Spatial Decision Support for Urban and Environmental Planning

A collection of case studies

Edited by
Davide Geneletti and Alias Abdullah

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PREFACE

It took us more than a year to have this book published and ready for lecturers, scholars, researchers, students and the public to use as reference. This book would not have been possible without the assistance and support of many individuals, organizations and more importantly the Publisher (i.e. Arah Pendidikan). This book attempts to create research collaborations and exchange of knowledge between scholars from different countries and continents. Firstly, we want to acknowledge the contribution by Emeritus Professor Richard E. Klosteman, President and CEO of What if?, who wrote introduction where he overviewed the whole scenario on the past, present and future of computer applications (particularly Spatial Planning and Decision Support Systems or SPDSS) in urban and environment planning. We are also grateful to all the authors who contributed to the other chapters and who helped us with the peer review. We would like to thank M.A. Sharifi and Javier Martínez from ITC, The Netherlands; Antonella Zucca from University of Milan, Italy; Inés Santé-Riveira, Rafael Crecente-Maseda, Marcos Boullón-Magán and David Miranda-Barros from University of Santiago de Compostela, Spain; Davide Geneletti from University of Trento, Italy; Stefano Bagli and Paolo Mazzoli from GECOsistema srl, Cesena, Italy; Alberto Pistocchi from Provincia di Napoli, Italy; Piergiogio Valentini from Provincia di Milano, Italy; Nor Sallehi Kassim from Federal Department of Town and Country Planning, Malaysia; Rafikul Islam, Alias Abdullah, Mansor Ibrahim and Muhammad Faris Abdullah from International Islamic University Malaysia (IIUM), Malaysia; Manuel Mendoza, Erna López, Luis Miguel Morales-Manilla and Gerardo Bocco from Universidad Nacional Autónoma de México, Mexico; and Camilo Alcántara from Wisconsin University, USA for contributing their articles and sharing their knowledge and experiences. To our colleagues, Michael Batty (Bartlett Professor of Planning at University College London, UK), Jacek Malczewski (Professor, University of Western Ontario, Toronto, Canada), Dr. Luc Boerboom (ITC, The Netherlands), Dr. Marjan van Herwijnen (vrije Universiteit, The Netherlands), Ruslan Rainis (Professor, Universiti Sains Malaysia), Ahris Yaakub (Professor, Universiti Teknologi Malaysia) and Muhammad Nur Azraei (IIUM Consultancies Sdn. Bhd.) whose active involvement, research and publications encouraged the growth of GIS and SPDSS applications in urban and environmental planning, your support is greatly appreciated.

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Chapter 2

Optimising Land Use Allocation At Municipal Level By Combining Multicriteria Evaluation And Linear Programming

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This chapter describes the use of a Spatial Decision Support System called RULES in the development of a general land use plan for the municipality of Guitiriz, NW Spain. The data, procedures, and model used in developing the plan are described. Firstly, suitability maps for each land use were obtained by means of the ideal point analysis, which is a multicriteria evaluation method that allows to modify the degree of compensation among the evaluation factors. Subsequently, the land use areas were optimised by using a linear programming model whose objective functions include the maximisation of gross margin, rural employment, cultivated land, and naturalness of vegetation, as well as the minimisation of production costs and use of agrochemicals products. Finally, an optimisation algorithm based on the simulated annealing was used for the spatial allocation of urban growth and of agricultural and forestry uses. The land use plan obtained using this system was compared with the existing land use plan, which is currently being processed. The results of this comparison lead to a series of conclusions concerning the effectiveness and usefulness of this tool as a means of supporting the development of planning laws.

Keyword

Spatial decision support system
Rural planning
Land evaluation
Land use plan

INTRODUCTION

e complexity of the land use planning process has increased because of the increasing number of conflicting interests, the need to facilitate public participation, increased demand for better information and justification of decisions, and the reduced time available for the design of land use plans. Consequently, numerous computer-based tools have been developed to assist planners and technicians in the analysis and design process (Klosterman, 2001). However, it remains necessary to demonstrate the efficiency of these systems in terms of planning practice and real-life planning problems (Geertmand and Stillwell, 2003). To accomplish this, it is necessary to measure in definable ways the capacity of such systems to support planning in the political arena (Brail, 2001).

The process of land use planning involves different stages that require different types of analysis (van Ittersum *et al.*, 1998). A number of software applications have been designed to assist in the evaluation of land suitability. Such applications include ALES (Rossiter, 1990), MicroLEIS (De la Rosa *et al.*, 1992), and ArcviewLESA (Day *et al.*, 2000). Other systems analyse the optimum area for each type of land use: GOAL-QUASI (van Ittersum, 1995) and ADELAIS (Siskos *et al.*, 1994). However, there are currently many applications that deal with multiple land use planning stages, such as What-If (Klosterman, 1999) and SIRTPLAN (FAO, 2000). Most land planning software focuses on urban planning, e.g. CommunityViz (Kwartler and Bernard, 2001), UrbanSim (Waddell, 2000) and Smartplaces (Croteau *et al.*, 1997). Other systems are specifically designed for agroforestry use, including LADSS (Matthews *et al.*, 1999), AEZWIN (Fischer *et al.*, 1998), LUPAS (Roetter *et al.*, 2005), and NELUP (Watson and Wadsworth, 1996). For a complete review of these systems, see Sante and Crecente (2006). In the present paper, a Spatial Decision Support System termed RULES (Santé and Miranda, 2006) is applied to a rural municipality in Galicia, NW Spain, for the purpose of rural and urban land use planning.

A law recently passed in Galicia – *Law 9/2002 of Urban Planning and Preservation of the Rural Areas of Galicia* – establishes the obligation of each municipality to develop a general land use plan (*Plan General de Ordenación Municipal – PGOM*). Most municipalities in this region are rural municipalities, characterized by extensive areas of agriculture and forestry and a scattered population that largely resides in small settlements. A lack of experience in developing this type of plan and a shortage of methodologies or models for land use planning that are adapted to this region has led to an increasing demand for tools and systems that facilitate the land use planning process.

This paper describes the application of RULES in developing a *PGOM* for the municipality of Guitiriz. This *PGOM* must be consistent with Law 9/2002, including the need to consider both urban and rural land use categories. This study aims to identify the ways in which RULES can improve this type of land use plan, including facilitating the management and processing of information, providing a structured and quantitative methodology, numerically analysing the consequences of planning decisions, the provision of justification of the decision-making process, and the design and evaluation of different land use scenarios. Likewise, the weaknesses of the system, in terms of the development of this kind of plan, will be assessed, such that a series of conclusions can be drawn regarding the improvement or extension of the system. The obtained results will be used to evaluate the global applicability of the system to elaborate upon the land use plans. A comparison of the land use plan generated by the proposed system and the land use plan that is currently under administrative proceedings (and which has been designed without the use of a planning support system) will enable the identification of areas of potential improvement in RULES, as well as those areas that already function well.

This paper begins by briefly describing the system and the tools available in the system that can be used to support decision-making at different stages of the land use planning process (Section 2). Section 3 provides a description of the data, procedures, and techniques applied in using RULES to develop the *PGOM* for the municipality of Guitiriz. This section also includes an analysis of the obtained results and a comparison with the current land use plan. Finally, Section 4 analyses the strengths and weakness of the system in terms of the design of land use plans and support for the application of the new planning law.

DESCRIPTION OF THE RULES SYSTEM

RULES integrates three stages of a land use planning process in such a way that the results of one stage can be used as input data for a different stage. To achieve this, several analytical models for each of the three stages have been included in a single GIS: GeoMedia Professional®. The three stages correspond with three systems modules: (1) land evaluation, (2) area optimisation and (3) spatial allocation.

Land Evaluation Module

This module includes three techniques for evaluating the suitability of land. Two of these are multicriteria analysis methods: weighted linear summation and ideal point analysis. The third method is the FAO framework (FAO, 1996) with the limitation scoring system (Triantafilis *et al.*, 2001).

Weighted linear summation is the multicriteria evaluation procedure that is most frequently used to obtain suitability maps for a particular activity (e.g. Eastman *et al.*, 1998; Maendoza, 1997). To apply this method, the user must introduce the raster layers that correspond to the evaluation factors, which must be standardised to a common scale, and the weights assigned to these factors, whose sum must be equal to 1.

Ideal point analysis (Barredo, 1996) is based on calculating each alternative's (cell's) distance from the ideal point using the following equations:

$$a_i = \frac{L_{max} - L_i}{L_{max} - L_{min}} \qquad (1)$$

$$L_i = \left[\sum_{j=1}^{J} w_j \, |x_{ij} - 1|^P\right]^{1/P} \qquad (2)$$

where a_i is the suitability of cell I, L_{max} is the maximum distance value, L_{min} is the minimum value, L_i is the distance from the cell i to the ideal point, w_j is the weight assigned to factor j, x_{ij} is the standardised value between 0 and 1 of the factor j in the cell i, and p is the metric for the distance calculation, which indicates the degree of compensation between the factors; i.e. the degree to which factors with a low score can be compensated for by more positive factors.

To apply the FAO framework with limitation scoring, the user must reclassify the values of each evaluation factor into the FAO framework's five suitability classes (FAO, 1976): S1, highly suitable; S2, suitable; S3, marginally suitable; N1, currently not suitable; and N2, permanently not suitable. The programme will then assign a limitation score to each value of a factor, in accordance with its suitability class: 0 points for S1, 1 point for S2, 3 points for S3, 9 points for N1, and 27 points for N2 (Triantafilis *et al.*, 2001). Finally, the user should select a linear or sigmoidal fuzzy function to obtain the suitability by standardising the accumulated limitation score.

The result of these three techniques is a continuous suitability map with values between 0 and 1.

Area Optimisation Module

The area optimisation module has been developed from LINDO® libraries. These were used to construct a customised optimisation application that has been integrated into the GIS environment to solve a linear programming model. In this model, the decision variables correspond to land uses and the objective functions include the maximisation of gross margin, rural employment, cultivated land, and naturalness of vegetation, as well as the minimisation of production costs and use of agrochemical products. This model enables the different land use options to be examined in terms of the area assigned to each land use and according to the priorities or aspiration levels that the decision-maker assigns to each objective.

First, the user must adjust the model's parameters by selecting the objectives and land uses, introducing the technical coefficients, and inserting the right-hand terms of the land availability and demand constraints. To solve the model, the user can then select between techniques that assign priorities *a posteriori* (weighting method (Cohon, 1978) or constraint method (Goicoechea *et al.*, 1982), *a priori* (goal programming (Cohon, 1978), or in an interactive way.

Spatial Allocation Module

The aim of the third module is to design the final land use map. RULES includes two previously developed spatial allocation methods. These are the hierarchical optimisation and the ideal point analysis for conflicting objectives, as described in Barredo (1996). In addition, a new heuristic algorithm based on simulated annealing has been designed to optimise the spatial allocation of uses. Hierarchical optimisation is applicable when the priorities of the uses are known. To apply the ideal point analysis, a numerical weight must be assigned to each use. Hierarchical optimisation and ideal point analysis both base land use allocation exclusively on the suitability of each land unit (cell) for the different uses. In contrast, the algorithm helps us to consider the compactness of the zones assigned to each individual land use, as well as the compactness of the zones assigned to land uses with similar characteristics, grouped in categories.

The simulated annealing algorithm (Kirkpatrick *et al.*,1983) emulates the behaviour of a thermodynamic system that, as the result of configurational changes subject to the Boltzmann probability distribution, finally adopts its least-energy configuration as its temperature is gradually reduced to absolute zero by means of a cooling schedule (Metropolis *et al.*, 1953). When applied in non-thermodynamic contexts, energy is replaced by the objective function to be minimised or maximised, and temperature is an arbitrary parameter that is used to control the thoroughness of the search for the optimum. To execute this algorithm, the user can alter the values of two groups of parameters (Santé *et al.*, 2006): parameters for altering the energy function and parameters that correspond to the cooling schedule used in simulated annealing. The first group includes the weighting factors for the three terms in the following optimisation function:

$$F_{(i)} = \sum_{j=1}^{3} \alpha_j f_j (i)$$

$$F_1(i) = \sum_{j=1}^{I} w_n A_{in}$$

$$F_2(i) = \sum_{n=1}^{N} \sum_{rn=1}^{Rn} P_{rn}$$

$$F_3(i) = \sum_{m=1}^{M} \sum_{rm=1}^{Rm} P_{rm}$$

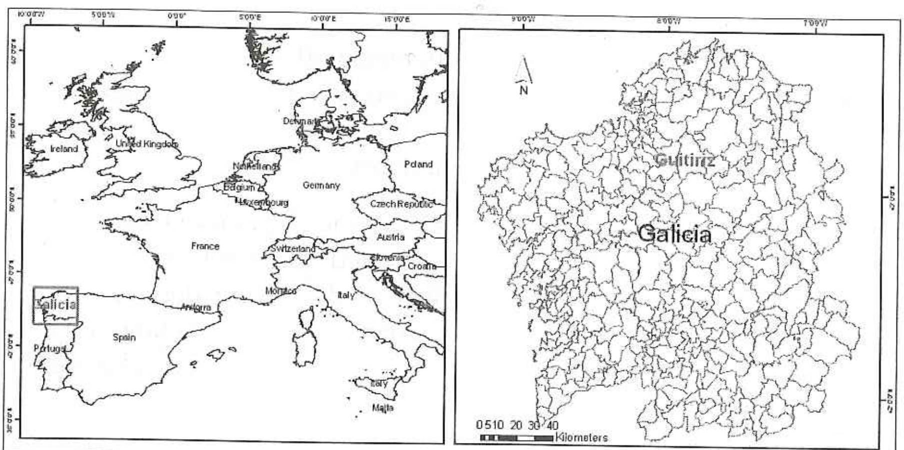
where A_{in} is the suitability of cell i for the use n; w_n is the weight of use n; I is the number of cells in the study area; P_{rn} is the perimeter of the r_n-*th* zone of the R_n zones with use n, measured as the number of axes of the cells of r_n that are adjacent to a cell with a different use to that of n; and P_{rm} is the perimeter of the r_m-*th* zone of the R_m zones with category m. The parameters used to define the cooling schedule include the initial temperature, number of transitions for each temperature, minimum number of temperatures, and the control parameter. The higher the initial temperature, the more time is required to calculate the algorithm and the more reliable the final solutions. Likewise, the higher the number of temperature transitions, the lower the number of temperatures, and the closer the control parameter to 1, the greater the probability of obtaining the optimal solution and the longer the required processing time.

APPLICATION OF THE SYSTEM TO THE *PGOM* FOR GUITIRIZ

Study Area

Guitiriz is a rural municipality within Galicia, NW Spain, of 29 263 ha in size (Figure 1): 9907 ha (33.8% of the municipality) is agricultural land, 8647 ha (29.5%) is reforestation, 1514 ha (5.2%) is hardwood forest, 7659 ha (26.2%) is brushwood, and just 25 ha (0.085%) is urban land.

FIGURE 1. Location of the study area



The 6086 inhabitants of the municipality are distributed throughout 310 population settlements, of which Guitiriz is the main village, containing approximately 25 per cent of the population (1536 inhabitants), while Parga has 426 inhabitants and Pardiñas 104 inhabitants. The remaining settlements have populations of less than 100 inhabitants. The widespread distribution of the population in small villages results in serious deficiencies in terms of services, development, and quality of life, and the provision of infrastructures and services is expensive. In addition, the small scale of land holdings in the agrarian sector leads to low productivity and low yields.

Guitiriz is a strongly rural municipality, but new possibilities of urban growth have arisen with the recent construction of a new highway, the central location of Guitiriz within a larger rural region, and the increasing exploitation of Guitiriz's thermal water, natural features, and landscape as tourist attractions.

Data

Suitability factors

The first set of information required by the system is data concerning factors for the evaluation of land suitability. These factors were introduced into the system as raster coverages with a pixel size of 10 by 10 m. The suitability factors used in the plan were land capability, slope, altitude, current land use, habitat value, plot size, common forest property, distance to road network, distance to markets, labour availability, degree of development of farmer's association, plots with Common Agricultural Policy subsidies, proximity to urban land, proximity to water-supply network, proximity to electricity lines, proximity to rubbish collection network, and proximity to sewerage network.

Land capability was established using the Land Capability Classification (Klingebiel and Montgomery, 1961) adapted to Spain (Ministerio de Agricultura, 1974). The slope and altitude data were derived from a digital elevation model with a resolution of 5 m. The current land use map (compiled in 2005) was provided by the local government. The habitat value was calculated as the weighted summation of the ecological, cultural, and economic values for each habitat unit (Consellería Medio Ambiente, 2005). The size of the plots was obtained by rasterising the cadastral parcel map using the value of the attribute *Area*. Communal forests represents the land surrounding a village that belongs to the inhabitants of the village. These communal forests are generally very large, much larger than the mean plot size. The distance to the main road network was classified in the following way: very short distance (< 1 km to highway or < 500 m to national network), short distance (1 – 2 km to highway or 0.5 – 1 km to national network or < 500 m to secondary network), medium distance (0.5 – 1 km to secondary network or < 500 m to local network), long distance (0.5 – 1 km to local network), and very long distance (the remaining area). The map of distance to markets was obtained by calculating the distance to the two main villages of the municipality. The labour availability was calculated from the number of people working in the agrarian sector in each parish. The degree of development of the farmer's association was calculated from the number of farmers who were members of cooperatives in the parish. The Distance command in GeoMedia was used to calculate the distance of each pixel from urban land and from the water supply, street lighting, street network, electricity lines, and sewerage and rubbish collection networks.

Table 1 provides details of the suitability factors used in the evaluation of land suitability for each land use, as well as the weights assigned to each factor. The weights for each suitability factor were established using the hierarchical analytic process (Saaty, 1980) on the basis of comparing pairs of factors according to their relative importance for each land use.

Technical coefficients and constraints of the land use area optimisation model

The coefficients of gross margin, production cost, rural employment, cultivated land, use of agrochemical products, and naturalness of land use are required to calculate the optimum area of agricultural and forestry use. The values of the coefficients of gross margin in the model, as currently parameterised for Guitiriz, were obtained from the Spanish Agricultural Census, or, in the case of forestry use, from an unpublished study of seventeen areas in Galicia. The unpublished study also details the coefficients of labour requirement, production cost, and use of agrochemical products. The degree of naturalness was calculated by directly assigning a number to each land use according to the scale proposed by Géhu and Géhu-Franck (1979). This scale assigns a naturalness index between 0 (urban systems) and 10 (natural and indigenous complex structures that have not undergone soil modification or human exploitation) to the landscape according to the structure of the vegetation, the characteristics of the flora, and the degree of modification of the soil and human intervention.

The land use areas are each subject to the constraint that they cannot exceed the total area of land in the study area that will sustain that particular land use, which for the purposes of this study was taken to be

TABLE 1. Factors and weights used in the evaluation of land suitability for each land use

	Urban	Maize	Cereals	Potato	Pluri-annnaul fodder	Other fodder	Vegetables and fruit	Meadow and pasture	Eucalyp-tus	Softwood forest	Hardwood forest
Land capability		0.2630	0.2407	0.2570	0.1540	0.2505	0.1671	0.1540	0.0987	0.1672	0.1327
Slope		0.1389	0.1206	0.1473	0.0918	0.1574	0.1671	0.0918			
Altitude		0.0305	0.0449	0.0159	0.0140	0.0227	0.1026	0.0140	0.0987	0.0248	
Current use		0.2096	0.2168	0.2130	0.2793	0.2505	0.2858	0.2793	0.4404	0.4185	0.3920
Habitat value	0.0176	0.0451	0.0136	0.0434	0.0119	0.0275	0.0846	0.0119	0.3026	0.2872	0.3920
Plot size		0.1389	0.1293	0.1404	0.2313	0.0936	0.0200	0.2313	0.0353	0.0606	0.0555
Forest common property		0.0093	0.0095	0.0100	0.0168	0.0116	0.0118	0.0168	0.0242	0.0416	0.0278
Distance to markets		0.0129	0.0208	0.0232	0.0239	0.0148	0.0465	0.0239			
Distance to road network		0.0129	0.0208	0.0232	0.0239	0.0148	0.0465	0.0239			
No. of people working in the agrarian sector		0.0465	0.0361	0.0434	0.0422	0.0426	0.0242	0.0422			
No. of farmers who are members of cooperatives in the parish		0.0722	0.0666	0.0704	0.0509	0.0516	0.0294	0.0509			
Plots with Common Agricultural Policy subsidies		0.0202	0.0804	0.0129	0.0599	0.0623	0.0143	0.0599			
Proximity to urban land	0.3950										
Proximity to water supply	0.1132										
Proximity to street lighting	0.0535										
Proximity to street network	0.2261										
Proximity to electricity lines	0.0535										
Proximity to sewerage network	0.1132										
Proximity to rubbish collection network	0.0279										

land with a suitability value of 0.6 or greater in the land suitability maps. In addition, each land use area cannot be less than the area dedicated to that land use by farms according to the Agricultural Census of 2001.

The urban land demand is calculated from projections of growth in the number of houses and according to the norms established by Law 9/2002.

Application of the System and Results

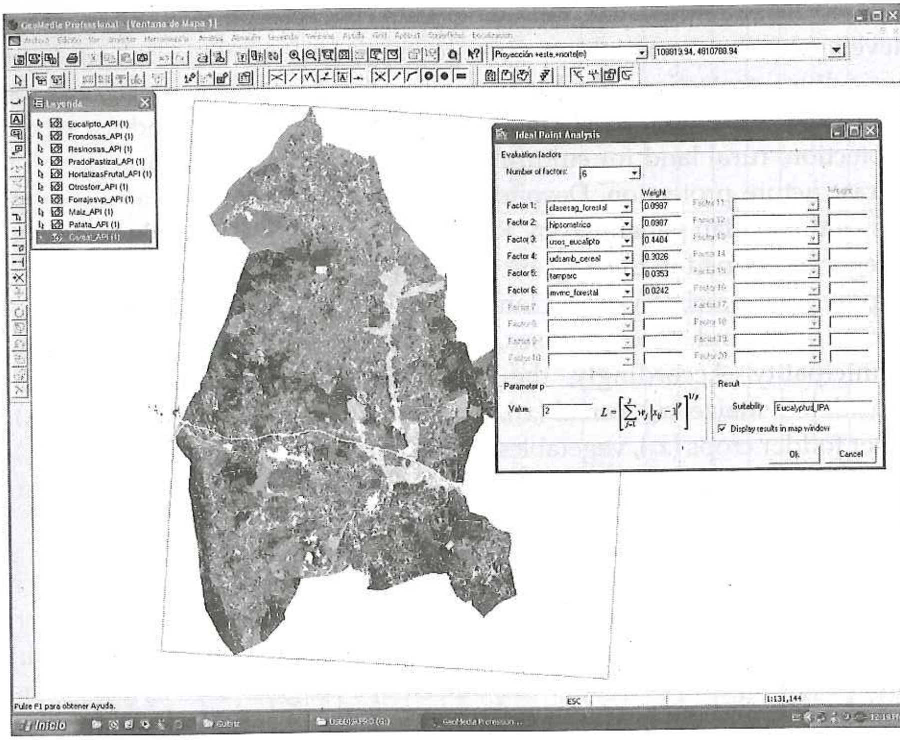
Law 9/2002 defines the following land use categories: urban land, developable land, expansion zone of rural settlements, rural land for agriculture protection, rural land for forestry protection, rural land for landscape protection, rural land for natural spaces, rural land for water protection, rural land for cultural heritage protection, and rural land for infrastructure protection. Despite the fact that the land use categories of the land use plan generated by RULES must be adjusted to the land use categories defined in this law, more specific land uses were considered to improve the precision of the land use allocation, mainly in the case of agricultural and forestry uses, due to the rural character of this municipality. Accordingly, the following land use categories were considered: maize (x_1), cereal (x_2), potato (x_3), perennial green fodder (x_4), other fodder crops (x_5), vegetables and fruit (x_6), meadow and pasture (x_7), eucalyptus (x_8), softwood forest (x_9), hardwood forest (x_{10}) and urban land.

The first step in drawing up a land use plan using RULES is to obtain a raster-based GIS coverage for each land suitability evaluation factor. These coverages represent the input information required to obtain suitability maps for each land use. Such maps are generated by one of the three methods in the land evaluation module: weighted linear summation, ideal point analysis, or the FAO framework. The next step is to determine the area of each land use using the area optimisation module. Finally, the suitability maps and the areas of each land use obtained in the two aforementioned modules are used as input data for the spatial allocation module.

Land evaluation

The suitability maps were obtained from an ideal point analysis (see Figure 2) because this method provides a procedure that is more systematic and quantitative than the FAO framework; it also contributes to a reduction in the subjectivity, which is interesting in this case because the opinions of the different agents involved in the process were not available. This approach enabled the selection of an intermediate degree of compensation among factors by assigning a value equal to 2 to the parameter p.

FIGURE 2. The command for obtaining suitability maps using ideal point analysis and the results of its application



Area optimisation

Rural land uses

The optimisation model arising from the technical coefficients described in the previous section is shown in Table 2.

This model was solved using a generating technique termed the weighting method. The interactive techniques are more appropriate for group-based decision-making, with the aim of guiding the decision-making process;

TABLE 2. Data matrix of the multiobjective linear programming model

Rural land uses										
X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	
970	378	1611	490	623	3458	140	303	293	121	Maximise gross margin (€/ha)
115	580	201	687	926	4910	265	87	106	149	Minimise production cost (€/ha)
13	16	43	12	151	529	4	5	13	11	Maximise rural employment (work hours/ha)
1	1	1	1	1	1	0	0	0	0	Maximise cultivated land
67	38	200	65	60	97	18	0.26	0.09	0.09	Minimise use of agrochemical products*
3	3	2	4	3	2	7	1	1	10	Maximise naturalness (index proposed by Géhu and Géhu-Franck (1979))
1	0	0	0	0	0	0	0	0	0	⩾ 160 ha
0	1	0	0	0	0	0	0	0	0	⩾ 174 ha
0	0	1	0	0	0	0	0	0	0	⩾ 121 ha
0	0	0	1	0	0	0	0	0	0	⩾ 3383 ha
0	0	0	0	1	0	0	0	0	0	⩾ 141 ha
0	0	0	0	0	1	0	0	0	0	⩾ 42 ha
0	0	0	0	0	0	1	0	0	0	⩾ 3753 ha
0	0	0	0	0	0	0	1	0	0	⩾ 210 ha
0	0	0	0	0	0	0	0	1	0	⩾ 5889 ha
0	0	0	0	0	0	0	0	0	1	⩾ 908 ha
1	0	0	0	0	0	0	0	0	0	⩽ 8308 ha
0	1	0	0	0	0	0	0	0	0	⩽ 6934 ha
0	0	1	0	0	0	0	0	0	0	⩽ 8584 ha
0	0	0	1	0	0	0	0	0	0	⩽ 4368 ha
0	0	0	0	1	0	0	0	0	0	⩽ 9103 ha
0	0	0	0	0	1	0	0	0	0	⩽ 9484 ha
0	0	0	0	0	0	1	0	0	0	⩽ 3991 ha
0	0	0	0	0	0	0	1	0	0	⩽ 7253 ha
0	0	0	0	0	0	0	0	1	0	⩽ 8434 ha
0	0	0	0	0	0	0	0	0	1	⩽ 4532 ha
1	1	1	1	1	1	1	1	1	1	⩽ 21 038 ha (total available area)

* The coefficient of use of agrochemical products (AC) for each land use i is $AC_i = (B_i - B_{min})/(B_{max} - B_{min}) + (F_i - F_{min})/(F_{max} - F_{min})$ where B_i and F_i are respectively the number of biocide applications and the quantity of fertiliser (kg/ha) required per year by land use i, and the subscripts max and min indicate the maximum and minimum values of these parameters.

however, in this case, as there is only one decision-maker, the set of possible solutions was approximated by a generating technique to enable the subsequent selection of a solution that provides an achievement rate that is approximately equal for all the objectives (see Table 3).

TABLE 3. Solution of the land use area optimisation model

Land use	Area (ha)
Maize (X_1)	160
Cereals (X_2)	174
Potato (X_3)	121
Pluriannual fodder (X_4)	3383
Other fodder crops (X_5)	141
Vegetables and fruit (X_6)	2675
Meadow and pasture (X_7)	3753
Eucalyptus (X_8)	210
Softwood forest (X_9)	5889
Hardwood forest (X_{10})	4532

Objective	Achievement rate (%)
Gross margin	44
Production costs	56
Rural employment	43
Agricultural land	42
Agrochemical	58
Naturalness	90

Urban land

Extrapolating the data in Table 4 over the next thirty years, the projected increase in total household numbers for this period will be 125 for detached houses and 99 for blocks of flats. The *PGOM* establishes a minimum building plot for blocks of flats of 160 m^2, with 600 m^2 for detached houses. Therefore, the area required for future blocks of flats will be 15 840 m^2 and 75 000 m^2 for detached houses. The maximum building area available in zones of condominiums is 0.85 built m^2/m^2 and 0.60 built m^2/m^2 in zones of detached houses. Consequently, the required area is 18 636 m^2 for condominium lots and 25 000 m^2 for detached houses: a total of 143 636 m^2. According to Law 9/2002, the area required for open spaces and green zones must be in excess of 18 m^2/100 building m^2, representing a minimum of 10 per cent of the total area. In addition, the law establishes that the area available for public community facilities must in excess of 10 m^2/100 building m^2, again representing a minimum of 10 per cent of the total area. Therefore, the required area increases to 15 960 m^2. In the same way, the area required for parking is two parking spaces per 100 m^2 built. This represents 25 m^2 for each parking space in order to include areas for access and service ways, resulting in a total area for parking of 71 818 m^2. Accordingly, the total urban land area will be 255 673 m^2, which must be increased by 10% to accommodate area that must be passed to public land. The final required urban land area is therefore 281 241 m^2.

The current *PGOM* for Guitiriz establishes an area of 655 324 m^2 devoted to residential use, of which 38.53 per cent is existing urban land. This means a total of 402 828 m^2 for urban growth. This figure is much larger than the calculated urban land demand.

TABLE 4. Number of permits issued for new dwellings in the period 1998 – 2005

	1998	1999	2000	2001	2002	2003	2004	2005
Detached houses	8	2	6	5	7	–	–	1
Blocks of flats	2	2	2	5	4	4	2	2

Spatial allocation

The first step was the allocation of zones, corresponding to the land use categories, whose limits can be established by following the procedures defined by various laws: rural land for natural spaces, rural land for water protection, rural land for cultural heritage protection, and rural land for infrastructure protection. The rural land for natural spaces comprises the *Site of Community Interest* "Parga-Ladra-Támoga", the core zone of the *Biosphere Reserve* "Terras do Miño", and the wetlands included in the Wetland Inventory of Galicia. The rural land for infrastructure protection (roads, gas pipelines, electricity lines, railways, etc.) was delimited according to the establishments (distances) of the sectorial laws applicable in each case. The rural land for water protection was established in terms of 100 m of riverside protection for the two main rivers (Parga and Ladra Rivers), 50 m for an additional four important rivers (Labrada, Roca, Escádebas and Mariz Rivers), and 25 m for the remaining rivers and streams. For the demarcation of rural land for cultural heritage protection, a total of 190 elements were identified whose protection areas were established according to Heritage laws.

The optimisation algorithm based on simulated annealing, which is available in the land allocation module of RULES, was used for the allocation of urban growth and agricultural and forestry uses. This algorithm not only maximises the land suitability for the assigned uses, as with the two other methods available in RULES, but also maximises the compactness of the land use regions. In addition, it enables the grouping of land uses with similar characteristics; this facilitates the reclassification of the land use map provided by the system in terms of the land use categories defined by Law 9/2002. In applying the algorithm, each land use was assigned the area shown in Table 3. All the land uses received the same weight except for urban land use, which was given a weight five times greater than the weight of the other uses. In the first application of the algorithm, only the function for the maximisation of suitability was considered. This was undertaken by assigning a weight of 1 to this function and 0 to the other two functions to maximise the compactness. In the second application of the algorithm, the objective function corresponding to the maximisation of suitability was given a weight of 0.5, and the terms for the maximisation of compactness of land use zones and of land category zones were given a weight of 0.25. These two applications were undertaken to check if the spatial distribution of land uses could be improved without too great a reduction in the suitability of the solution. The values utilised for the parameters of the cooling schedule were as follows: 0.98 for the control parameter, 1 for the initial temperature, 30 million transitions for each temperature, and 300 as the minimum number of temperatures. The resulting land use maps are shown in Figures 3 and 4.

FIGURE 3. Land use map obtained by assigning a weight of 1 to the function of suitability maximisation and 0 to the functions for the maximisation of compactness

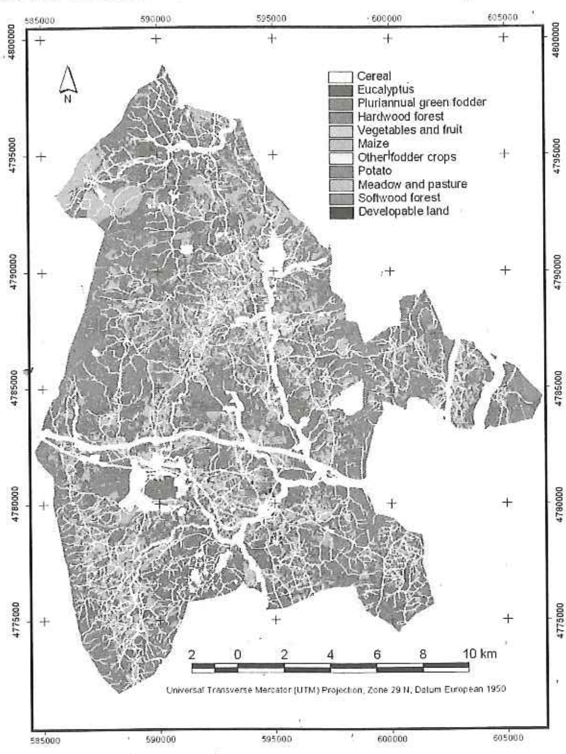
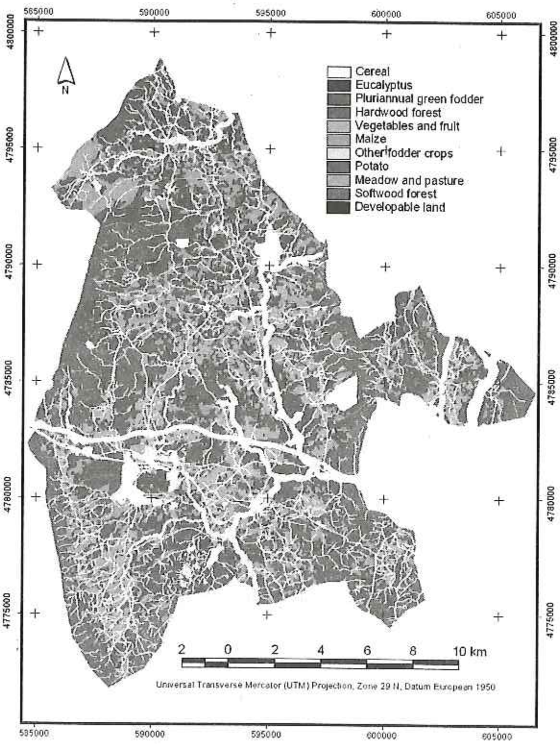


FIGURE 4. Land use map obtained by assigning a weight of 0.50 to the function of suitability maximisation and 0.25 to the functions for the maximisation of the compactness of land use patches and land category patches



Results

The quality of the two land use maps was evaluated according to the data presented in Table 5. The compactness of land use zones and categories was notably improved in the second application of the algorithm: the mean area was more than six times larger for the land use patches and more than five times larger for the land category patches. The sum of boundaries decreased by 53 per cent for the land use patches and by 46 per cent for the land category patches, and the number of land use patches decreased by 84 per cent and the number of land category patches decreased by 82 per cent. This improvement was achieved at the expense of a reduction in the total suitability by 1.54 per cent. The reduction in the suitability is not considered to be significant when compared with the important improvement obtained in the spatial distribution of the land uses and categories. For this reason, the second land use map was selected to compare with the land use category map of the current PGOM.

TABLE 5. Characteristics of the land use maps obtained from the two applications of the algorithm

	First application ($\alpha_1 = 1, \alpha_2 = 0, \alpha_3 = 0$)	**Second application** ($\alpha_1 = 0.5, \alpha_2 = 0.25, \alpha_3 = 0.25$)
Suitability	1 436 372.500	1 414 290.125
Compactness of land use zones		
Mean use patch area (ha)	0.21	1.35
Use patch boundary (km)	13 761	6526
No. of use patches	98 839	15 629
Compactness of land use categories		
Mean use patch area (ha)	0.37	2.09
Use patch boundary (km)	10 640	5759
No. of use patches	56 802	10 109

In the current PGOM, the zoning of land use categories into rural land for natural spaces, rural land for water protection, rural land for cultural heritage protection, and rural land for infrastructure protection was carried out by applying the corresponding sectorial laws. The delineation of rural land for agriculture protection and rural land for forestry protection did not follow a defined methodology; instead, it was based on the current land use and the planner's own criteria. The criteria employed to delimit developable land and the expansion zone of rural settlements involved an attempt to consolidate the urban network and provide continuity to isolated urban areas. The initial delimitation of both land categories was modified on the basis of subsequent meetings with the owners.

The land use map obtained with RULES was reclassified into the land categories defined by Law 9/2002 (see Figure 5). Urban land was reclassified as developable land or expansion zone of rural settlements according to its location in terms of whether the land was located next to one of the two main villages or next to a rural settlement. The land uses of maize, cereal, potato, pluriannual green fodder, other fodder crops, vegetables and fruit, and meadow and pasture were classified as rural land for agriculture protection. The eucalyptus and softwood forest were reclassified as rural land for forestry protection, and the hardwood forest was classified as rural land for landscape protection.

To compare the two land use category maps in a quantitative way using a coincidence or comparison matrix, it was necessary to use the same number of land categories in both maps. To achieve this, the rural land for forestry protection and rural land for landscape protection in the map obtained using RULES were grouped in a single category of rural land for forestry protection. In addition to visual analysis of the resulting map (see Figure 6), the k-index obtained from the coincidence matrix provides a quantitative measure that indicates the degree of similarity between the two maps. The results show a value of 0.4795 for the k-index, which represents a moderate level of correlation. This index provides only a quantitative value in terms of the degree of coincidence between the two images because it only quantifies the number of matching cells in the two maps. It is therefore useful to analyze each land category separately.

FIGURE 5. Land use map obtained using RULES and reclassified into the land categories defined by Law 9/2002

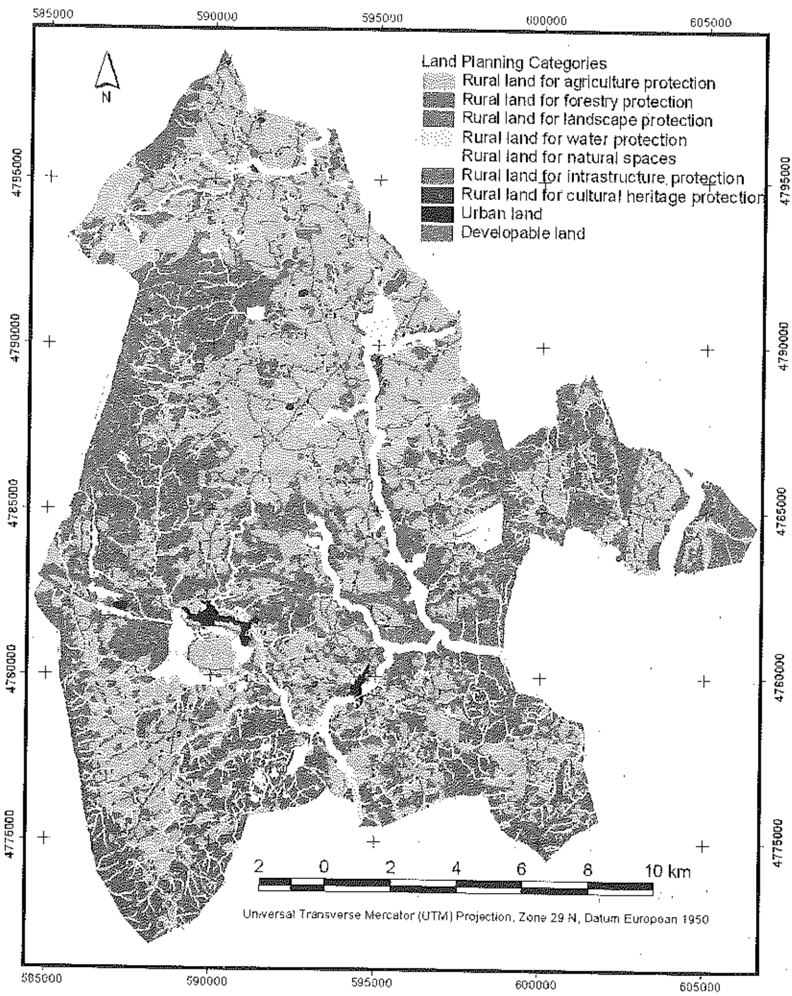
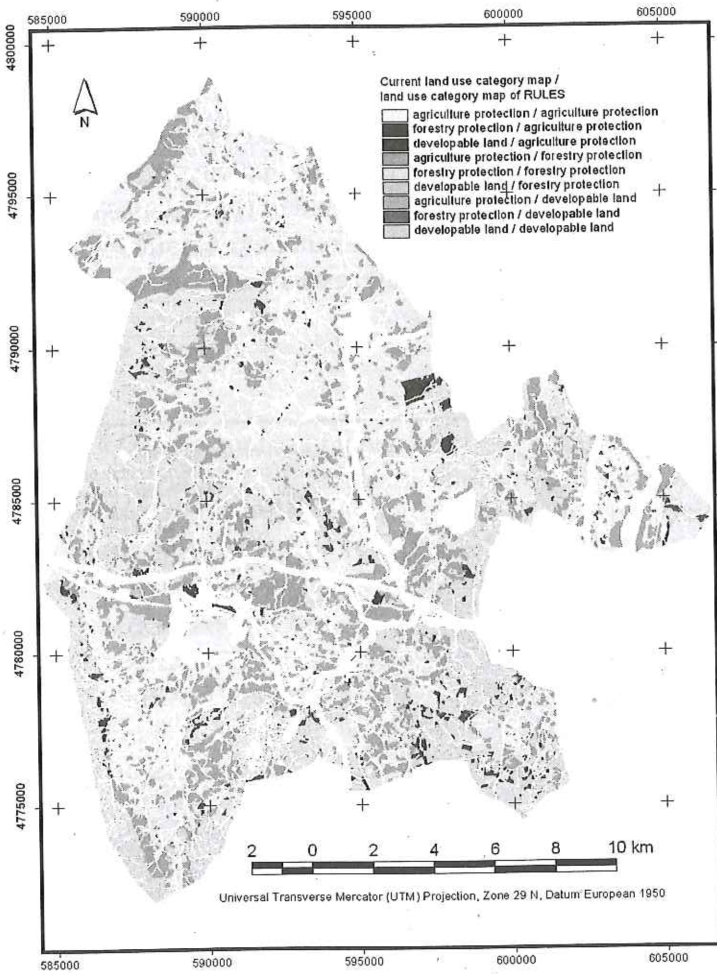


FIGURE 6. Map of the cross-classification between the current land use category map and the land use category map obtained using RULES



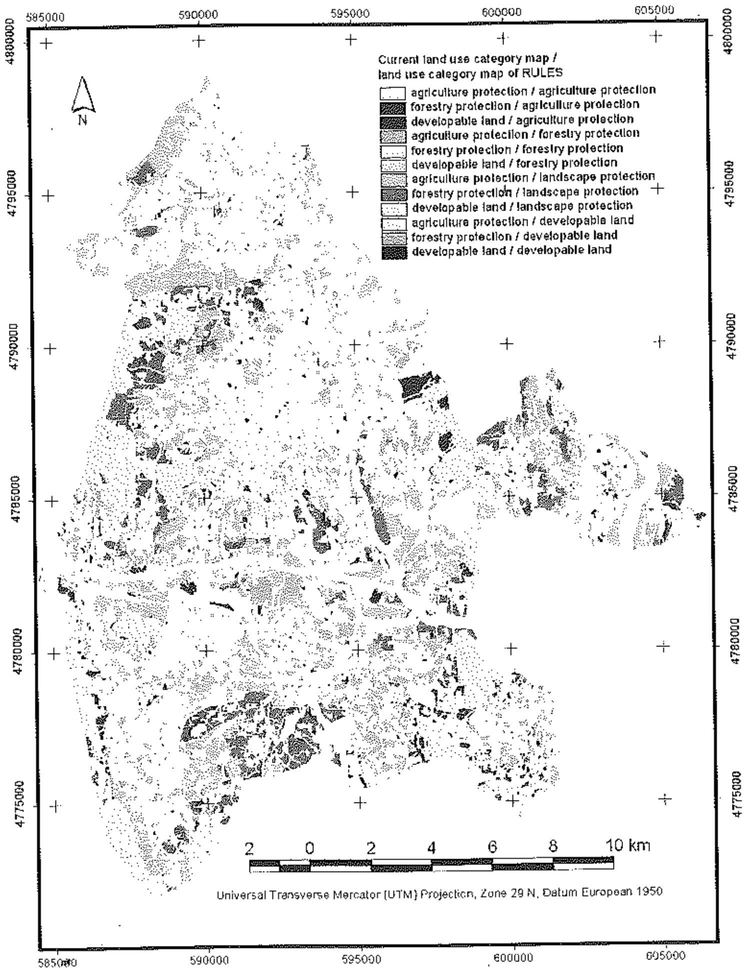
In Table 6, 93 per cent of the cells assigned by the system to rural land for agriculture protection belong to the same category in the current land use category map; however, only 55 per cent of the cells allocated to rural land for forestry protection are assigned to the same category in the current PGOM. This is due to the fact that the area allocated to rural land for forestry protection in the current PGOM is much larger than the area obtained using the area optimisation module in RULES. This factor is the reason for the main differences between the two maps (see Figure 6). With regard to developable land, the degree of similarity between the two maps is very low. This discrepancy between the two maps occurs because in RULES, all the developable land was allocated in the area surrounding the two main villages, as a high weighting was given to the factors related to proximity to water supply and sewerage network, and this infrastructure is only available in these two villages. In contrast, in the current PGOM most of the developable land is located in the expansion zones of the small rural settlements. Moreover, the developable land area of the current PGOM is considerably larger than the area allocated using RULES. As explained in Section 3.3.2, this discrepancy occurs because urban growth in the current PGOM for Guitiriz is overestimated and does not correspond to the actual demand for urban land.

TABLE 6. Coincidence matrix (number of matching cells) between the land use category map of the current PGOM and the land use category map obtained with RULES

	Current land use category map		
Map obtained using RULES	**Rural land for agriculture protection**	**Rural land for forestry protection**	**Developable land**
Rural land for agriculture protection	934 653	56 576	10 134
Rural land for forestry protection	474 983	581 584	1914
Developable land	2401	65	61

If we consider the original reclassification of the land use map obtained using RULES, the cross-classification map would be that shown in Figure 7, which clearly displays one of the main advantages of the system presented in this paper. The capability of RULES in enabling the analysis of more specific and defined land uses results in increased precision when defining the land categories and even the inclusion of new land categories that it would not be possible to differentiate without this tool. In this case, the inclusion in the analysis of different species or types of forest plantations has enabled the differentiation of rural land for forestry protection from rural land for landscape protection. Different categories of rural land for agriculture protection can also be identified according to the type of crops that are most suitable for each zone. For example, rural land for intensive agricultural crops (vegetables, fruit and potato), rural land for extensive agricultural crops (maize and cereal), and rural land for fodder crops (pluriannual green fodder, meadow and pasture, and other fodder crops) could have been delineated. In this case, the result would be that shown in Figure 8.

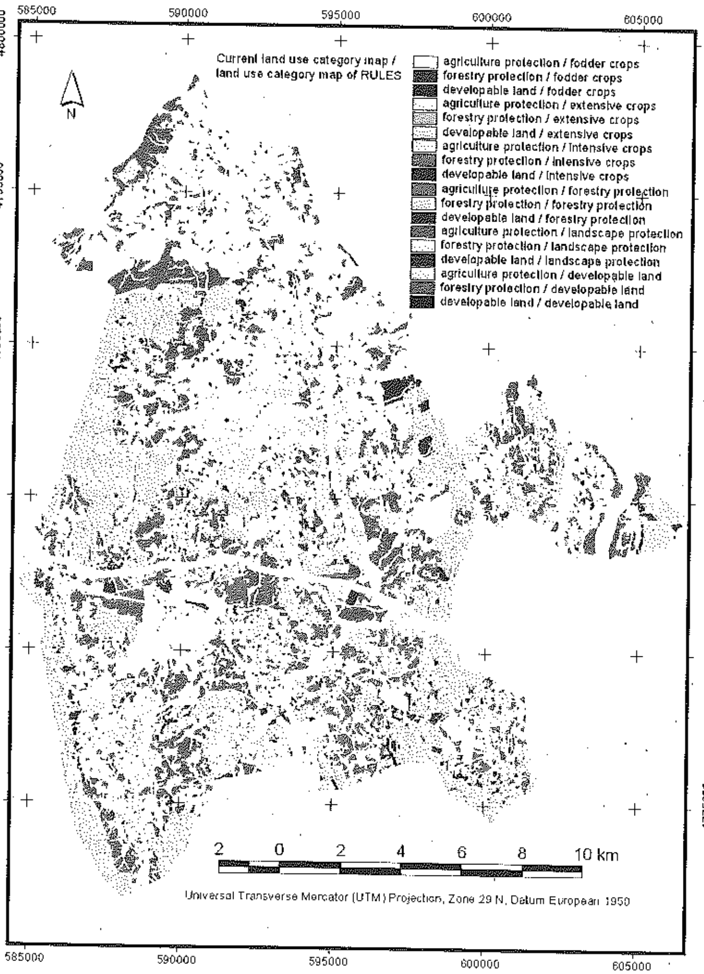
FIGURE 7. Map of the cross-classification between the current land use category map and the land use category map obtained using RULES with the category of rural land for landscape protection



DISCUSSION AND CONCLUSIONS

An analysis of the strengths and weaknesses of RULES as a planning support system is described in Santé and Miranda (2006). In the present paper we aim to emphasise the advantages and drawbacks of its use in the development of a PGOM. Among the advantages of RULES in this regard is its aforementioned capability to base the analysis on perfectly defined land uses. This enables the differentiation of land categories that

FIGURE 8. Map of the cross-classification between the current land use category map and the land use category map obtained using RULES for the different agricultural land categories



are otherwise difficult to distinguish and even enables an increase in the number of categories established by the law. The obtained value of the k-index demonstrates that there is an acceptable degree of difference between the map generated by RULES and the current land use category map; consequently, it can be considered that the system provides a coherent solution that reflects reality. Other advantages of RULES that relate more to the planning process than to the final result are as follows: the ability to simultaneously consider a large number of factors, which is impossible for planners using current techniques; the ability to rapidly obtain multiple alternative land use category maps that can be subsequently evaluated in public sessions, whereas up to now only a single land planning option has been proposed; and the ability to justify the scenarios proposed to the community at public meetings.

Among the drawbacks of RULES is its inability to consider urban morphology and aesthetic or architectonic criteria in the spatial allocation of urban land. To address these limitations, a new module based on cellular automata is currently being developed to improve the allocation of urban land. In addition, the compactness of the land category regions in RULES is inferior to the compactness of maps designed using the traditional method; however, this is related to the objective of maximising the suitability, which is not quantified in such a precise way in the traditional method. The following limitations are identified in terms of the work process: intensive data requirements, mainly with regard to the technical coefficients required for the design of the area optimisation model; lack of an optimisation model for urban land uses comparable to the model employed for agroforestry land uses, although in these land uses the law imposes a restriction on the permitted area; and the need for tools to apply the sectorial laws that delimit certain land categories.

In summary, the RULES system can be adjusted to accommodate Law 9/2002 and facilitate the generation of the land use category maps that constitute the main elements of PGOMs. In addition to this application, this approach can be used in a great diversity of planning situations as it allows to deal with any group of data. It can be used to generate alternative land use maps or land use category maps that reflect the different objectives and perspectives of the agents involved in a land use planning process. These scenarios can be attained by modifying: the evaluation factors, the weights assigned to the land uses, and the plan objectives; the inclusion or exclusion of certain uses; and the characteristics of the agroforestry uses, etc. This allows to examine the consequences of the decisions taken throughout the planning process and begins to understand the relationship between the factors involved in the problem. The aim of the system is to support decision-making and to provide useful tools for evaluating alternative designs.

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Chapter 3
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In the last decade, planners around the world have begun to develop and use spatial decision support systems (SDSS) and planning support systems (PSS) in their professional work. These tools combine spatial and non-spatial data with models for determining the implications of alternative policy choices and visualisation tools for displaying results in easily understandable formats.

This book presents a collection of case studies that illustrate the use of spatial information and GIS in combination with a number of decision support methods and techniques, such as multicriteria evaluation, linear programming, SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, and simulation models. The case studies deal with a broad range of planning problems: strategic environmental assessment, urban poverty monitoring, protected area design, land use planning at municipal and national level, health risk assessment, and land suitability analysis.

The chapters in this book bring together applications in very different contexts from Europe, Southeast Asia and Latin America, illustrating the power that today's decision and planning support tools are providing urban and environmental planners the world over.

This book is essential reading for all students and researchers, as well as practitioners and decision makers, who are involved in urban and environmental planning and management.

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