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Article

Productive and socioeconomic characterization of a sheep production system in a natural protected area in Mexico

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Abstract:

Natural protected areas experience pressure from increased human presence and productive activities. Agricultural, socioeconomic and grazing resource use data were used to characterize a sheep production system in the Nevado de Toluca Flora and Fauna Protection Area, Mexico. Based on sheep producer (n= 162) interviews, 25 variables were analyzed with multivariate and univariate statistics. A principal components analysis identified six factors explaining 71 % of variance. A cluster analysis identified three groups of producers [small (28 %), intermediate (35 %) and capitalized (6%)] differentiated by the number of animals, cultivated area and income (P<0.05). Overall, lamb mortality was generally high (23 %), forage oats (*Avena sativa*) were planted on 50 % of cultivated area, and maize (*Zea mays*) on variable percentages. Head of household age and schooling did not differ between groups (P>0.05), and sheep were found to contribute less than 30 % to household income. Rotational grazing in the forest was used by 58 % of producers, but 60 % used a semi-stabling approach. The Nevada de Toluca sheep production system does not depend on producer capitalization, but sheep are essential to the family economy. Management practices are compatible with conservation efforts in the natural protected area.

Key words: Small ruminants, rotational grazing, Nevado de Toluca, Natural resources, Silvopastoral systems.

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Introduction

Livestock systems occupy about 45 % of the planet's terrestrial surface area[1]. They occur in many forms, from extensive mixed grazing, which integrates agricultural and livestock production, to highly mechanized, market-oriented systems[2]. Extensive small ruminant systems tend to use native vegetation for grazing[3] as part of an intricate relationship between agriculture, livestock and natural resources on which many households depend[4]. This relationship has been discussed in terms of its environmental impacts[5], which are particularly salient when these systems are located in and/or use natural protected areas (NPAs). Grazing of livestock in NPAs poses a dilemma between exploitation and use restrictions on natural resources[4].

Production systems are understood as a population of units similar in terms of resource base, livelihoods and limitations[6]. They can be characterized by their structural components, and technical-productive and economic indicators. This allows integration of complex and diverse elements in an analysis[7], as well as development of strategies and recommendations aimed at achieving greater production system efficiency and profitability. This applies to characterization of livestock production in protected areas[8], in which grazing is treated as the main element of interaction between livestock and natural resources[5,9,10]. No research has yet been done on sheep production systems (SPSs) in NPAs in Mexico that incorporates socioeconomic aspects, grazing dynamics and productive results. The present study objective was to characterize the productive, agricultural and socioeconomic aspects of the sheep production system in the Nevado de Toluca Flora and Fauna Protection Area (NT), and analyze use of grazing resources to better understand this system and identify opportunities for its improvement.

Material and methods

Study area

The study area was the Nevado de Toluca Flora and Fauna Protection Area, in the State of Mexico, Mexico. This NPA has elevations ranging from 3,000 to 4,660 m asl. Climate is sub-humid semi-cold (CEh), with average annual temperatures ranging from -2 to 7 °C, and annual precipitation from 1,000 to 1,400 mm. Overall NPA area is 53,987 ha, divided among 61 agricultural nuclei. Within the NPA are twenty towns and a total of approximately 10,000 inhabitants(11). These communities have about 191,000 head of livestock of which 60 % are sheep. Grazing is done in forest and grasslands inside communal use areas(11). Originally a national park, NT was reclassified as a Flora and Fauna Protection Area in 2013, a change which allows people living in the NPA to maintain ownership of their land and continue some productive activities, without changing land use(12).

Producer identification and data collection

During 2015, a total of 162 questionnaires were applied to sheep producers who had been chosen by convenience sampling. This is the same method used in previous studies, although it does not allow building of a reliable sampling framework(13). The questionnaire had three sections: (i) livestock, which recorded data on number of animals, feeding and grazing, reproduction, health and technical practices; (ii) agricultural activity, which recorded the number of crops, cultivated area and machinery; and (iii) socioeconomic characteristics, which covered head of household age and education level, income sources, family participation in labor, experience and training. Producers had no records on technical and economic information, which is common in family production systems(7,14,15). As a result, the collected data was supplemented by direct observation during visits to production units, as well as forty in-depth interviews with sheep producers held during grazing periods.

Statistical analysis

A principal component analysis (PCA) was done using 25 variables to provide an initial approach to the variables describing SPS in the study area. The PCA produced small groups of linear combinations (components or factors) which explained as much variance as possible in the original data with minimal data loss[16]. Parsimony of the principal components (PC) was verified with the Kaiser-Meyer-Olkin (KMO) test, and sample suitability confirmed with the Bartlett test of sphericity[16]. Orthogonal varimax rotation was applied to the PCs to improve interpretation[6,16].

Linear PCA combinations were introduced into the hierarchical cluster analysis (CA) to form groups of producers and characterize the SPS. Case clustering was done following Ward's method, and the squared Euclidean distance used as a measure of similarity. A dendrogram analysis and cluster coefficient were applied to identify the number of groups[6]. Because group size was not homogeneous, differences between groups were identified with an analysis of variance (quantitative variables) by comparing Hochberg means[17]. Categorical variables were analyzed with contingency tables and a χ^2 test[6]. Statistical analysis results were triangulated with field observations and interviews. All statistical analyses were run with the SPSS ver. 22.0 program.

Results and discussion

Sheep production system in the Nevado de Toluca

The SPS in the NT is a low-tech family-run system closely linked to agriculture, and which provides financial security, much like a previously described SPS[18]. Most of the sheep herds were fed by grazing, and supplemented in stables. Breeds were mainly Suffolk, Hampshire and crosses thereof, chosen for weight and ease of handling. Reproduction is continuous although females exhibit marked seasonality. Mating occurs most frequently in the summer with births between November and February. This is the coldest time of the year, which may contribute to high lamb mortality due to respiratory diseases.

Factors characterizing SPS

The PCA identified six principal components (PC) which explained 71% of the variance. Results for the KMO test (0.61) and Bartlett's test of sphericity (*P*<0.001) confirmed analysis trustworthiness. Sixty percent (60%) of the analyzed variables were retained in the PC (Table 1), which coincides with previous reports of a 64% retention of variables(7,13). This suggests that characterizing these production systems may only require from 10 to 20 variables, and that production unit size (i.e. number of hectares and animals) has the highest relevance in classification(19). Variables with communality values less than 0.5 were excluded from the PCA because this indicates they had low associations with the selected PC(16,17).

Table 1: Principal components with associated variables, correlation coefficients and explained variance per component

Component	Variables	Variable-Factor Correlation	Explained Variance*
1	Animals	.770	20.2 (20.2)
	Parturitions, %	.768	
	Cultivated surface, ha	.767	
2	Age, years	.903	14.3 (34.5)
	Education level, years	-.712	
	Experience, years	808	
3	Mortality (adults), %	.746	11.2 (45.7)
	Mortality (lambs), %	.739	
4	Cultivated species	.678	9.4 (55.1)
	Family participation, #	.654	
	Machinery, #	.792	
5	Forest grazing, %	.779	8.9 (64)
	Distance to grazing, km	.816	
6	Weaning, %	.830	6.9 (71)
	Deparasitization, %	.717	

* Cumulative variance indicated in parentheses.

Principal component one (PC 1, *capitalization*) incorporated variables relating to system assets (Table 1), which determine the investment capacity in technical practices(20). The second one (PC 2, *human capital*) showed the inverse relationship between head of household education level, age and experience. This reflects these adults' limited access to education, due in part to the lack of formal employment opportunities and nonexistent infrastructure for access to educational services. These are associated with the nature of the NPA and led these adults to enter productive activities at an early age(21).

The third component (PC 3, *animal health*) highlighted adult animal mortality (11%) and lamb mortality (23%), both of which were higher than values reported for other SPSs(22). Animal health management is therefore an area of opportunity for improving system productive and financial efficiency. The fourth component (PC 4, *agriculture*) associated crop diversity with family participation and use of machinery. This is characteristic of mixed production systems, in which exploitation of agricultural and livestock resources depends on working as a family(19).

The fifth component (PC 5, *rotational grazing*) linked forest grazing with the distance traveled to grazing. In this technique animals are allowed to graze freely on a surface for short periods (about 10 min) along relatively long routes (2 to 4 km), much like the grazing circuits used in the French Mediterranean(9). Finally, PC 6 (*technical practices*) associated deparasitization with weaning, which occurs at time of sale and without prior weight gain regimes that could improve producer income(14). Deparasitization was implemented in 70 % of the studied herds, a rate higher than the 58% reported for other SPSs(23).

Sheep production groups in the NT

The cluster analysis identified three producer groups, differing mainly in terms of quantity of animals, cultivated agricultural area and income from sheep and agricultural. As has been done in other studies(8,24), these differences were used to classify the groups as small producers (Group 1), intermediate producers (Group 2) and capitalized producers (Group 3). Following are descriptions of the productive, socioeconomic and grazing resources use aspects of each producer group.

Sheep production

Data on the SPS show small producers (28 %) had the fewest animals, and weaned and deparasitized at lower rates, probably due to their lower training levels (Table 2). Intermediate producers (35 %) had an intermediate number of animals, but the highest percentages of deparasitization and weaning. Capitalized producers (6 %) had the largest number of animals with herds about 120 % larger than in other regions of Mexico(18,22), but

20 % smaller than herds in Europe(3,8). Despite the differences in capitalization, parturition and lamb mortality rates did not differ (P>0.05) between the three groups. Clearly in this SPS the resource base is not reflected in productivity(19), probably due to lack of inadequate training.

Table 2: Quantitative (mean and SE) and qualitative (%) characteristics of sheep production system by producer groups based on cluster analysis

Variables	Group 1 (n=74)	Group 2 (n=70)	Group 3 (n=18)	P^*
Quantitative variables:				
Number of animals	16.2±1.4[a]	24.6±2.3[b]	71.7±7.2[c]	.000
Parturitions, %	84.4±2.7	83.0±2.4	85.7±3.7	.861
Mortality (adults), %	16.5±2.3[a]	9.6±1.2[b]	7.5±1.4[b]	.002
Mortality (lambs), %	24.1±3.2	22.8±2.2	23.4±3.6	.942
Qualitative variables, % producers:				
Weaning	4	57	22	.000
Deparasitization	51	86	83	.000[&]
Training	27	31	50	.170
Sale of animals:				
Lambs	65	64	89	.117
Grown animals	54	59	56	.860
Waste	38	47	72	.030
Self-supply	7	3	11	.327[&]
Wool	20	9	22	.106[&]

[abc] Different letter superscripts in the same row indicate significant difference (P<0.05). [*] P value in ANOVA and χ^2. [&]More than 20% of squares with counts less than five.

Sheep product marketing data showed that the small and intermediate producers sold some lambs when young (4 to 5 months of age) and the remainder throughout the rest of the year, and less than half discarded unproductive animals (Table 2). This confirms financial security as one of the main functions of livestock in this system since animals are sold in response to financial need(18,23). In contrast, the larger, capitalized producers sold more lambs and waste animals because their facilities and limited labor did not allow increases in herd size. This finding suggests that herd size self-regulates and that animal load therefore remains stable, leading to improved herd productivity without increased size(15), largely through use of reproductive management techniques and health treatments. Sale of wool was almost null since only about 20 % of producers sheared their sheep and these just discarded the wool due "to its low price" ($1.00/kg); the market therefore limits development of this system(14).

Agricultural production

Small producers had less agricultural surface, fewer crops and less machinery. Most agricultural production was used for subsistence, and 12 % of these producers owned no farmland. Intermediate producers had greater crop diversity and more machinery use, although this was not owned by them. They tended to sow higher percentages of forage oats (*Avena sativa*), fava bean (*Vicia faba*), pea (*Pisum sativum*) and common bean (*Phaseolus vulgaris*) (P>0.05). While they sold a higher percentage of potato (*Solanum tuberosum*) than the small producers, a third sowed small amounts (<0.3 ha) for family use (Table 3). The capitalized producers had more cultivated area and machinery use, grew potato (*S. tuberosum*) on 18 % of their land and maize (*Zea mays*) on 26 %; in contrast, the small and intermediate producers planted *S. tuberosum* on only 9% of their land and *Z. mays* on 41 %. The proportions of crops and their commercial purpose depended on producer capitalization level. In general, all three groups grew oats on 50 % of their land. They allocated *Z. mays* for subsistence, and fodders and crop waste to feed horses and ruminants. These in turn provided fertilizer for crops in a complementary management system between agriculture and livestock production like that reported in other SPSs[18,22]. This highlights that NT sheep producers have traditionally developed a comprehensive resource use strategy.

Table 3: Quantitative (mean and SE) and qualitative (%) variables of agricultural production in Nevado de Toluca sheep producer groups

Variables	Group 1	Group 2	Group 3	***P****
Quantitative variables:				
Crops cultivated	1.9±0.1^a	2.5±0.1^b	1.9±0.3^{ab}	.004
Surface cultivated, ha	1.9±0.2^a	3.1±0.3^a	5.3±1.7^b	.000
Machinery$^\#$	1.9±0.2^a	3.3±0.2^b	2.7±0.4^{ab}	.000
Qualitative variables, % producers:				
Crops:				
Oats (*Avena sativa*)	70	86	83	.069
Maize (*Zea mays*)	64	79	50	.030
Potato (*Solanum tuberosum*)	28	30	39	.683
Others:	19	29	11	.130
Subsistence crops				
Maize (*Zea mays*)	98	100	100	.503^f
Potato (*Solanum tuberosum*)	52	29	14	.115^f
Others	86	81	50	.483^f

^{abc} Different letter superscripts in the same row indicate significant difference (P<0.05). * P value in ANOVA and χ^2. $^\#$Total possible: vehicle, yoke of oxen, tractor, chainsaw, forage shredder, forage packer. ^{f} More than 20% of squares with counts less than five. Others= fava bean (*Vicia faba*), pea (*Pisum sativum*) and common bean (*Phaseolus vulgaris*).

Socioeconomic aspects

The families (5 members) of small producers participated less in agricultural activities because at least one member took non-agricultural jobs outside the NPA, consequently reducing dependence on natural resources[(2)]. Intermediate producers had larger families (6 members) and these were responsible for a larger share of agricultural activities. However, they also had more income sources since different members could service the livestock after other activities (e.g. housework, jobs, or school) (Table 4). The present data support engagement in multiple activities as a strategy for increasing income and ensuring the flow of financial resources to the household[(10)]. The capitalized producers were younger, had finished elementary school and their families (5 members) covered all livestock care needs. These results coincide with other studies done in rural Mexico[(25)], but contrast with results for European countries where 30% of producers have a high school or university education[(20)] and family members contribute from 33 to 74% of labor[(8,13)].

Table 4: Socioeconomic aspects of producer groups formed in cluster analysis

Variables	Group 1	Group 2	Group 3	*P*[*]
Age, head of household (years)	52.6±1.6	53.6±1.4	48.7±2.4	.247
Education level, head of household (years)	4.7±0.4	3.8±0.3	5.6±0.8	.061
Family participation [#]	2.2±0.4[a]	3.0±0.2[b]	2.6±0.3[ab]	.004
Income sources	5.3±0.2[ab]	5.8±0.2[b]	4.6±0.5[a]	.006
Annual income, sheep, $	5,699.2± 790[a]	17,554.0± 4651[a]	101,790.3± 51,257[b]	.000
Sheep contribution to income, %	13.3±2.3[a]	17.3±2.2[a]	30.6±7.8[b]	.009
Annual agricultural income, $	11,123.5± 3,051.4[a]	33,291.9± 12,218.2[a]	133,943.3± 70032.5[b]	.001

[abc] Different letter superscripts in the same row indicate significant difference (*P*<0.05). [*] *P* values in ANOVA. [#]Number of members participating in agricultural and livestock activities.

Income

Incomes from agriculture and livestock did not differ (*P*>0.05) between the small and intermediate producers (Table 4). The ANOVA detected no differences due to high intragroup variability. This phenomenon has been observed in studies including socioeconomic aspects[6,13]. In addition, income flow from sheep was not continuous because producers kept animals for sale later when they needed money, leading to productive cycles exhibiting various high and low sales periods; for example, only 16% of the studied households sold animals during the study period. Income from sheep was highest among the capitalized producers, although sale of sheep provided only a third of overall household income. The NT SPS is clearly a complement to family income[14,24], in addition to employment outside the NPA, remittances and government subsidies.

Use of grazing resources

Most (97%) of the surveyed producers grazed their herds in the grazing-only or semi-stabled modalities (grazing-stabled). Of these, 58% grazed in the forest, although this proportion increased among the capitalized producers, who used grazing-only to avoid raising costs from feed purchases[22]. The small and intermediate producers used semi-stabled (Table 5), because their herds required less feed volume, allowing them to reduce grazing and channel their labor into higher-income activities[2].

Table 5. Sheep grazing and feed management by producer group (%)

Variables	Group 1 (n=74)	Group 2 (n=70)	Group 3 (n=18)	*P*[*]
Feed management:				
Grazing	26	26	44	.060
Semi-stabled	73	64	44	.055
Stabled	1	10	11	.060[&]
Forest grazing:	57	51	67	.490
Feeds used:				
Hayed forage	84	96	89	.065
Balanced feed	18	31	39	.068
Mineral salt	64	84	100	.001

[*] *P* value in χ^2. [&]More than 20% of squares had counts less than five.

Forest grazing circuits were frequently changed and differed between producers, who modified their routes year-round based on their perception of vegetation availability[5,9]. This suggests that pressure on grazing resources is regulated by apparent fodder availability, previous grazing cycles and *in situ* agroecological characteristics. Management of this SPS may therefore be compatible with conservation efforts if animal load is adjusted by developing methodologies appropriate to rotational grazing and adequate knowledge is shared occurs between producers.

Sheep herds are grazed in the NT forest mainly in the dry season (March to May) when pasture quantity and quality decreases. During the rainy season (June to October) the preference is for grasslands containing the genera *Vulpia*, *Nassella*, *Trisetum*, *Muhlenbergia*, *Potentilla*[26], and forest grazing decreases. After local crops are harvested (November to February) field stubble and roadsides are grazed. Producers in this SPS are clearly adapting to year-round resource availability[22,26]. Their experience in grazing area use could be incorporated into zoning plans within the new Flora and Fauna Protection Area designation, essentially integrating local knowledge into management plan design[27].

Feeding

Most producers (88%) provided feed concentrate (commercial and empirically-processed homemade mixtures) to their herd, confirming that traditional grazing management is transforming into a semi-stabled system, with day-grazing followed by stabling and supplementary feed in the evening. This arises from producer interest in intensifying production[1,5] and adaptation strategies responding to restrictions on natural resource use[4]. Some producers (22 %) were intensifying their strategy by stabling weaned lambs to promote weight gain and consequently higher sales prices (Table 5). However, producers need to be careful that intensification does not undermine profitability due to the need for input purchase[3].

The technological transition observed in the NT has been reported for different production systems[5,7,14]. It also suggests that use of grazing resources in NPA should be incorporated into more complex feeding strategies that include commercial feed and cultivated fodder. Grazing-based systems that adequately integrate their resources can be financially efficient and environmentally friendly[3,15], since grazing can contribute to maintaining biodiversity[10] and avoids accumulation of combustible material[13,28].

The main feeds used in the study area were hayed oats and corn stover (Table 5); both are low cost because they are by-products of crops grown by producers. A very few producers fed their sheep mixtures of wheat bran or soybean (13 %) or potato waste (2 %), although use of this resource has not been documented. Feed management practices in the NT are similar to those used in other SPS[22,23]. They also approximate traditional agrosilvopastoral management in which resources are used in an integrated manner, although different plant strata do not necessarily share the same space[27]. This differs from agroecological designs in which trees are combined with different vegetation strata to provide animal feed[28].

Conclusions and implications

Three groups of sheep producers were identified within the Nevada de Toluca Flora and Fauna Preservation Area. These were distinguished by their level of capitalization in the form of quantity of animals, cultivated owned and income generated. Capitalization was not reflected in productivity since all three groups had similar parturition and lamb mortality rates, highlighting the need for increased training to raise production and income levels. Agricultural production did not correlate with producer capitalization because those with more productive assets devoted more area to commercial crops. The crop-to-livestock ratio in the studied system agrees with conservation strategies, since, for example, use of manure decreases application of chemical fertilizers. Social aspects such as head of household age and education level did not affect sheep system productivity, although system economic efficiency depended on family labor. Sheep production was not the main income source among the studied producers but was essential to the family economy because it provided the financial safety not available from other economic components. Any management plan for the study area needs to consider that this sheep production system is in transition from an extensive to a semi-stabled grazing strategy. It therefore requires improved feeding strategies to reduce grazing within the natural protected area, and definition, where appropriate, of action plans for sustainable use based on level of grazing area deterioration and its relationship to animal load. Adoption of agrosilvopastoral management strategies can help to make sheep production compatible with conservation efforts. However, the area's biological and socioeconomic characteristics mean achieving a technically viable model requires interaction and cooperation among multiple actors with interests in the natural protected area.

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