Trop Anim Health Prod
DOI 10.1007/s11250-017-1249-0

REGULAR ARTICLES

A multi-criteria approach to identify favorable areas for goat production systems in Veracruz, México

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Received: 15 July 2016 / Accepted: 30 January 2017

Abstract This research identifies favorable areas for goat production systems in the state of Veracruz, Mexico. Through the use of the analytic hierarchy process, layers of biophysical and soil information were combined to generate a model of favorability. Model validation was performed by calculating the area under the curve, the true skill statistic, and a qualitative comparison with census records. The results showed the existence of regions with high (4494.3 km^2) and moderate (2985.8 km^2) favorability, and these areas correspond to 6.25 and 4.15%, respectively, of the state territory and are located in the regions of Sierra de Huayacocotla, Perote, and Orizaba. These regions are characterized as mountainous and having predominantly temperate-wet or cold climates, and having montane mesophilic forests, containing pine, fir, and desert scrub. The reliability of the distribution model was supported by the area under the curve value (0.96), the true skill statistic (0.86), and consistency with census records.

Keywords Analytic hierarchy process · Caprine systems · MCAS-S · True skill statistic

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Introduction

Goat culture is one of the primary activities on which more than 1.5 million Mexicans depend. In 2009, the goat population exceeded 8 million head, which were distributed among 494 thousand production units, with a size ranging from 20 to 250 goats; these units are distributed in arid and semi-arid regions (64%) and temperate regions (36%) (Salinas-González et al. 2010; Escareño et al. 2011; Orona et al. 2013). The states with the largest goat populations are Puebla, Oaxaca, San Luis Potosi, Guerrero, and Zacatecas. However, in these states, goat culture is performed in moderately difficult topography and climate (Valerio et al. 2009). In the state of Veracruz, goat production systems in this area are considered extensive and depend on an interplay of factors such as altitude, climate, rainfall, land use, and temperature for generating products (Brunschwig et al. 2004; Salinas et al. 2011). However, the selection of sites for the establishment of new goat production systems has been performed empirically, and has been limited by the lack of a comprehensive analysis of the factors involved, over-exploitation of natural resources, and effects from climate change. Thus, it is necessary to guide these processes with objective and reliable mechanisms.

The combination of geographic data, expert judgment, and data processing using the analytic hierarchy process (AHP) coupled with geographic information systems is suitable for efficient and low-cost agricultural planning (Saaty 2008; Sour et al. 2013). These tools have been used for the delimitation of dairy pastures, goat production potential, identification of grazing areas (Brunschwig et al. 2004; Salinas et al. 2011; Sour et al. 2013), and the identification of favorable zones for different wild goat species (Granados et al. 2003; Morovati et al. 2014). Therefore, the objective of this research was to apply the AHP to identify favorable zones for goat production systems (GPR) in the state of Veracruz, Mexico.

Published online: 09 February 2017

Materials and methods

Generation of the distribution model of favorability was performed by combining information layers or factors influencing goat production system distribution in a structured, hierarchical way (Zelenović et al. 2012), using published information and consultation with experts in goat production systems regarding the identification of factors with the greatest impact on such systems. The factors were selected by the experts based on their domain expertise (Schmidt et al. 2015). Physical and edaphic factors influencing the productive performance of goats and forage production were considered as composite categories. The selected factors were elevation (ELE, meters above sea level (masl)), average annual rainfall (AAR, mm), annual average temperature (AAT, °C), climate type according to Köppen (CLIT) and modified by García (2004), soil texture (STEX), and land use (LUSE). The factor hierarchy is shown in Fig. 1; to calculate the suitability areas (Mf), layers are combined from left to right in the physical and soil groups, and then they are combined; in all cases, weights *W*s are used to rank their importance. The layers of information were obtained from the Consejo Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO 2015) and were rasterized at a resolution of 1 km^2. The response function for each factor was constructed by converting the original values to an ordinal scale of three to five categories, with the highest category being the most favorable. The rating of factors and the number of categories was made qualitatively according to the requirements of the species and in accordance with the experience of experts. Three experts were consulted regarding goat production systems to rate the relevance of factor pairs using a nine-point scale (Saaty 2008). The number of experts consulted is within the range analyzed by Schmidt et al. (2015), and they were selected according to their availability and their domain expertise on caprine production systems, forage production, and animal production systems; their professional experience ranged from 30 to 50 years. The rating of the factor levels was accomplished by group consensus to minimize individual bias (Kaplan 2000).

The weights associated to the factors were obtained using the normalized eigenvalues of the square matrices representing the factor groups. Subsequently, the model favorability (Mf) was constructed by combining the layers associated with their weights: $XC_{(ij)} = \sum W_i X_{ij}$, where $XC_{(ij)}$ is the added value of the cell of a composite layer, W and X are weight and factor, respectively, while j refers to the value of the cell in the i-th layer. Finally, at municipality level, the average favorability was classified into three groups indicating different degrees of geographical favorability: $0 \leq X \leq 0.3$ low favorability (LF), $0.3 < X \leq 0.6$ moderate favorability (MF), and $0.6 < X \leq 1$ high favorability (HF).

To validate the favorability model, locations of existing goat production systems in the municipalities of Coatepec, Coacoatzintla, Perote, Tatatila, and Xico were used. Other points were obtained by calculating geographical centroids of municipalities where historical census records exist for goat production systems: Altotonga, Atzalan, Ayahualulco, Chiconquiaco, Ixhuacán de los Reyes, Jalancingo, Jilotepec, Las Minas, Las Vigas de Ramírez, Tatatila, Tlacolulan, and Villa Aldama (Herrera 2010). In total, we obtained $n = 20$ independent records of the presence of GPR. Given these independent points, we extracted favorability values from the model and applied two statistical tests: (1) construction of the receiver operating characteristic (ROC) and area under the curve (AUC). The AUC is close to one for reliable models and is close to 0.5 for models that are indistinguishable from a random one; and (2) calculation of the true skill statistic (TSS) which varies between −1 and 1, with acceptable models having values close to one. The statistics were calculated using the extracted values and 10,000 randomly chosen points from the suitability map (Elith et al. 2006). To interpret the data, if the AUC and TSS values are close to 1, the model is able to discriminate between a point of system presence and a point selected at random (Allouche et al. 2006). To calculate the AUC and TSS, it was necessary to convert the suitability map to one of presence (1) and absence (0). The value of the TSS statistic was selected using a probability threshold that

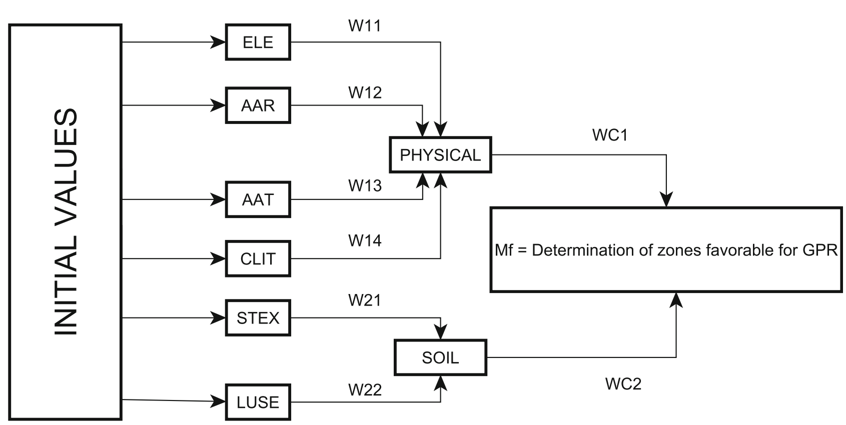

Fig. 1 Hierarchical process of combining factors to model zones favorable for goat production systems. *W* the weight of each of the layers, *WC* the weight of the composite layers, *Mf* is the model of favorability, *GPR* goat production systems

gives the highest value of the statistic at different threshold values from 0.1 to 0.9 (Gray et al. 2010).

The second model evaluation was conducted qualitatively by visually comparing the most favorable areas with the occurrence of GPR obtained from the 2007 agricultural census using the top 95% quantile values (INEGI 2007). The rating of the geographic layers and their combinations to build the favorability model was performed using MCAS-S v3.1 (ABARES 2015); municipal geographic centroids were calculated using QGIS v2.8.3 (QGIS Development Team 2015). The characteristic values of the comparison matrix were calculated using R; tests were conducted with independent values using the programs *PresenceAbsence* and *pROC* in R v3.1.3 (R Core Team 2015).

Results

Table 1 shows the selected factors with their initial values. In terms of ELE, AAR, and AAT, we considered a range with the greatest favorability of 1500 to 2500 masl, 1000 to 1500 mm and 8 to 16 °C, respectively. In the case of CLIT, the climate, types C were preferred; for LUSE the highest preferences were for jungles and grasslands. For STEX, soil texture, medium was the most preferred. Regarding the relative importance of the factors, the weights for ELE, AAT, CLIT, and AAR were 0.27, 0.33, 0.24, and 0.17, respectively while the weights of the factors LUSE and STEX were 0.86 and 0.14, respectively. The composite layers received weightings of 0.88 (physical) and 0.12 (soil). The paired comparison matrices for the hierarchical levels are presented in Table 2 from which the weights were derived; for example, ELE was considered five times more important than AAR.

The favorability model shows that the state of Veracruz is dominated by areas having low favorability (64,345 km^2), this representing 89.6% of state territory. These areas are located in the northern municipalities, bordering the states of San Luis Potosi and Tamaulipas, nearshore and downstate (Fig. 2). The MF and HF regions represent only 4.1% (2985.8 km^2) and 6.2% (4494.3 km^2), respectively, of the area over the entire state (Fig. 2). These areas are located in three mountainous regions: Sierra de Huayacocotla, Perote, and Orizaba (zones I, II, and III in Fig. 2, respectively). Table 3 lists the three zones studied and the main municipalities having MF and HF for the establishment of GPR in Veracruz. As for the evaluation of the distribution model using quantitative indices, the AUC (Fig. 3) had a value of 0.96, with a 95% CI (0.94, 0.97); the ROC line was distant from a random model, while the TSS value was 0.86; these values were calculated with a binarization cutting level of $c = 0.2$; observed GPR are presented in Fig. 2 and most of them are within the HF category. In addition, the qualitative comparison of the identified favorable zones with the areas of occurrence of these GPR, as recorded by an agricultural census (INEGI 2007), provided a partial visual match because these

Table 1 Factors selected for goat production systems associated with their categories and ordinal values of favorability

Factor	Categories (favorability values[a])					Source[b]
ELE (masl)	500–1000 (1)	1000–1500 (2)	1500–2000 (5)	2000–2500 (4)	>2500 (3)	Williams-Linera et al. (2002); Franco-Guerra et al. (2008); Escareño et al. (2011).
ARR (mm)	0–500 (3)	500–1000 (4)	1000–1500 (5)	1500–2000 (2)	>2000 (1)	Williams-Linera et al. (2002); Salinas-González et al. (2010); Escareño et al. (2011).
AAT (°C)	0–4 (1)	4–8 (2)	8–12 (3)	12–16 (4)	16–20 (2)	Williams-Linera et al. (2002), Salvador and Martínez (2007), Arias et al. (2008), Escareño et al. (2011).
CLIT[c]	C(f) (3)	C(m) (3)	Cb′(m)(f) (2)	BS1kw (1)	BSokw (1)	Williams-Linera et al. (2002); Franco-Guerra et al. (2008); Salinas-González et al. (2010); Escareño et al. (2011).
STEX	Coarse (2)	Medium (3)	Fine (1)			Salinas-González et al. (2010); González-Camarillo et al. (2012).
LUSE	Forests (3)	Jungles (4)	Grasslands (5)	Scrub (2)	Chaparral (1)	Williams-Linera et al. (2002); Márquez and Márquez (2009); Salinas-González et al. (2010); Sour et al. (2013).

[a] Favorability values in a row are ordinal values, with 1 representing the lowest favorability. The values were assigned by experts by group consensus

[b] References provided low and high values for numerical factors and suitable values for nominal factors

[c] Köppen climate type modified by García (2004)

Table 2 Pairwise comparison matrices for calculating factor weights used to identify suitable zones for GPR in Veracruz, Mexico

Physical					Soil			Composite layer		
	AAR	ELE	AAT	CLIT		LUSE	STEX		Physical	Soil
AAR	1	1/5	2	1/3	LUSE	1	6	Physical	1	7
ELE	5	1	1	1/2	STEX	1/6	1	Soil	1/7	1
AAT	1/2	1	1	5						
CLIT	3	2	1/5	1						

The number in the cell represents the relative importance of each factor pair evaluated by the experts; the rating scale ranges from 1 to 9 (Saaty 2008)

production systems have been reported in the municipalities of the three potential zones (Fig. 2, 2007 census); these areas are those having the largest inventories of goats. Therefore, both evaluation methods support the interpretation and use of the distribution model. Overall, the AHP allowed the identification of favorable areas for the establishment of goat production systems, by using relevant factors and their importance, elicited by the judgment of experts in a structured, hierarchical way.

Discussion

The greatest favorability was in the range of 1500 to 2500 masl, because there is greater abundance and quality of forage, and goats can consume buds and other new sprouts (Lasanta 2010). In terms of precipitation, the threshold was between 0 and 2000 mm, with precipitation between 1000 and 1500 mm as the most favorable (Martin et al. 2011). For temperature, the greater favorability was between 8 and 16 °C; at these temperatures, goats display superior growth and milk production, while at temperatures below 4 °C and greater than 20 °C, the animals suffer metabolic stress; as temperature increases, the feed intake usually diminishes resulting in a reduction between 3 and 10% of milk (Lu 1989; Alexandre and Mandonnet 2005; Arias et al. 2008; Salama et al. 2014). In terms of climate, climate types C (temperate) and BS (arid) were studied by Franco-Guerra et al. (2008) and Escareño et al. (2011); they demonstrated the presence of goat production systems in these climatic regions, although most favorability was observed in temperate climates; such production systems are developed principally in marginalized areas with limited water supply, as in arid climates. For land use, we considered forests, jungles, grasslands, scrub, and chaparral. Franco-Guerra et al. (2008) and Echavarría-Chairez et al. (2011) conducted studies on GPR developed in such ecosystems, and the highest favorabilities were for pastures, forests, and woodlands due to the high diversity of forage for goats in these ecosystems compared to xeric scrub ecosystems where plants are adapted to extreme drought (e.g., cacti). Given that soil type

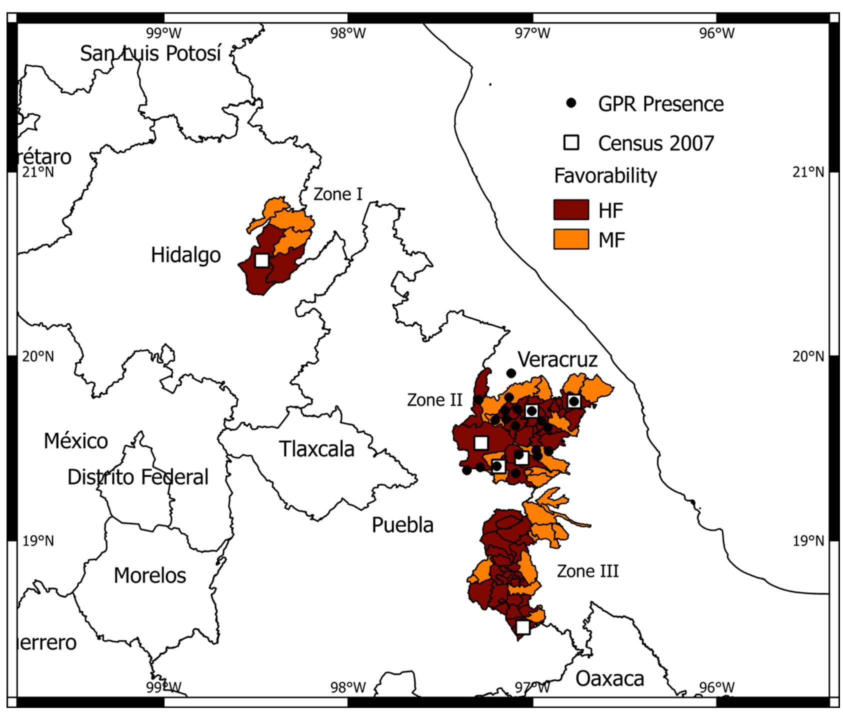

Fig. 2 Favorability zones for the establishment of goat production systems in the state of Veracruz. *HF* high favorability, *MF* moderate favorability. The *lines* correspond to municipal and state borders. The *circles* are locations of observed goat production systems and *squares* correspond to census data

Table 3 State zones and area coverage of main municipalities having moderate (MF) and high (HF) favorability for goat production systems

Zone	Favorability	Municipality	Area (km^2)
I	HF	Huayacocotla	484.6
I	HF	Zacualpan	270.1
I	MF	Zontecomatlán	244.0
I	MF	Texcatepec	208.4
I	MF	Ilamatlán	63.4
II	HF	Perote	548.9
II	HF	Xico	193.7
II	HF	Ixhuacán	153.7
II	HF	Chiconquiaco	144.2
II	HF	Tlacolulan	143.3
II	HF	Jalancingo	138.9
II	MF	Altotonga	357.8
II	MF	Coatepec	218.9
II	MF	Juchique de Ferrer	200.6
II	MF	Ayahualulco	173.7
II	MF	Yecuatla	120.7
III	HF	Coscomatepec	165.9
III	HF	Acultzingo	147.6
III	HF	La Perla	119.0
III	HF	Soledad Atzompa	110.3
III	HF	Alpatláhuac	79.0
III	MF	Huatusco	205
III	MF	Ixtaczoquitlán	145.9
III	MF	Ixhuatlán del Café	141.6
III	MF	Tequila	103.3
III	MF	Maltrata	101.6

included soils with coarse, medium, and fine textures, the second soil type had higher favorability; this rating was consistent with González-Camarillo et al. (2012) who mentioned that the medium- to coarse-texture soils allow higher yields of crops as compared to fine-texture soils. According to Brunschwig et al. (2004), the factors ELE, AAT, and CLIT delimit and identify areas where there are milk production systems. The weighting of AAR was 0.17, as this criterion has more influence on forage production. LUSE had a greater weight (0.86) compared to STEX (0.14), similar to results reported by Williams-Linera et al. (2002) and Sour et al. (2013). LUSE is an important factor determining the degree of ecosystem resilience and its economic impact. The high weight score of the composite physical layer indicates that climatic factors are essential for the determination and establishment of GPR (Salinas et al. 2011).

The high prevalence of low favorability areas (>80%) of the territory of Veracruz is better suited for dual-purpose cattle production systems in the coastal plains (Vilaboa-Arroniz et al. 2009). The areas with categories MF and HF border with the state of Puebla, particularly with the municipalities of Tecamachalco and Cholula, where there are high inventories of goats (Hernández et al. 2001). The municipalities with MF and HF are located in zones having temperate-humid conditions and mountain cloud forests, and municipalities in colder areas having pine, fir, and desert scrub ecosystems. To a lesser extent, some systems are located in mountain foothills, such as Juchique de Ferrer and Yecuatla, and degraded areas lacking relevant vegetation in the municipality of Tequila (Márquez and Márquez 2009). The results obtained in this study are consistent with those of Márquez and Márquez (2009) who determined that most plant diversity is located in municipalities within mountain cloud

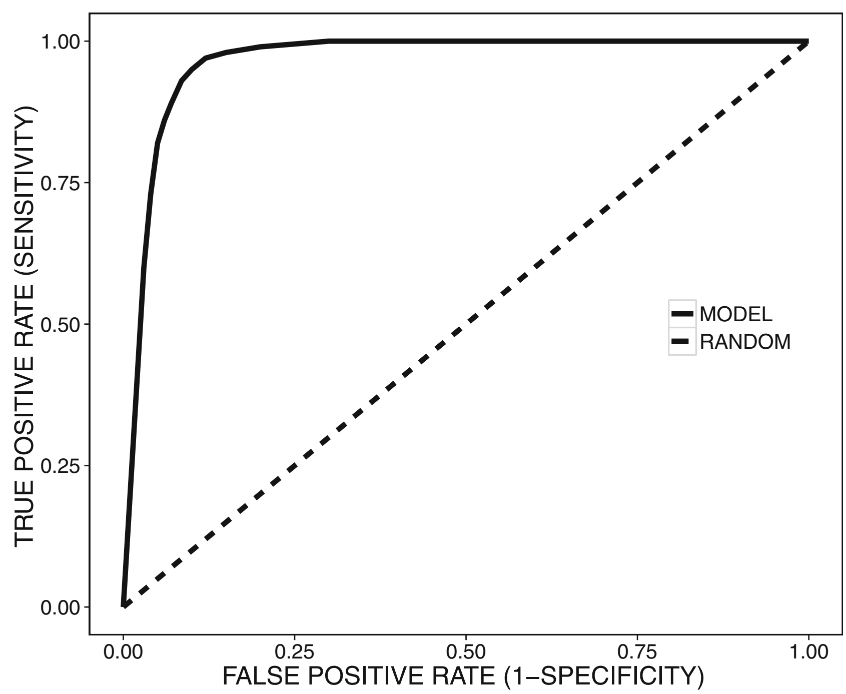

Fig. 3 Receiver operating characteristic (ROC) for the goat production system distribution model (*continuous line*) and for a null random model (*dashed line*)

forests. Also, Delfín-Alfonso et al. (2009) reported that the municipalities Altotonga, Jalancingo, Perote, and Xico in the state of Veracruz are potential sites for the reintroduction of white-tailed deer *Odocoileus virginianus* (Zimmermann, 1780). Sour et al. (2013) determined that the ideal grazing areas for goats were located in mountainous areas where the vegetation quality is better compared to other areas such as rural and coastal plains. Similar research has been developed for other species of goats, such as the Spanish ibex (*Capra pyrenaica* Schinz) in Andalucía, Spain (Granados et al. 2003), and the wild goat (*Capra hircus aegagrus* Erxleben) in Iran (Morovati et al. 2014). In these studies, favorable zones for these species are located in mountainous areas at altitudes of 1271 and 1000–2600 masl, respectively.

Regarding the model assessment, the value of AUC obtained in this study is similar to the 0.95 reported by Morovati et al. (2014) to evaluate a favorability model for wild goats in Iran. The estimated moderate and high favorability regions suggest analyzing the following aspects: (1) the potential expansion of goat production to other municipalities of Veracruz with favorable conditions for the development of this activity, as the INEGI (2007) agricultural census showed that only seven municipalities have high inventories. Yet, in the present study, we identified 24 and 49 municipalities having MF and HF, respectively, which are distributed among three zones in Veracruz. (2) Planning routes for the supply and marketing of dairy products made from goat milk; according to Hernández et al. (2001), some factors limit GPR and negatively impact the income of producers, such as the lack of land availability and marketing channels. By using multi-criteria analysis and geographic information systems, areas having high and moderate favorability were identified; these areas are located in the mountainous regions which are characterized by having low temperatures, high elevations, and vegetation composed of mountain cloud forest, pine forests, fir forests, and desert scrub, demonstrating that goat production systems in Veracruz can be established in different ecosystems. Statistical indices and qualitative visual analysis support the validity of the model. To promote the establishment of caprine production systems, the legal mechanism is through planning and coordination by the product-system framework established in the current legislation; this framework requires the participation of potential producers and a marketing analysis (CDHCU 2012).

Acknowledgements This research was supported by funding to the first author from Colegio de Postgraduados through Fideicomiso de Administración e Inversión No. 16730, and Consejo Nacional de Ciencia y Tecnología (CONACyT) for a doctoral scholarship.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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