Application of GIS techniques to aid conservation strategies: Landscape analysis of communal grazing resources in a Mexican mountain forest and connexion with participatory studies

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SUMMARY – This work considered the application of a Geographic Information System (GIS) with a participatory approach to evaluate the grazing resources of a mountain forest in central Mexico. The study region was enclosed within a protected area where land was communally owned and sheep flocks grazed the understorey vegetation. Firstly, satellite imagery was used to classify the study region according to the vegetation type. Each class was subsequently characterised at field level by measuring biomass production, botanical composition and growth patterns of the understorey vegetation during the rainy season. Subsequently, a participatory study was carried out with sheep smallholders to identify forage species, to estimate flock sizes and to locate the different grazing distribution patterns of their flocks on maps and aerial photographs. Thirdly, these field-collected data on grazing resources were linked with the associated biophysical properties of the landscape utilising a GIS. Finally, an analysis at landscape level was carried out in which current stocking rates were assessed and areas prone to overgrazing were identified. In addition, the analysis helped to optimise grazing patterns and to delineate a buffer belt for the grazing-exclusion zone of the protected area.

Key words: GIS, participatory approach, extensive grazing, understorey vegetation, Mexico.

RESUME – *"Etude de l'aménagement des pâturages communaux dans une forêt montagnarde au Mexique : Application de techniques requérant l'utilisation de SIG et adoption d'une approche participative dans le développement de stratégies d'aide à la conservation". Pour ces travaux, on a étudié l'emploi d'un Système d'Information Géographique (SIG) suivant une approche participative pour évaluer les ressources pastorales d'une forêt montagnarde située dans la région centrale du Mexique. La région à l'étude se trouvait à l'intérieur d'une zone protégée où les terres étaient en copropriété et les troupeaux d'ovins pâturaient la végétation pastorale de sous-étage. En premier lieu, on a utilisé des techniques d'imagerie satellite pour classer la région à l'étude en fonction du type de végétation. Chaque classe a ensuite été caractérisée sur le terrain, par mesure de la production de biomasse, par étude de la composition de la flore et par détermination des schémas de croissance de la végétation pastorale de sous-étage durant la saison des pluies. Une étude participative a ensuite été conduite avec les petits éleveurs d'ovins pour identifier les espèces fourragères, estimer la taille des troupeaux, et localiser les différents schémas de distribution du pâturage de leurs troupeaux sur des cartes et sur des photographies aériennes. Au troisième stade, on a utilisé un SIG pour établir un lien entre ces données de terrain sur les ressources pastorales et les propriétés biophysiques associées du paysage. Pour finir, on a conduit une analyse au niveau du paysage, pour laquelle on a évalué les densités de chargement actuelles et identifié les zones sujettes au surpâturage. L'analyse a en outre aidé à optimiser les schémas de pâturage, et à délimiter une ceinture tampon pour la zone d'exclusion qui s'applique au pâturage dans la zone protégée.*

Mots-clés : *SIG, approche participative, élevage extensif, végétation de sous-étage, Mexique.*

Introduction

The need to develop sustainable farming systems has motivated the inclusion of environmental conservation issues in agricultural research. In response to this, systems analysis research has focused on the development of generic methodologies not only to support decision-making at farm level, but also to assist policy-making at a regional level (Stoorvogel and Antle, 2001; Thornton and Herrero, 2001).

Extensive sheep production systems are good examples of the need to harmonize economic, environmental and social sustainability issues through the application of adequate analysis tools. Of particular interest is the fact that in this kind of farming system, conservation objectives might be jeopardised by practices associated with communal land tenure and by grazing practices in ecologically sensitive areas.

Advances in the understanding of the interaction between extensive grazing practices and vegetation dynamics of semi-natural ecosystems are key points in the search for sustainable grazing strategies. The production of integrated analysis tools stands as an alternative to project, explore and predict the effect of stocking rates and grazing pressure on the persistence of forage resources. Analysis tools based on Geographical Information Systems (GIS) have become increasingly important in the assessment of forage resources at landscape level (e.g. Hill *et al.,* 1999). The GIS capabilities to query, manipulate and display geo-referenced data facilitate a thorough evaluation of the use and production of forage resources adding a valuable spatial framework to the analysis.

The value of participatory techniques has also been recognised as a driving force in research activities (Chambers, 1997 ; Bocco *et al.,* 2000) and to enhance environmental conservation policies (Velázquez *et al.,* 2001). A concept that has been developed relatively recently is that of "participatory GIS", which implies the involvement of communities in the production of GIS data and spatial decision-making (Abbot *et al.,* 1998).

Thus, under a participatory framework, the utilisation of the forage resource by sheep in a montane forest of central Mexico was evaluated at a landscape level. Since the study area was included in a natural protected area, sheep grazing practices conflicted with conservation objectives. The rationale of this work recognises the role of local sheep smallholders in the enhancement of the conservation purposes of this protected area by means of the sustainable use of the region's grazing resources. Thus, sheep farmers' knowledge and expertise was incorporated in the construction of the GIS-based analysis tool through participatory exercises. This tool was applied to the spatial assessment of both the supply and demand of grazing resources. In this context, the sustainability of grazing resources could be evaluated both at their current use status and through the exploration of different scenarios.

Material and methods

Description of the study area

This study was carried out in the parish of Coajomulco located in the central region of Mexico (19°01'N, 99°16'W) with an area of 6135 ha. As a result of mountainous surroundings, the altitude varies between 2200 and 3200 m, generating a temperate sub-humid climate with annual precipitation averaging 1200 mm. Annual average temperature is 12°C, varying between 6°C and 18°C throughout the year. Montane forest is the principal vegetation type, with dominant tree species of *Pinus*, *Quercus*, *Abies* and *Alnus*.

With the exception of family crop plots, land in Coajomulco is communally owned. Smallholder *campesino* agriculture is practiced for the production of maize, faba beans and ornamental flowers. Oat and potato production for commercial purposes is also carried out. In addition, extensive sheep production is a popular activity that has been boosted by the high demand of sheep meat in the region. Sheep flocks make use of the forest understorey vegetation as well as the scrub and grass that grow in wood-cleared areas. Traditionally, sheep flocks graze during the day, and at night are kept in mobile pens that are rotated across the family plots to improve soil fertility. In the region, shepherding is an essential practice within the sheep production system. Although grazing is practiced throughout the year, agricultural by-products play an important role as a complementary feed source during the dry season.

In 1988, Coajomulco was included within the protected area denominated as "Corredor Biológico Chichinautzin". As a consequence, forest-based activities were strictly regulated. Although sheep flocks can still have access to the woodland's forage resources, a grazing exclusion zone was established to the northeast, enclosing 44% of Coajomulco's total area.

Methodological framework

Figure 1 shows the methodological framework used in this study. The first step to building the GIS was the generation of six different databases to organise the variables related to grazing practices: (i) vegetation distribution; (ii) botanical composition; (iii) biomass production; (iv) edible species; (v) flock inventory; and (vi) grazing distribution. For the organisation of the GIS, the vegetation distribution and grazing distribution databases [(i) and (vi)] contained geo-referenced data, whilst the rest contained attributes linked to the spatial data. The remainder of this section will describe the methodology that was undertaken to build each of these databases.

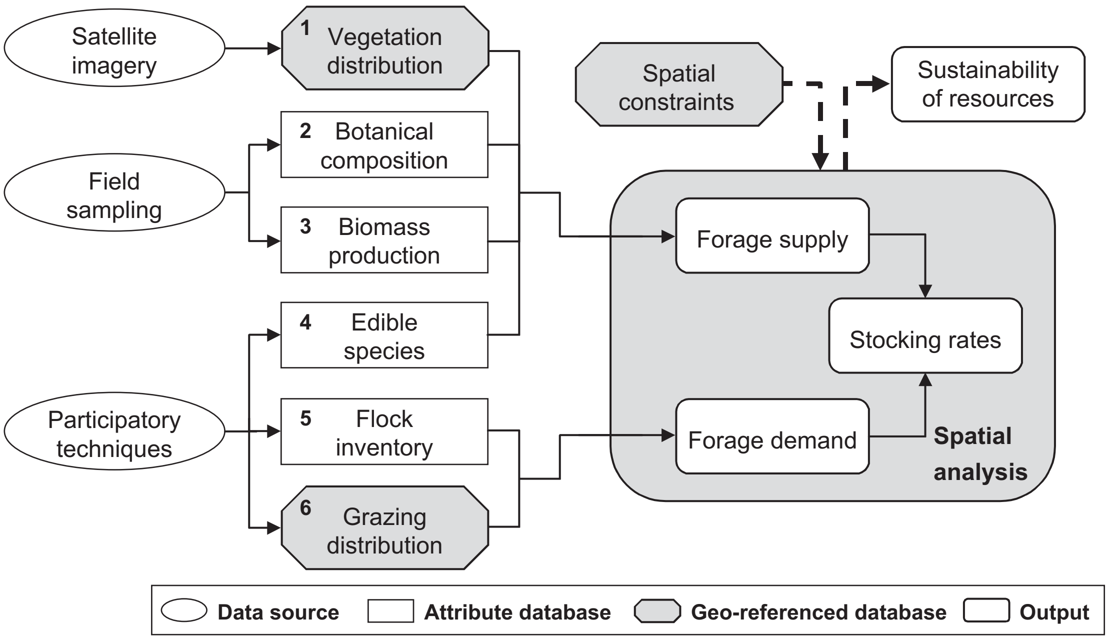

Fig. 1. Methodological framework. Integration of spatial and attribute databases.

Vegetation distribution database

Coajomulco's grazing resources were divided into two groups: (i) scrub and grass; and (ii) understorey vegetation. Different classes of understorey vegetation were identified according to their association with different type of woodlands. It has been suggested that there is an association between understorey vegetation composition and tree canopy structure (Beatty, 1984) and a previous ecological study in the area by (Hernández, 1977) described the presence of such an association. Thus, satellite imagery processing was used to identify the distribution of grazing resources by classifying the vegetation and land use cover of Coajomulco. A maximum-likelihood algorithm (Eastman, 2001) for a supervised classification procedure was used on a set of Landsat 7 ETM+ (Enhanced Thematic Mapper plus) images. A total of ten different classes were used to encompass the landscape variability of the study area. Thus, four different classes described the land use cover: urban, agricultural, scrub and grass and woodland. The woodland class was subdivided into seven different vegetation classes according to the type of wood (coniferous, deciduous or mixed) and the relative proportion of the dominant tree species according to the land use classification published by (CETENAL, 1976). Ground truth data or "training sites" to assist the classification procedure were obtained from a 1:50000-scale land use map (CETENAL, 1976) and a direct field survey with the assistance of a Global Positioning System (GPS) receiver.

Botanical composition and biomass database

Direct field measurements were used to evaluate both the botanical composition and biomass production of the vegetation of the study area. Sampling was carried out over two four-month periods: June to September for the rainy season, and December to March for the dry season. For the design of the sampling strategy, the ten classes of land cover were superimposed on a digitised aerial photograph in a PC-based GIS. A 3313 ha sampling area was defined and, following a north-south direction, parallel transects were drawn across it. The first transect was made on the western boundary of the sampling area and the following transects were spaced at 500-m intervals parallel to the first. This thus gave a total of ten transects, ranging between 2197 m and 8258 m in length, with an average length of 7042 m. With the help of a GPS receiver, transects were walked during sampling and field measurements were pinpointed within the corresponding vegetation class.

Both botanical composition and biomass production sampling were carried out with a 1 m^2 quadrat placed at 250-m intervals along the transects. Four rods were placed at each corner of the quadrat and a string positioned at a height of 1.20 m to set a sampling unit of 1 m × 1 m × 1.20 m. The 1.20-m aboveground limit for vegetation measurements was used as the grazing horizon of the sheep in Coajomulco. Once the sampling unit was defined, the criteria for inclusion of plant species in the measurements was constrained to vascular seed plants such as grasses, herbaceous species and shrub plants. For the evaluation of the botanical composition the dry-weight ranking method ('t Mannetje and Haydock, 1963), modified by (González-Estrada *et al.,* 2002) for complex plant communities was applied.

The biomass production sampling was carried out concurrently with the botanical composition sampling. Once the reading for the dry-weight ranking method was completed, all the plant material included in the sampling unit was carefully harvested by hand. The harvesting was carried out with respect to the plant structures that were likely to be grazed by sheep; therefore only leaves and young stems were collected, whereas highly lignified and decayed material was rejected. The collected material was weighed and subsequently dehydrated at 100°C for 48 hours to determine its dry-matter content.

In order to estimate the forage resources' re-growth capacity, two 4 m^2-grazing exclusion areas were randomly assigned in each woodland class, and a total of six 1.5 m^2-exclusion cages were used in the scrub and grass class. All the grazing exclusion areas were fenced to prevent plant species from being grazed. All the green material (leaves and young stems) was carefully harvested by hand, weighed and dried. During all the rainy season, monthly readings were carried out to estimate the re-growth capacity of both the understorey and the scrub and grass class.

Edible species database

A participatory interview was carried out with some of Coajomulco's shepherds. A herbarium containing the species identified during the botanical composition sampling was presented to them. Shepherds were asked to classify plant species in four categories: (i) edible; (ii) edible but low palatable; (iii) edible and toxic; and (iv) inedible. Species classification with the herbarium was double checked by interactive questioning and direct identification of plant species in the field.

Flock inventory and grazing distribution databases. A participatory exercise with the use of aerial photographs was carried out with sheep farmers. Sheep farmers were asked to sketch on enlarged aerial photographs of Coajomulco the grazing areas that are used by their flocks. Watering points, paths and access routes were also drawn. In addition, sheep farmers were invited to indicate the habitual areas where their own flock are herded. Some information about preference and distribution in time and space of shepherding practices was also gathered. Finally, a sheep farmers' census was updated with flock size information.

Stocking rates analysis

An analysis of the stocking rates during the rainy season was carried out assembling the six databases on a desktop-based GIS. The rainy season was divided in three two-month periods (May-June, July-August, September-October) in order to represent more accurately the seasonal distribution of grazing flocks. Firstly, an assessment of the current grazing regime was undertaken. Subsequently, the system was used in conjunction with non-linear optimisation techniques to produce an appropriate scenario where the grazing pressure was in accordance to both the conservation objectives of the protected area and the necessary forage supply for Coajomulco's sheep flocks.

The seasonal dry-matter production of edible species within each grazing zone was calculated. To do so, a spatial analysis was performed using the two geo-referenced databases: grazing zones distribution and land use/vegetation distribution database. The attributes' databases for biomass, botanical composition, edible species and flock inventory were linked to the analyses as represented in Fig. 1. For the assessment of the forage consumption, an average body weight per animal was set to 50 kg and a daily dry matter consumption of 1.1 kg.

Results and discussion

Vegetation distribution database

Table 1 summarizes the results of the satellite imagery classification procedure. The urban and agricultural classes were excluded from subsequent analysis. The vegetation was therefore distributed in eight different classes, seven classes for the woodland varieties and one scrub and grass class. The understorey vegetation sampling for biomass and botanical composition was carried out with reference to the geographical location of these classes.

Table 1. Supervised classification results on the satellite imagery of Coajomulco

Class	Area (%)	Woodland type†	Predominant tree species
Urban	0.5	–	–
Agricultural	8.9	–	–
Scrub and grass	16.4	–	–
Vegetation A	8.3	C	*Abies religiosa*
Vegetation B	32.0	C/D	*Pinus teocote, Pinus leiophyllus, Alnus jorullensis*
Vegetation C	12.9	C/D	*Pinus teocote, Quercus rugosa, Alnus jorullensis*
Vegetation D	8.6	D	*Quercus obtusa, Quercus rugosa, Arbutus glandulosa*
Vegetation E	4.2	C/D	*Pinus leiophylla, Alnus jorullensis, Pinus teocote*
Vegetation F	6.4	C	*Pinus montezumae, Pinus leiophylla, Abies religiosa*
Vegetation G	1.7	C	*Abies religiosa, Pinus montezumae*

†C = coniferous, D = deciduous.

Botanical composition database

A total of 273 different species were recorded across the eight vegetation classes. Table 2 shows the number of plant species recorded in each class. To assess concordance between botanical compositions in the seven vegetation classes, the Spearman's rank-order correlation coefficient (r_s) test was carried out. r_s values exhibited non-significant correlations ($P > 0.05$) between all of the botanical compositions obtained in each vegetation class. This statistical evidence suggested that there was indeed a strong association between the understorey vegetation and the tree species distribution that defined the layout of the vegetation classes. This finding is considered essential for further exploration of grazing resources through remote sensing in the area.

Table 2. Number of plant species and dry matter production during the rainy season for the plant material and edible plant material for each vegetation class registered during field sampling and participatory identification of edible species

Class	Plant material		Edible plant material	
	No. species	Dry matter/ha	No. species	Dry matter/ha
Vegetation A	27	791.93 kg	15	512.91 kg
Vegetation B	52	965.58 kg	28	564.38 kg
Vegetation C	110	357.08 kg	38	177.93 kg
Vegetation D	95	787.71 kg	41	394.72 kg
Vegetation E	50	1014.30 kg	25	553.60 kg
Vegetation F	38	691.42 kg	16	344.88 kg
Vegetation G	42	1215.17 kg	20	607.58 kg
Scrub and grass	46	1945.57 kg	38	1556.46 kg

Edible species database

Shepherds regarded a total of 127 plant species as edible and edible but low palatable. Some of the most common edible species that predominated in the understorey vegetation of different woodland classes were herbaceous species and shrub plants such as *Cunila lythrifolia*, *Salvia* spp., *Buddleia* spp., *Fuchsia microphylia* and *Stellaria cuspidata*. In addition, there were several grass species, of which the main genera were *Muhlenbergia*, *Stipa*, *Piptochaetium*, *Aristida* and *Vulpia*. Edible species in the scrub and grass class was dominated by grassy species. Some of the major species in this category were *Pennisteum clandestinum*, *Bromus carinata*, *Muhlenbergia macroura*, *Stipa constricta* and *Vulpia myuros*. Table 2 shows the distribution of edible species in the different vegetation classes as well as their correspondent seasonal biomass production value.

Flock inventory and grazing distribution databases

From the information sketched on aerial photographs, seven different grazing areas were identified. These are located around the parish town, three in the south, one in the east, one in the west, and two in the north. They were numbered clockwise starting from the one located in the most northern zone. Table 3 shows the extension of each of these zones. When the sketched zones were set up in the GIS it was found that 23% of the grazing zone 3 lay within the official grazing exclusion zone.

Table 3. Extension of grazing zones and their correspondent stocking rates values and grazing pressure indicators during the rainy season

Grazing zone	Extension (ha)	Stocking rate (head/ha)			Percentage of utilisation	Effect of grazing pressure†
		Bimonth 1	Bimonth 2	Bimonth 3		
1	35.52	0.37	0.39	0.56	23.2	+
2	179.80	0.75	1.87	1.60	25.2	++
3	256.76	2.09	1.83	1.52	33.7	-
4	67.76	3.35	3.41	3.82	48.3	--
5	58.32	3.41	3.41	3.82	60.2	---
6	39.76	0.55	0.55	0.00	15.6	+
7	146.64	1.45	0.98	1.33	55.7	-

†Negative (-) or non-negative (+) effect.

Through the participatory exercise it was found that access to the different grazing zones was done initially through the main path that ran in the middle of the town from south to north. Subsequently, agricultural land location and terrain features influence the distribution and accessibility of the grazing areas. It was also identified that the selection of the areas was mainly influenced by the proximity to night enclosure sites and one watering point situated in the grazing zone 3 (northeast). The sheep farmers' census recorded 31 sheep farmers in Coajomulco with an average flock size of 43 adult animals. This information was used to estimate the number of flocks, and consequently the number of sheep that had access to each patch of grazing area. It was identified that during the rainy season 65% of the flocks did not change their grazing area, 20% were changed once, and 15% did so twice.

Stocking rates analysis

Current scenario

The GIS-based analysis produced the stocking rates for each grazing zones, as well as an indicator of the degree of utilisation of the forage resources. Table 3 indicates the stocking rate values obtained throughout the three bimonthly assessments. Table 3 also indicates a overall percentage of utilisation of the forage resource in each zone. It can be appreciated for example, that the percentages of utilisation in zones 1 and 2 are very similar, but the stocking rates are much lower in zone 1. On the other hand, although the stocking rates in zones 4 and 5 are almost equal, the effect of them on the percentage of utilisation is different. The divergence between stocking rates and utilisation is due to the mosaic of vegetation classes within each grazing zone.

In addition, Table 3 indicates an estimation of the impact on the conservation value that the current grazing pressures exert over the forage resource. A key point in the search for sustainable stocking rates is the estimation of the maximum level of utilisation of the forage resource that does not affect plant regrowth potential after defoliation. According to (Mitchell and Kirby, 1990), grazing levels that produce woodland with maximum nature conservation value lie around what they considered a moderate level. Although the quantification of this "moderate level" is very specific for each case, the publications of (Grant and Armstrong, 1993; Mayle, 1999; Reimoser *et al.,* 1999) were used as guidelines. According to these authors' considerations and the visual assessment of the field site, the maximum level of utilisation was set at 30% for the understorey vegetation in woodland and 60% for the scrub and grass vegetation. Thus the sensitivity of each grazing zone to the grazing pressure will depend on the ratio woodland:scrub and grass class. It is interesting to notice that for example, the effect of grazing pressure for zones 3 and 7 was equally rated as (-), despite the fact that the percentage utilisation is 33.7% and 55.7% respectively. In this case, grazing zone 3 comprised almost exclusively woodland classes.

Alternative scenario

The development of an optimal scenario reduces the area of the grazing zone 3 by 23% setting up a buffer belt for the grazing exclusion area located at the west. Grazing zones 2, 4, 5 and 6 where identified without physical restrictions to be expanded. The non-linear optimisation model modified the number of flocks grazing in each zone in order to produce grazing pressure values with non-negative effects on the forage regrowth potential. Consequently, the extension of grazing zones 2, 5 and 6 was increased by 95%, 68% and 72% respectively. The location of supplementary feeding or watering sites was pinpointed on the systems in order to encourage sheep to make a thorough use of the expanded grazing zones. Under this scenario stocking rates (head/ha) across the vegetation zone and along the rainy season averaged 1.42, with a maximum and minimum value of 2.33 and 0.55 respectively.

Conclusion

The analysis and results of this work made evident the advantages of integrating GIS in the study of extensive grazing systems. The inclusion of participatory techniques was a key element in the development of this methodology. Through this methodological approach the trade-offs between agricultural and conservation objectives can be analyzed within a extensive grazing framework. An understanding of the dynamics in the use of grazing resources at a landscape scale is critical for identifying and assessing the ecological impacts of extensive sheep systems. It is necessary to improve the use of this methodology through a better understanding of the interaction between sheep and the understorey vegetation of temperate forests.

The core of the methodology presented here can be expanded through the integration of biological simulation models and more complex optimization techniques (e.g. multiple criteria, neural networks) in the development of a more versatile decision-support tool.

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