documents between two persons (Flores, 2016) that is a usual subsistence strategy and means to build social bonds. A person provides livestock and the other one land, labour and inputs, and benefits are shared in equal parts. These shared agreements in some communities of NPAFFNT enable larger incomes from the sale of sheep and manure (Estévez-Moreno *et al.*, 2019).

CONCLUSION

It is concluded that the sustainability of the farms in the study area fluctuates along the year following the availability of natural resources. Although the agroecological scale shows the potential of the locality to make use of natural resources and manage them properly, and the socio-territorial scale shows that there are areas of opportunity, the condition of being in a protected natural area limits the possibilities of improvement that are required locally; because the NPAFFNT management program of itself prohibits the construction of houses with materials other than those available on the site (wood).

It is advisable to increase the educational level of the inhabitants, especially the youngest, and farmers receive specialized technical training in agricultural and livestock production for community memmbers are a starting point to improve the efficiency of farms so that they may also implement more sustainable practices in the use of natural resources.

The weakest scale of sustainability in the studied village is the economic scale both in indicators of economic viability and productive efficiency, as well as in the seasonal fluctuations observed in these indicators due to there is no intensification in sheep production and this activity is carried out as a savings strategy for families.

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CONFLICT OF INTEREST

Authors declare there are no conflicts of interests.

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