MAPPING FOR DECISION MAKERS: A LAND ALLOCATION METHODOLOGY FOR RURAL COMMUNITIES IN MEXICO

Edward Chart, Janet Mersey
Department of Geography, University of Guelph, Canada

Introduction

With the merging of decision making tools within computer based geographic information systems a new tool has emerged which provides land management organizations, tasked with making decisions on how land should be used, with an efficient and adaptable way of tackling land use allocation problems. For land management organizations, decisions about land use are implicit in their implemention of sustainable development concepts in rural regions. Decisions about what is, and what is not sustainable has meant accepting trade offs in the allocation of land resources at all levels (Davies and Young 1995).

Many regions in rural Mexico are currently grappling with these types of concerns (Jardel et al. 1992). These problems are often associated with rapid economic development, where there exists little room for concern over the survival of the local ecosystem (Grindle 1986). The Sierra de Manantlan Biosphere Reserve (SMBR), located in west central Mexico, in the state of Jalisco, is one of these regions. The SMBR offers the opportunity to examine the application of a regional planning objective, designed to efficiently manage land in the reserve at the communal land ownership level (Graf and Rosales 1996; Bird 1997). Within the reserve, communal land ownership operates under several land tenure systems. The most common form is the *ejido* system, which is a communally governed region divided up amongst a formerly landless peasant population (Gerritsen 1995).

This paper will look at the application of the IDRISI-UNITAR multi-criteria decision making module as a means for preparing a land use allocation model for the Ejido Zenzontla, located partially within the core zone of the Sierra de Manantlan Biosphere Reserve. The Ejido Zenzontla case study will examine the step by step application of the IDRISI-UNITAR multi-objective land allocation model. This paper will outline the critical steps in the process, how these steps were completed.

Ejido Zenzontla

To understand the current troubles facing the Ejido Zenzontla it is important to review recent local history. At the end of the Mexican Revolution in 1920, *hacienda* lands were broken up and turned over to the local peasants that had worked on them. These land grants were known as Ejido's, and represented the fruits of Emiliano Zapata's peasant uprising over their claim to local land and water rights in 1911. On the 21st of November 1945, 630 hectares were granted to the newly designated Ejido Zenzontla, with several informal additions later. The first formal addition to the Ejido occurred in 1980 through presidential decree and represented an additional 3,714 hectares, making up the majority of land currently held by the Ejido. With the passing of article 21 in 1994 the Mexican government radically changed the traditional ejido system. Moving it from a traditional internally closed common land system to a more open one, where land could be bought and sold.

The primary land-use priorities in the Ejido Zenzontla were identified through the consultation process with local inhabitants and researchers within the Manantlan Institute of Ecology Conservation Biology (IMECBIO), followed by a review of the local community development research conducted by the institute. In order to avoid being overwhelmed by the complexity of small scale local land-use activities, the selection of a few macro scale activities, that would be well suited to spatial mapping at the regional scale, was considered most suitable for this research. The three land-use priorities identified as most important to the Ejido Zenzontla were, maize agriculture, cattle ranching and conservation.

Maize Production Factors

In any agricultural activity, topography is a key element in the evaluation and management of land (Van der Zaage 1988). It effects how efficiently land can be cultivated and how accessible the land is for cattle grazing. It also plays a key role in determining the sensitivity of land to erosion (Parsons et al.1981; Benito and Pascal 1998).

When questioned about cultivation of maize, slope was the factor most often cited in interviews with SMBR researchers and local farmers, as being significant in deciding how maize would be cultivated on a given piece of land. Although not the only factor, slope plays the dominate role in determining erosion rates, especially in warm wet climates of the Sierra Madre del Sur (Millward and Mersey 1998). Local awareness of the relationship between steep slopes and erosion rates has recently been highlighted in the SMBR by the use of stone terracing on some farmlands in the regions to control soil loss through runoff erosion. Steep slopes also directly effect the type of farming practice which farmers can use on their fields (Gerritsen 1995). When dealing with gentle slopes, farmers may employ the *yaunta de lluvia* (rainfed) and *yuanta de rego* (irrigated) cropping styles. With slopes greater 15% however, farmers employ the more traditional *coamil* (rotational) style of farming (Gerritsen 1995).

Water accessibility was another significant factor in maize cultivation cited in interviews with SMBR researchers and local farmers. The current situation with respect to water availability in the SMBR and surrounding regions can be best described as seasonally dependant. As noted by van der Zaage (1988) the lands within and surrounding the SMBR suffer from an acute shortage of water during the dry season (November-June). The most serious problems occur when extreme shortages, due to periodic variations in the climatic cycle, increase the pressures for limited water supplies by local farming, industrial and residential concerns. The primary source of water in the River Ayuquila comes from precipitation high up in the Sierra Madre del Sur.

Pasture Production Factors

Slope steepness was identified as a critical issue by local farmers, next to disease and pests. Farmers acknowledge that steep terrain is a common cause of cattle loses (Benito and Pascal 1998). Steep slopes are therefore a problem for cattle and make for poor locations for pasture lands. Due to the limited amount of suitable land in the region, even marginal land is used for pasture. By incorporating slope into the analytical procedure steep lands can be avoided as much as possible. The importance placed on water accessibility for cattle is similar to that for agriculture. Though not a specific concern for the development of pasture lands, with many natural species well adapted to the region climatic conditions, the stress placed on cattle during the dry season is significant. The inclusion of vegetation is obvious, as an indicator of important natural pasture species. As with maize, the most feasible factor to employ as a measure of lands with suitable water access is their distance to water sources, primarily rivers. With the locations of rainfed cisterns being difficult to identify due to their small size and distribution, river systems serve as a the only suitable alternative, and are actively employed by farmers as watering locations for cattle. The less a farmers has to move his cattle to water, the better, and fields located near rivers will also produce a higher quality fodder more quickly and are able to produce during dry periods. Climatic considerations for cattle livelihood are very important, especially in the more exposed dry land forest regions within the region (Gerritsen 1997; Benito and Pascal 1998). Heat stroke has been identified as another significant cause of cattle mortality in the region (Jardel 1996; Benito and Pascal

1998).

Conservation Factors

Slope was selected due to the significant threat of erosion faced along steep slope regions. As noted by past researchers, during the rainy season when local rivers exhibit a large sediment carrying capacity, which reflects sediment loss from exposed fields. Using the slope model, conservation activities are identified as most desirable on steep slope regions where soil loss is a problem and ecological biodiversity is high. Vegetation diversity captures both the importance local people place on the gathering of fruits, wood from within the Reserve as noted by (Jardel et al. 1992; Jardel et al. 1993), but also the natural ecological diversity that exists in the region and is significant to research activities. Proximity to the core zone reflects the current preservation activities of the SMBR, were core zones are viewed as the most sensitive, and surrounding regions are treated as buffer zones.

Landuse	Factor	Data Source
Maize	Slope	[illegible]
	Soil	[illegible]
	Temperature	[illegible]
	Precipitation	[illegible]
	Water Access	[illegible]
Cattle Grazing	Slope	[illegible]
	Vegetation Type	[illegible]
	Temperature	[illegible]
	Precipitation	[illegible]
	Water Access	[illegible]
Conservation	Slope	[illegible]
	Vegetation Diversity	[illegible]
	Proximity to Core Zone	[illegible]

Creation of the Factor Maps

Having selected the research locations, identified the main land-use priorities and selected the factors that will represent each of the land-use priorities, the next stage in the project is the creation of the maps which represent the spatial distribution of each of the factors. Each map was developed separately using the data available from the SMBR and IMECBIO.

Factor Standardization

Following the creation of the factor maps, which used various units of measure, each map was standardized to a common scale or value range in order to permit the map combination procedure required to create the each suitability map. The need for a common data range in raster based map overlay procedures is due to the variable nature of data mapping, where data limits are rarely consistent between different themes (ie. degrees for temperature; metres for elevation). Each factor map was standardized to a common range of 256 classes, the largest range allowed in IDRISI, in order to capture the maximum resolution possible in the topographic data. Several standardization approaches were used in this research to accomplish this task. Boolean classification, which is defined as a hard classification method, uses both obvious and forced separation in the data as locations for division. The second approach used in the research was a linear stretch classification.

Factor Weighting

Factor weighting is an important aspect of any decision procedure because it captures the level of influence that each factor has in the development of the suitability maps, and by consequence the final allocation map. Factor maps are the base from which suitability is determined, the weighting of factors allows this base to reflect the realities of local the condition as accurately as possible.

To develop weights for each of the factors identified for each land-use, a systematic approach to weight selection was conducted using matrix based questionnaires. Pairwise comparison matrices were constructed for each of the three land-uses. This allowed comparisons among the various factors to be made using a nine point continuous rating scale. Each respondent was asked to fill out the matrices for each objective. Twelve candidates were selected from the research staff at IMECBIO and management staff at the SMBR.

Of the twelve questioned, seven fully responded to the matrices. Five of the respondents were from IMECBIO those backgrounds covered a wide range of research activities; two respondents were from the SMBR.

A completed pairwise comparison matrix contains within its structure, multiple factor associations, from which the relative importance of a factor to factor comparison can be verified. These multiple comparisons are used to evaluate the consistency of a respondents evaluation of the factor relationships within the pairwise comparison by means of a consistency ratio. This ratio indicates the probability that the matrix ratings were randomly generated. Consistency ratios were generated for each of the factors using the IDRISI MCE module. A consistency score greater then 1.0 suggests that the rating has been randomly generated, or contains a number of logical inconsistencies and needs to be reevaluated.

Respondents were asked to fill out a maize and pasture comparison matrix with 5 factors, and a total of 10 weighted factor comparisons. For conservation the respondents were asked to fill out a comparison matrix with 3 factors, and a total of 6 weighted factor comparisons. The matrices were filled out for the Ejido Zenzontla using a nine point weighting scale. Of the 9 individuals asked to fill out matrices, 7 individuals responded. Each completed matrix was then converted from a fractional weight to a weighted score, using the IDRISI weighting module, and verified for consistency.

Multi-Criteria Evaluation (MCE)

The MCE procedure involves the combination of each of the factors maps with their corresponding weights to form a final image showing the most suitable locations for a particular activity (the MCE). In IDRISI there are three options for creating the MCE's, these are through boolean intersection, weighted linear combination and ordered weighted averaging.

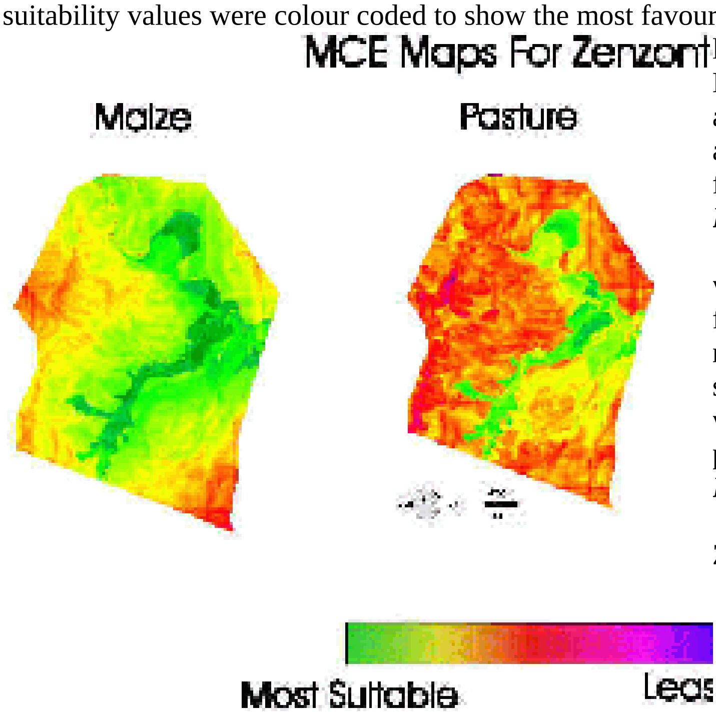
In this project, the weighted linear combination was chosen as it is the approach most commonly used in multi-criterion evaluations (Voogd 1983). The structure of the weighted linear combination operation which conducted on a cell by cell basis, is as follows:

$S = w_i x_i$ *(Of cells)*

Where: $S =$ is the suitability score (0-255).
$w_i =$ is the weight for factor i (0-1).
$x_i =$ is the score for factor i (0-255).

Using the IDRISI MCE module this procedure is accomplished by multiplying each factor map (i.e., the raster cells within each map) by its weight and then summing the results. The weights must sum to 1, thus the resulting suitability map will have a range of values that mirror the distribution of standardized values in the original factor map used.

Three suitability maps for the study region were constructed using this procedure. The range of suitability values were colour coded to show the most favourable lands in green and the least favourable lands in blue. Land areas excluded from the MCE's are shown in black and represent land areas that are either out side of the Ejido or are areas that have been excluded in the factor maps.



Maize

The maize MCE maps for Zenzontla were constructed from five equally weighted factor maps. Using equally weighted factor maps in this approach gives each factor the same level of importance when determining which area is most suitable for maize production.

Pasture

The pasture MCE maps for Zenzontla were constructed from five weighted factor maps. The weights used for the factor maps in this approach are based on a single pairwise comparison matrix, the only matrix that passed the consistency evaluation. The weighted factor maps for pasture allow dominant factors to play a more important role in the identification of suitable areas.

Conservation

The conservation MCE maps for Zenzontla was constructed from three weighted factor maps. The weighted factor maps in this approach are based on two pairwise comparison matrices, the two matrices that passed the consistency evaluation. The weighted factor maps for Conservation allow for dominant factors to play a more important role in the identification of suitable areas.

Multi Objective Land Allocation (MOLA)

The MOLA module in IDRISI has been designed to deal with conflict resolution in multi objective problems. The MOLA procedure requires that each suitability map (MCE) be weighted and a corresponding land area target assigned to each landuse. The procedure then iteratively reclassifies the ranked suitability maps to perform a first stage allocation, checks for conflicts, and then allocates conflicts based on minimum-distance-to-ideal-point rule using the weighted ranks (Eastman et al. 1993). The process then continues until a solution achieved. In this paper two weighted MOLA allocation scenarios are presented to demonstrate the flexibility of the MOLA procedure in providing land-use managers with potential allocation patterns. The first scenario was conducted with an equal weighting amongst all the suitability maps. This was done to create a baseline allocation from which to compare subsequent allocations and test the sensitivity of the allocation procedure to differentiate between different objective prioritizations. The second allocation scenario was conducted with the weight placed on maize agriculture.

Land Target Development

The land targets for maize were based on data from both the annual maize production and the mean productivity of the land with Zenzontla. The annual maize production for a family of four was used to estimate the production of maize in (kg) required throughout the region for the whole population. The mean annual maize production(kg) was then divided into the mean productivity of the land in (kg per hec). This yielded an area value that represented the average amount of land required to be under cultivation to meet basic farmer requirements based on the last five years of crop production.

The land area target values for pasture land were derived from estimates of the number of cattle residing within the study region. Several recent surveys have been conducted to identify the number of cattle farmers are maintaining on the land. These survey estimates were adopted as the number of cattle within the region. The amount of land required to maintain the cattle was ascertained by estimates of stocking rates, identified by the surveyors, from there talks with farmers and through independent observations. The stocking rate was determined to vary between 1.0 to 2.5 cattle per hectare. The value varied depending on location as well as on the quality of the cropping season. When crop production is low the crop residues are poor and the amount of cattle that can be sustained drops. The worst case scenario for stocking rates (1.0) in the region, as reported by the researchers, was used as the average stocking rate in both regions. The stocking rate multiplied by the number of cattle with each region provided the total amount of land required to support the herds for one year.

The land target for conservation was first considered to be equal to the amounts encompassed by the region that fell within the borders of the core zones. However the logic behind this was not in keeping with the goals of the study which were to identify all areas of potential use or preservation. The best method for obtaining a conservation target is to identify minimum areas required to support a healthy ecology. This requires a through understanding of the fauna that live within the region and what there mobility habits are, and a full understanding of the florae within the region. Currently, this information not available or is not fully completed. However, recent research on species diversity does show that some locations outside of the core zones contain significant biological diversity. It is logical then to consider all areas not assigned to agriculture as having a conservation potential until more information is forthcoming.

Zenzontla Equal priority Scenario

The first scenario run was the baseline allocation, where each land use is treated as being equally important, with no priority given to satisfying the objectives land requirements. In order to setup an equal weighted allocation scenario each objective was given an weight value of 0.33. The land area targets were calculated using the data provided above. The MOLA module output for the equal

weighted land-use allocation pattern for Zenzontla shows a well clustered concentration of locations for maize, pasture and conservation activities. The allocation of agricultural areas appears located primarily around the main river channels of the Ayuquila and Passion rivers. Agricultural zones also appear well intermixed with large islands of land zoned for pasture. While less homogenous in structure, the areas identified for pasture land appear large and dispersed, throughout the agricultural zone. Land allocated to conservation appears very widespread, it is shown covering large areas of the region especially in the south and southwest proportion of the Ejido. In the development of the approach, conservation has been treated as an open ended target. This means that targets are calculated for both grazing and crops, the total of this land area is then subtracted from the total land area to arrive at the maximum amount of land not required to meet other demands that may have possible conservation potential.

Zenzontla Maize Priority Scenario

The second scenario was conducted with a allocation bias towards maize agricultural with pasture and conservation remaining equal. The weighting approach for this scenario was .5 for maize, .25 for conservation and .25 for pasture. The MOLA output for this scenario shows visually notifiable change in activity pattern. The change is most noticeable in the lands allocated to pasture and maize. With maize as the dominant factor, land originally allocated to pasture located in the east central portion of Zenzontla has shifted to maize. Pasture land has been moved to lands located further south in areas originally allocated to conservation. While many small pockets of pasture land also appear scattered throughout the Ejido.

Concluding Remarks

As noted above land tenure within the Zenzontla Ejido is serious issue, which is difficult to clearly characterize. The tenure situation in Zenzontla is quite complex, with the traditional concept of communal land having been long since redefined by the political elite in each region. Clearly then any discussion about land allocation must consider the reality of land-use conflicts in their various manifestations within the region. It is quite possible that MOLA can further the goal of compromise and facilitate conflict resolution, by helping land management organizations explore allocation options from various perspectives more easily. It is important to realize, however, that MOLA is not a perfect solution to the land-use conflict problem. At best it represents only an objective assessment based on imperfect data. To become truly valuable to the management of land in the Ejido and SMBR, it requires the active integration of local and expert knowledge, to review and refine data to better reflect the on site realities of farming and management in rural subsistence agricultural communities.

References

Benito, C., L. Pascal. 1998. *Diagnostic de L'activite d'elevage dans la Reserve de Biosphere de la Sierra de Manantlan, Mexique: Le Cas Du Secteur Ejidal*. IMECBIO, CUCSUR. Universidad de Guadalajara CUCSUR, Autlan, Jalisco.

Biot, Y., P.M. Blaikie, C. Jackson, R. Palmer-Jones. 1995. *Rethinking Research on Land Degradation in Developing Countries*. World Bank Discussion Papers. # 289.

Bird, A.C. 1997. *Sierra de Manantlan Biosphere Reserva Project: GIS Consultancy*. Prepared for the Overseas Development Agency, London, England.

Davies, J., E.Young. 1995. Sustainable Development and Rural Aboriginal Communities. *Australian Geographer*. 26 (2): 150-155.

Eastman, R.J., A.K. Kyem, J. Toledano, W. Jin. 1993. *GIS and Decision Making*. United Nations Institute for Training and Research. Explorations in Geographic Information Systems Technology, Volume 4. UNITAR European Office, Geneva, Switezland.

Gerritsen, P.R.W. 1995. *Styles of Farming and Forestry: The Case of the Mexican Community of Cuzalapa*. Circle for Rural European Studies, Wageningen, Netherlands.

Gerritsen, P.R.W. 1997. *Farmer Perception, Valuation and Management Practices of Ecosystems* (Draft). IMECBIO, CUCSUR, Universidad de Guadalajara, Autlan, Jalisco.

Graf, S.H.M., J.J.A. Rosales, 1996. *Analisis Sociodemografico de la Reserva de la Biosfera Sierra de Manantlan y su Region de Influencia*. IMECBIO, CUCSUR, Universidad de Guadalajara, Autlan, Jalisco.

Grindle, M.S. 1986. *State and Countryside: Development Policy and Agrarian Politics in Latin America*. The John Hopkins University Press, Baltimore, Maryland.

Jardel, E.J., R. Gutierrez, P. Leon. 1992. Conservacion de la Diversidad Biologica y Problematica Agraria en la Reserva de la Biosfera Sierra de Manantlan. A.L. Anaya (ed.) In *Las Areas Naturales Protegidas De Mexico*. Mexico City, D.F..

Jardel, E.J., A.L. Santiago, M.E. M. Munoz 1993. El Bosque Mesofilo de Montana de la Sierra de Manantlan. *Tiempos de Ciencia*. 30: 20-28.

Jardel, E.J. 1996. Efectos Ecologicos Y Sociales De La Explotacion Maderera De Los Bosques De La Sierra De Manantlan. In *IV Coloquio Internacional De Occidentalistas*. Universidad De Guadalajara, Guadalajara, Jalisco.

Millward, A.A., J. Mersey 1998. *Mapping and Modelling Soil Erosion Potential in the Sierra de Manantlan Biosphere Reserve, Mexico.* (MSc. Thesis) Department of Geography, University of Guelph, Ontario.

Parsons, David B. 1990 (re-issued 1997). *Manuales para Educacion Agropecuaria: Maiz.* Trillas/SEP, D.F.

Santiago, A.L., E.J. Jardel. 1993. Composicion Y Estructura Del Bosque Mesofilo De Montana En La Sierra De Manantlan, Jalisco-Colima. *Biotam*. 5 (2): 13-26.

Voogd, H. 1983. *Multicriteria Evaluation for Urban and Regional Planning*. Piron, London, England.