

# **A decision support system for farmland preservation: Integration of past and present land use**

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## **Abstract**

Preservation of agricultural land is a common need in many States and regions in the European Union and worldwide. Underlying reasons for this need are diverse, as are the approaches chosen to facilitate farmland preservation. Zoning is very often the main instrument used to protect agricultural land from urbanization and afforestation. This chapter presents a multi-criteria decision analysis system intended to support zoning decisions. In this study, parcels are used as the unit of analysis. The system of analysis integrates biophysical criteria related to the productivity of land, structural factors related to the efficiency of farming activities and landscape configuration as defined by present and past land use. As an intermediate step to define landscape configuration, a methodology for classification of historical aerial photographs is proposed, based upon object-oriented classification of individual land parcels with the aid of supervised decision trees and ancillary textural information. The resulting decision support system takes the form of a parcel rating system, allowing end users to identify agricultural areas for which protective zoning should be implemented by selecting progressively lower scoring parcels until the desired total area (ideally based upon demand estimates) is satisfied.

**Keywords:** Decision support system, Land abandonment, Geographic information systems, Automatic classification, Farmland preservation.

## Introduction

The development of strategies to protect agricultural land has been a common issue in planning literature for the past three or four decades (Singer et al. 1979, Nellis & Maca 1986, Daniels & Reed 1988, Bunce 1998). In the North American context, alleged urban sprawl was perceived as the most relevant threat for the preservation of agricultural land; both scientific and governmental reports initially demonstrated this concern with expressive - if not necessarily accurate - titles such as “Foodland: Preservation or Starvation” (Ontario Institute of Agrologists 1975), “The Vanishing Land” (MacGregor 1980) or *Where Have all the Farmlands Gone* (National Agricultural Lands Study 1980; Bunce 1998). As a result of this concern, a large variety of strategies for farmland preservation are currently implemented in the United States, from the Purchase or Transfer of Development Rights (PDR, TDR) to the creation of agricultural districts or Cluster Development (Brabec & Smith 2002, Tulloch et al. 2003, Bengston et al. 2004).

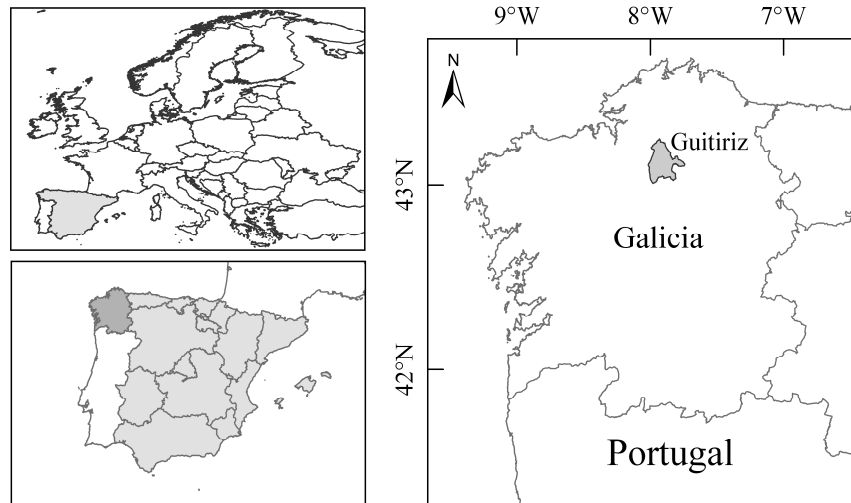
Industrial-era attempts to protect agricultural land were specifically motivated by the preservation of national food production capacity. This perspective is still prevalent in the developing world, as in the case of China (Skinner et al. 2001, Lichtenberg & Ding 2008, Tan et al. 2009). On the contrary, most industrialized countries are currently more concerned about the overall ecological and social consequences of urban sprawl than about its implications for food security in particular. As a result, preservation of agricultural land is often addressed in the more general context of preservation of open space, which may include not only agricultural areas but also semi-natural areas or even forests. The apparently dated concept of farmland preservation has often been redefined as “countryside preservation” in, for example, the United Kingdom, the Netherlands and Germany (Koomen et al. 2008).

In the European context, urbanization and development of transportation infrastructure have comprised the most substantial changes in land cover currently affecting agricultural land. In Europe, approximately 13,000 km<sup>2</sup> of former agricultural land changed to other land uses between 1990 and 2000. Nearly 8,000 km<sup>2</sup> of this transitioned to urban, industrial and infrastructural uses, particularly concentrated in Belgium, the Netherlands, northern Germany and specific locations along the coastal areas of the European Union (EEA 2006). Nevertheless, although less influential than urbanization in terms of total area transitioned, abandonment of agricultural activities (i.e., transitions from agricultural land use to forest or semi-natural areas) also involves important social, environmental, and economic implications (MacDonald et al 2000). This specific cause of land use transition has recently received attention from the European Commission. Marginalization of agriculture, subsequent abandonment of agricultural land use has been on the European agenda since the first reforms of the Common Agricultural Policy (CAP) in the 1990s, when peripheral or mountainous regions were expected to be

those most affected (Baldock et al. 1996, Pinto Correia & Breman 2008). Even though afforestation may be associated to some positive effects (e.g., carbon sequestration), the overall balance of this particular kind of land use transition is strongly dependent on the type of pre-existing landscape. The consequences of the abandonment of agricultural land are considered to be negative not only from the environmental perspective (Suárez Seoane et al. 2002, DLG 2005), but also from the cultural (Höchtel et al. 2005), economic (Gellrich et al. 2006) and social (Soliva 2006) points of view – especially in cultural landscapes that resulted from “the combined works of nature and of man” (UNESCO 2008) or “High Nature Value farming” (EEA 2004). In Mediterranean regions, a particular negative effect of abandonment of agriculture is an increase in volume and continuity of biomass resulting from the encroachment of spontaneous vegetation, or from afforestation of former agricultural land, which creates ideal conditions for large wildfires (Moreira et al. 2001, Romero Calcerrada & Perry 2004, Millington 2007).

As one of such regions affected by wildfires, Galicia - an autonomous region located in the northwest of Spain (Fig. 1) - has recently passed several laws requiring the zoning of protected agricultural land. The delineation of protected agricultural land designates areas in which land use changes, including afforestation, may require special permits or simply would not be allowed. Examples of such legislation include the passing of Regional Law 3/2007, regarding wildfires, and Regional Law 7/2007 regarding the regional Land Bank.

This chapter describes a multi-criteria decision analysis (MCDA) system developed to support the process of land use planning, particularly the zoning of protected agricultural land. The use of MCDA systems is common practice in the support of planning activities (Malczewski 1999, Geneletti 2007, Geneletti & van Duren 2008). The purpose of the system defined here is to help planners in the selection of parcels that should be part of the protected agricultural land at the municipal scale, according to social, environmental and economic criteria. More specifically, the objectives include the development of a MCDA system that: a) takes into account both current and past land use; b) is adaptable to social reality (variable demand for agricultural land); and c) can be used for multiple purposes (not only for the support of land use planning, but also for land banking, open space preservation, or land consolidation projects).



**Fig. 1.** Location of Galicia (right, with Guitiriz highlighted) within Spain and Europe. (Spatial data source: Global Administrative Areas, <http://www.gadm.org>.)

### ***Decision Support Systems for planning purposes***

A decision support system (DSS) may be defined as “an interactive system that helps decision-makers in the use of data and models to solve unstructured problems” (Gorry & Morton 1971). As Witlox (2005) points out, spatial location problems are typically unstructured or semi-structured problems, resulting from difficulties to “specify the relevant criteria (variables) at the outset of the problem, specify the weights to be assigned to criteria, establish site-specific constraints before knowing the resulting consequences, and capture all relevant data with sufficient accuracy” (p. 440). DSSs developed to solve location problems are usually referred to as Spatial Decision Support Systems (SDSSs), and they should consist of at least of three main components (Makowski & Wierzbicki 2000): a database, a model or set of models (very often a MCDA system), and an interface with which end users interact (usually a geographic information system).

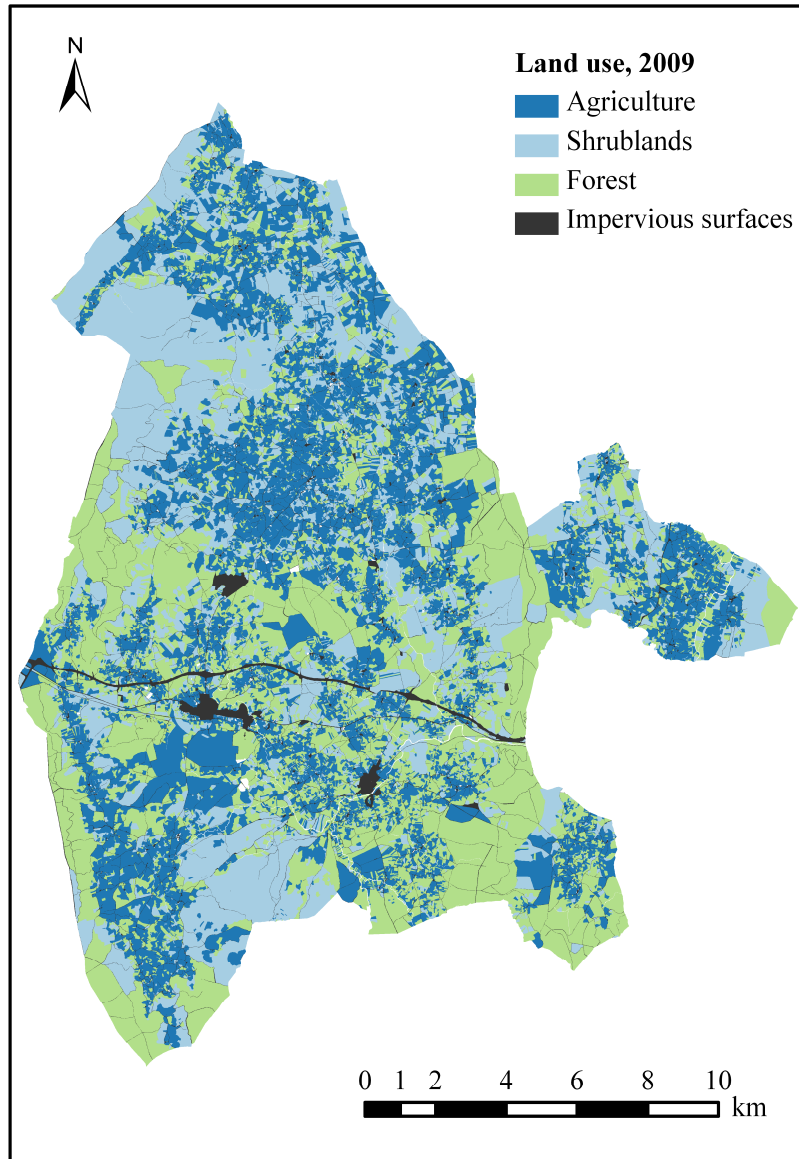
In the last years, there has been a very interesting debate on the usefulness of SDSSs. For example, McCown (2002) argues that “the pure DSS idea is elegant - easy-to-use software on a computer readily accessible to a manager to provide interactive assistance in the manager’s decision process... But review of 30 years of DSS R&D shows that the reality has been more chaotic than elegant” (p. 19). Among the suggested reasons for the lack of real use, many authors point out that much attention has been usually paid to the technical aspects (algorithms, decision

rules, models, etc.) and comparatively less attention has been given to the integration of the system in the decision-making process (Matthews et al. 2008, McCown 2002, Uran & Janssen 2003).

### ***Study area***

To test the proposed MCDA system we selected a Spanish rural municipality (Guitiriz, Fig. 1). This municipality was selected because its local master plan was being developed at the time, and the authors of this work could be in close contact with the planning team. Guitiriz has a total area of 294 km<sup>2</sup> and a hilly topography with altitudes ranging from 400 to 800 m above sea level. As it is the case of all rural municipalities in the region, population has been diminishing since the 1950s (11,500 inhabitants in 1950 and 5,727 in 2011; INE 2010b). Population density in Guitiriz (19 inhabitants/km<sup>2</sup>) is much lower than the Spanish and Galician averages (87 and 94 inhabitants/km<sup>2</sup>, respectively). In addition, the population of Guitiriz has a large proportion of elderly people - 31% of total population is 65 or older (INE 2010b). High population dispersion, with more than 310 different human settlements within the municipality, is another important aspect which demonstrates the complexity of the planning process.

Agriculture has traditionally been the main source of employment, but currently involves about one-third of the working population (INE 2010b). Most of these jobs are generated by small dairy farms that almost exclusively use the labour of relatives; these family farms very often cease their activities as older farmers reach the age of retirement. There were 2,000 farms in Guitiriz in 1962, but only 1,259 in 1999 (INE 1963, 2010a). In recent years many parcels formerly used by farms have been abandoned or afforested, thus preventing them from being transferred (by lease or sale) to farms still active in the area. Fig. 2 shows current (2009) distribution of land uses within the municipality.



**Fig. 2.** Land use in the study area (municipality) of Guitiriz in 2009 (Spatial data source: Spanish Land Parcel Information System, <http://sigpac.mapa.es/fega/visor>.)

## Materials

The most important data source for this research is the Spanish Land Parcel Information System (SIGPAC), created in 2004 to comply with European Union (EU) regulations (Council Regulation 1593/2000). SIGPAC is based upon the cadastral map at 1:5,000 scale, it includes information about the land use, structure and characteristics of the 71,208 agricultural and forested parcels in the municipality. For this study, we used a version of SIGPAC updated for 2009.

To gather information about the historical use of land, we employed aerial photographs taken in 1957. The end of the 1950s is commonly accepted as a turning point in the abandonment of the traditional agricultural system in Galicia (Bouhier 1979) and the changes in the demographic structure in Spain (Collantes Gutiérrez & Pinilla Navarro 2011).

Information about the biophysical quality of land was taken from a map published by Diaz-Fierros Viqueira & Gil Sotres (1984), as it is the only land suitability map available covering the study area that follows the methodology proposed by the Food and Agriculture Organization of the United Nations (FAO 1976). However, this map was prepared at the regional scale (1:200,000), and for this reason it was deemed reasonable to supplement it at the parcel level with detailed data about slope derived from topographic maps at 1:5,000 scale.

## Methodology

The form of the MCDA proposed here is essentially that of system of rating land parcels, loosely inspired by the Land Evaluation and Site Assessment system (LESA). LESA was introduced by the USDA Soil Conservation Service in 1981 (Steiner et al. 1994) and has been used for the preservation of agricultural land by a number of state agencies in the United States and Canada (Androkovich 2013). For this study, each of the 71,208 rural parcels in the municipality was rated according to its estimated suitability for agricultural use, based upon biophysical, structural, and land use (past and present) criteria. It is worth noting that the proposed system is not intended to provide a fixed demarcation of protected agricultural land; instead, zoning of the protected area should be preceded by an external estimate of the total area demanded by local farms for agricultural activities, which is the input that enables the MCDA to proceed by adding the most suitable parcels until the desired total area is reached. Such an approach follows the recommendations of the FAO (1976) for suitability assessment and land use plans, by taking into account not only the biophysical quality of land (soil, climate, topography), but also social variables related to the structure of property and the demand for agricultural land (which is determined externally).

The proposed system can be considered innovative because it establishes a departure from the usual raster-based approach in decision support systems (Borjórquez-Tapia et al. 2001, Ceballos-Silva & López-Blanco 2003), and integrates the past land use of the area in the current planning activities. The development of this SDSS is a unique yet simple attempt to address the problem of scarce implementation that often plagues MCDA systems (Uran & Janssen 2003, Matthews et al. 2008). The system is also an attempt to recover part of the landscape structure existing in the 1950s, characterized by the existence of blocks of parcels used for agriculture - called “*agras*” by local inhabitants. Forest plantations made since then often disrupted these landscape units (Calvo et al. 2011), a trend that the system proposed in this study tries to reverse – at least in part.

The structure of the proposed MCDA system takes the form of a simple weighted linear combination (WLC), one of the most common approaches in the implementation of MCDA in geographic information systems (Malczewski 2006). Three main groups of variables have been selected to estimate the degree to which each land parcel fulfils the requirements to become protected agricultural land: biophysical quality of land, structural characteristics of parcels, and current and past land use. The intention behind the selection of these three criteria groups is to protect the best quality soils, minimize erosive processes and facilitate agricultural production. For each of the criteria groups, several variables were selected (Table 1) and their values calculated for each individual parcel. Values of the variables were then transformed into relative scores ranging from 0 (minimum desirability) to 100 (maximum desirability), according to the contribution of the original values to the achievement of the objectives of the MCDA system. Different weights were assigned to each variable in an attempt to express their relative importance for the objectives of the zoning process (Table 1).

The first group of relative weights for the variables (Weight Set 1) stresses the importance of protecting the best soils for agricultural use (50% of the overall weight in the proposed scheme) and leaves the consideration of current land use and parcel characteristics in a secondary place (25% each in the proposed scheme). The final score ( $V$ ) assigned to each parcel results from the weighted summation of the rated criterion layers, according to equation 1,

$$V = \sum_{i=1}^n w_i a_i \quad (1)$$

where  $w$  is the weight assigned to each variable (the product of the weight assigned to the group of variables and the weight of each variable inside its group) and  $a$  is the value of the transformed (rated) variable.

The weighting scheme was developed in consultation with the team of technicians (architects and rural engineers) in charge of the municipal plan, who deemed it acceptable. It is clear, though, that this procedure does not account for the validity of the weights proposed; although the team generally agreed on the scheme,

subsequent discussion showed that a considerably large range of importance of each variable was possible, and that more than slightly different outcomes could have been equally held as acceptable. In order to present the range of possible contributions of each criteria group, a sensitivity analysis was performed using two alternative weight sets. The alternative weights represent an approach giving equal importance to the three sets of variables (Weight Set 2) and another one giving more importance to variables of present and past land use (Weight Set 3). Keeping in mind that the objective of the MCDA system is the ranking of parcel suitability for agricultural use, we looked for changes in the rank of each parcel, as was the focus of Geneletti and van Duren (2008). Small changes in the relative ranking of a particular parcel would mean that the inclusion of that parcel in the preserved area is not strongly dependent upon the weight set used (importance ranking of variables) and therefore is expected to be more readily accepted by planners and local residents.

**Table 1.** Variables selected and alternative weight sets

Variable group	Weight sets			Variable and variable weight within group
	1	2	3	
Biophysical factors	0.50	0.34	0.25	Soil productivity (0.50)
				Average slope of parcel (0.50)
Structural factors	0.25	0.33	0.25	Parcel area (0.34)
				Parcel shape (0.33)
				Accessibility from roads (0.33)
Land use factors	0.25	0.33	0.50	Present land use (0.50)
				Past land use (0.50)

### ***Rating of biophysical variables***

To prevent the most productive soils from being occupied by other land uses, data from a soil productivity map was included in the pool of variables. The map offers estimation for five categories of suitability and two agricultural uses (arable land and pastures) according to the system proposed by FAO (1976). In this system, the categorization scheme assigns S1 for the most suitable soils, S2 and S3 for those less suitable, and N1 and N2 for unsuitable soils. The values of the variable for each type of parcel were rated from 100 to 0 according to the scheme of Table 2.

**Table 2.** Rating scheme for the variable “soil productivity”

Suitability class		Assigned rating
As arable land	As pastureland	
S1	(any)	100
S2	S1	100
	S2	90
	S3	80
S3	S1	70
	S2	60
	S3	50
N1	S1	40
	S2	30
	S3	20
N2	S1	10
	(others)	0

(Source: Suitability classes as defined in Díaz-Fierros Viqueira & Gil sotres [1984].)

The map takes into account many biophysical characteristics of soils (texture, minerals, water reserve, stoniness and slope). Although a bit dated at the time of writing this study and with a rather small scale (1:200,000), it still is the most comprehensive source of information about soil productivity for the most areas in Galicia. To complement that information, the average slope of each parcel was separately included, as derived from much more detailed topographic maps (1:5,000). The link between slope and suitability for agricultural use depends upon the potential for facilitation of mechanization on a particular parcel. Local practice considers any form of mechanised farming to be inadvisable above a slope of 25% - although such parcels are still commonly used as pastures. In an area of similar characteristics in the Pyrenees, arable land was found to have a mean slope of approximately 5%, whereas pastures were located in areas with a mean slope of 20% (Mottet et al. 2006). Following this reference, parcel slope was rated at 100 when lower than 5% and 0 when higher than 25%, decreasing in a linear relationship between both values.

### ***Rating of structural variables***

Parcel characteristics such as size, shape, and possibility of direct access from roads were calculated from the cadastral map, using a geographic information system. Shape was measured through an area/perimeter ratio as expressed by Eq. 2.

$$Shape.index = 100 \frac{4\sqrt{Area(m^2)}}{Perimeter(m)} \quad (2)$$

The shape index has a value of 100 in the case of a perfectly square shape (though the value could be larger than 100 if the parcel approximated an oval or circular shape); the value is less than 100 in the case of elongated or complex shapes. Because values resulting from Eq. 2 are comprised between 0 and 100, they can be used directly as part of the rating system.

Parcel size was rated using the average size of parcels leased in the Land Bank of Galicia (1 ha) as a reference. The Land Bank is a public service that acts as mediator in many land rental agreements. We interpreted the average size of parcels leased under this system as a conservative estimation of the optimum size of parcels that farmers would be willing to cultivate. Accordingly, parcels larger than 1 ha were rated at the maximum (100), and smaller parcels were rated linearly to zero. The third variable in this group, direct access from public roads, was represented as a logical variable (true/false), and parcels were rated 100 when direct access existed and zero if not.

### ***Rating of land use variables***

Inclusion of present land use in the rating system was based upon two assumptions: that it would be preferable to designate as protected agricultural areas those parcels that are already being used for agricultural purposes, and that agricultural parcels currently surrounded by forested parcels should receive less priority in the rating system (shades projected by near forest stands have a negative impact on agricultural parcels, like for example on the amount and quality of pastures). This meant considering not only the present land use of the parcel itself but also the land use of neighbouring parcels. In order to combine both, forest parcels were assigned the minimum rating (0), while parcels with other land uses were assigned a rating equal proportionate to the share of the perimeter *not* shared with forest parcels.

On the other hand, the purpose of including past use is to maintain or recover, to some extent, past land use. Rating of past land use was established at 100 for parcels used as arable land or pastures in 1957 - 50 for shrublands (areas covered by woody perennial plants, smaller than trees), and zero for forest parcels, based upon automatic classification of the aerial photographs from that year. This is based on evidence that farmers often transform former shrublands into farmed area (Corbelle-Rico et al., 2012).

### **Automatic classification of historical photographs**

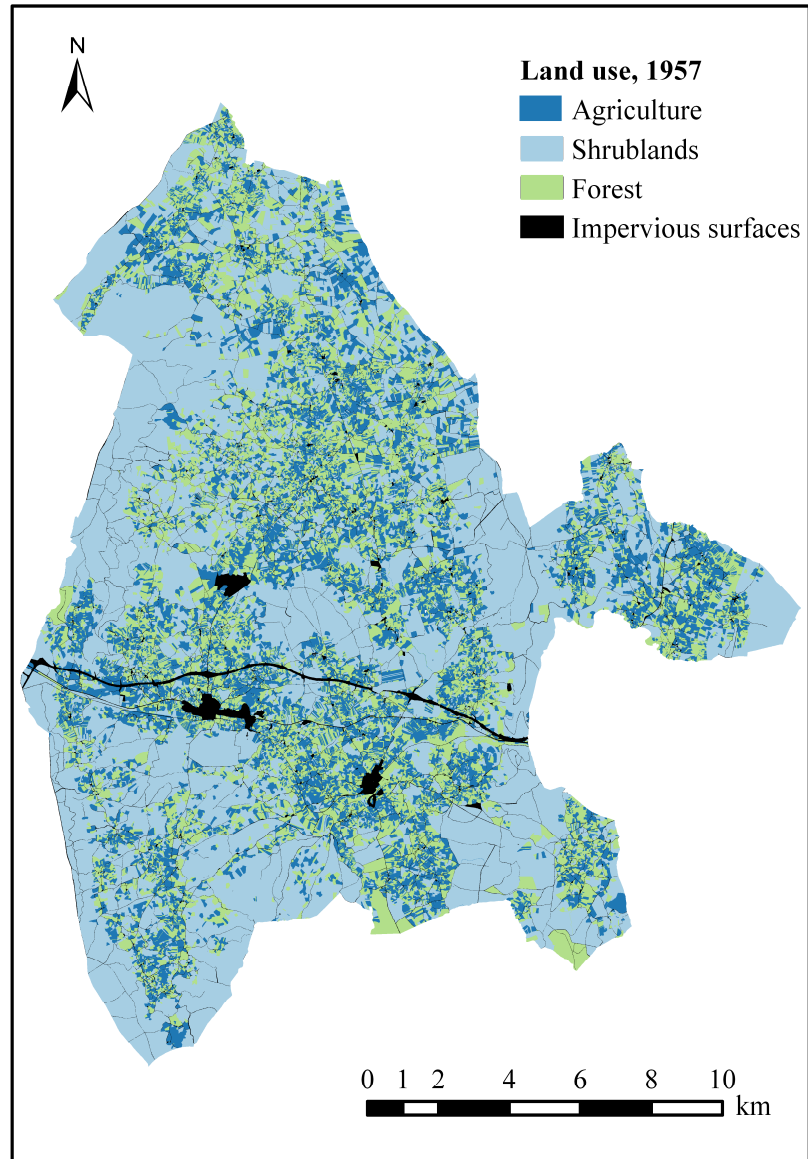
For the automatic classification of the aerial photographs from 1957 (previously orthorectified and mosaicked), an object-oriented automatic approach was employed. Automatic classification of black and white (panchromatic) images is usually a difficult task given the low amount of spectral information they possess; object-oriented methods usually attain better results in terms of classification accuracy and consistency (Laliberte et al. 2004, Marignani et al. 2008). Such an approach fit well with this work, as land parcels can easily be used as “objects” to be classified. Classification of panchromatic images typically benefits from the use of textural measures (Cots Folch et al. 2007), but even with the use of this complementary information, the number of classes in the final classification is generally low - usually only two (Hutchinson et al. 2000, Laliberte et al. 2004, Pillai et al. 2005) or three classes, at most (Carmel & Kadmon 1998, Kadmon & Harari-Kremer 1999). Despite this result, global accuracy values are usually low, ranging between 60% (Carmel & Kadmon 1998) and 80% (Kadmon & Harari-Kremer 1999), though sometimes reaching 90% (Pillai et al. 2005).

The goal of the classification process was the identification of four land cover classes: arable land, pastures, shrubland, and forest. These classes were easily distinguishable separable by their mean grey levels, with arable having the highest values (very light grey in the original photographs) and forest the lowest (very dark grey, almost black), while pastures had grey values in the middle. Only shrublands were not distinguishable, due to their heterogeneous nature – however, such a pattern can be easily detected via textural image processing (e.g., the use of local variance, which typically yields higher values for heterogeneous areas than for the rest of the classes). The use of textural features to improve image classification - proposed by Haralick et al. (1973) - has been demonstrated by previous studies (e.g., Cots-Folch et al. 2007; Johansen et al. 2007).

A supervised decision tree was fitted to a sample of 100 parcels selected by quota sampling in order to obtain 25 of each class, which are then visually classified. The methodology makes use of the J48 algorithm available in the R package RWeka (R Development Core Team 2008, Hornik et al. 2009). Global accuracy of the resulting classification was assessed by means of a ten-fold cross-validation process<sup>1</sup> which estimated to result in approximately 88% global accuracy.

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<sup>1</sup> Sample data is randomly divided into ten subsets. One subset is left out of model fitting process, and is used to assess classification accuracy; the process is then repeated nine more times until every sample observation has been used for accuracy assessment.



**Fig. 3.** Automatic classification of past (1957) land use in the municipality of Guitiriz. (Spatial data source: Spanish Land Parcel Information System, <http://sigpac.mapa.es/feqa/visor>.)

### *Independence of variables*

In any set of attributes or variables that are considered to be the input for MCDA, it is likely that variables could be correlated. If this was the case, some of the variables would be redundant, and the results of the analysis would be affected (Malczewski 2000). To test the independence of the seven variables included in this work, correlation was assessed using Spearman's rank correlation coefficient (a non-parametric measure of dependence between two variables). The seven variables were not demonstrated to be redundant (Table 3); correlation coefficients were between -0.25 and 0.25 in every case.

**Table 3.** Correlation between rated values of the seven variables used in the study

Variables	1	2	3	4	5	6	7
1. Soil productivity	1.00	0.20	-0.14	-0.03	0.00	0.10	0.04
2. Parcel slope		1.00	-0.04	-0.08	0.01	0.24	0.09
3. Parcel area			1.00	0.24	0.20	-0.12	-0.14
4. Parcel shape				1.00	0.04	0.00	-0.07
5. Parcel access					1.00	0.04	-0.03
6. Present land use						1.00	0.15
7. Past land use							1.00

Spearman's rank correlation coefficient

### *Allocation of preserved farmland*

The proposal for the selection of parcels to form the protected agricultural space depends on estimation of agricultural land demand by active farms in the municipality. Current practice for planners in Galicia usually assumes demand to be equal to, or slightly greater than, current area of agricultural land, although other slightly more complex methods are occasionally used. When most farms in the municipality are specialized in dairy farming, a rough estimation of demand is sometimes derived from total existing headage (livestock units) and maximum stocking rate (livestock units/ha) allowed by European Common Agricultural Policy subsidies.

## Results

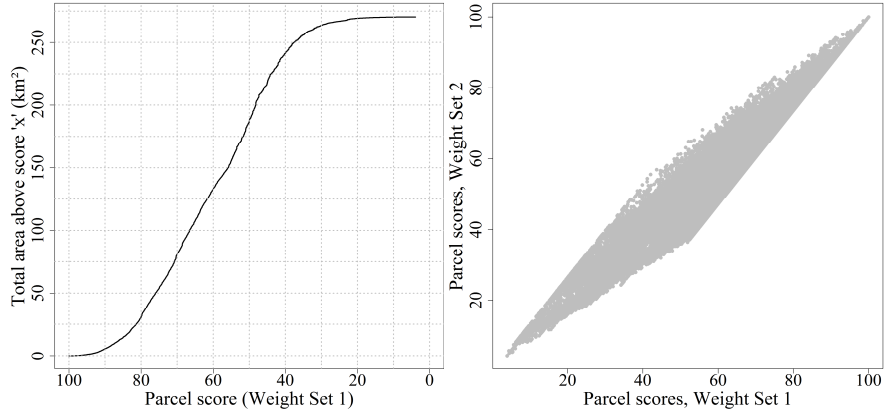
Once the amount of desired protected land is established, the MCDA system accumulates the highest-scoring parcels until the desired total area is reached. Results of the MCDA system are summarized in Fig. 4. Figure 4a presents the relationship between parcel scores obtained using Weight Set 1 ( $x$ ) and the area accumulated by parcels having received equal or higher scores ( $y$ ). This graphic is intended to allow decision-makers (planners) to determine which parcels should be included in the protected area; for a desired amount of preserved farmland ( $y$ ) (based on estimated demand of land by local farms) the curve indicates the minimum suitability score above which parcels should be selected. As the area intended for protection increases, parcels with lower scores must be selected to accumulate the total area. Obviously, the use of different weight sets would result in slightly different curves, but this influence is rather limited. Correlation is high between parcel scores resulting from the use of Weight Sets 1 and 2 (Fig. 4b), 2 and 3 (Fig. 4c), 1 and 3 (Fig. 4c), meaning that selection of weights has relatively little influence on the relative ranking of parcels. In other words, parcels with most suitable characteristics would appear among the highest-scoring parcels for all weight sets, therefore the final set of parcels included in the protected area would not change very much. Table 4 presents the Spearman's rank correlation coefficient for the three sets of scores: as shown in Figs. correlation is especially high in the case of the highest and lowest scores (Figs. 4b, 4c and 4d), as these correspond to parcels generally characterized by high/low ratings for all of the variables.

An example of application of the system (based upon the curve in figure 4a) is presented in Fig. 5. Three proposals for total protected agricultural area are presented - for hypothetical target areas of 86 km<sup>2</sup> (the total of current area occupied by agriculture in the municipality), 68 km<sup>2</sup> (-20%) and 105 km<sup>2</sup> (+20%). It can be seen in the figure how the protected area is formed by parcels with the highest suitability values (in orange), and how additional areas could be added (in blue and green) to increase the total amount of protected area. In comparing with Fig. 2, it is apparent that the selected parcels generally follow current land use, meaning that zoning would not impose severe changes in land use.

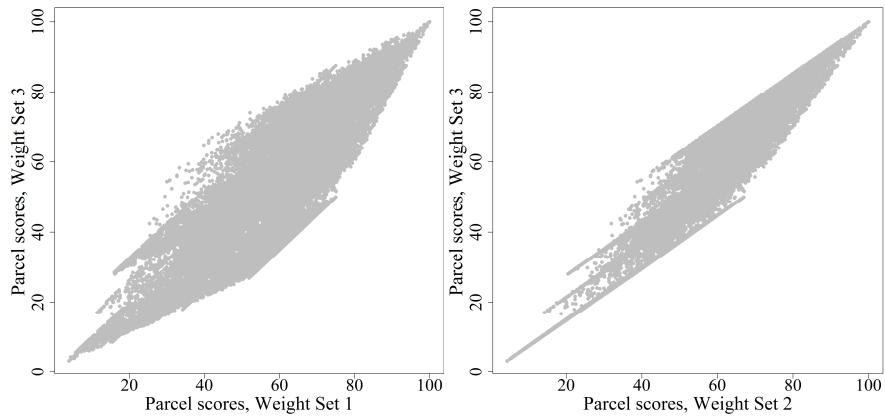
**Table 4.** Correlation between parcel scores resulting from different weight sets

	Weight set 2	Weight set 3
Weight set 1	0.96	0.88
Weight set 2	-	0.96

Spearman's rank correlation coefficient

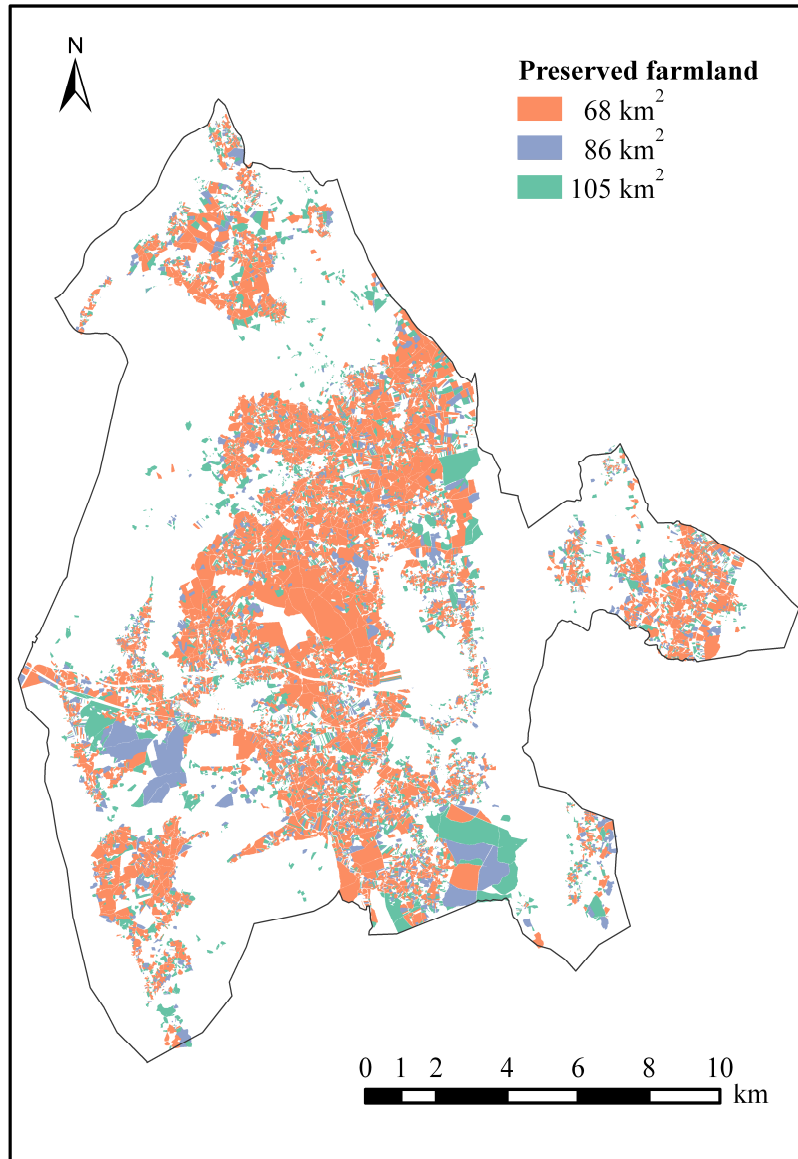


(a) Total preserved area and parcel scores (Weight Set 1) (b) Score correlation, Weight Sets 1 and 2



(c) Score correlation, Weight Sets 2 and 3 (d) Score correlation, Weight Sets 1 and 3

**Fig. 4.** Area of accumulated parcels above a given score (a) and correlation between parcel suitability scores resulting from different weight sets (b, c, d).



**Fig. 5.** Selected parcels for different total areas of protected agricultural land. (Spatial data source: Spanish Land Parcel Information System, <http://sigpac.mapa.es/fega/visor>.)

## Discussion

The results of the sensitivity analysis show that a high degree of correlation exists between scores calculated for each parcel using each of the three different weight sets. In practical terms, this means that when the desired amount of protected area is either proportionally small or large with respect to the total area of the municipality, maps resulting from the different weight sets would be quite similar – whereas when the desired total protected area is close to one half of the total municipal area, the differences between the solutions from the various weight sets are likely to be at their maximum. In this particular case, desired total protected area is about one third of the total municipal area (around 86 km<sup>2</sup>), which means inclusion of parcels over a score threshold around 70 (see Fig. 4a). Around this point, scatterplots show strong correlation between various weight set solutions, even if we consider that weight sets 1 and 3, for example, do not represent slightly different views - but rather, opposite approaches. In conclusion, the selection of the most suitable parcels for agricultural use may be considered relatively stable, regardless of the set of weights used in the MCDA.

An approach based upon the rating of individual parcels inherently enables the inclusion of characteristics of the parcel structure in the decision system. It may be argued that this would also be possible using a more conventional raster-based approach, but a parcel-based approach was also demonstrated to fit well with the automatic classification of past land use. In addition, the parcel-based approach also fits better the actual practice of planners, who tend to avoid, whenever possible, dividing parcels into several zoning categories. Regarding the classification of past land use, the success of the proposed methodology is clearly dependent upon the degree of change that has since affected the parcel, as well as on the availability of historic remotely-sensed data or data about past land uses.

In terms of implementation in real cases, our experience showed that the large number of zoning categories that exist under the law makes it impossible to simply transfer the results of the MCDA system to the final plan. At least six other categories of protected rural land may be included in the plan, for example “right-of-way preservation” for public utilities or infrastructures, “landscape preservation”, or “preservation of waterways”. Nevertheless, the results of the system were used as a guideline; after adjustments were made to include or exclude individual parcels - sometimes only fractions of parcels – in order to account for other categories of protected rural land, the results served to designate the protected agricultural area. While many of these additional categories of protected rural land could also be included in the proposed SDSS, interaction with planners revealed their preference for simple systems from which they could derive results to be used externally, in combination with other information in a desktop GIS. In this fashion, the SDSS proposed here served as only a component of the larger, personalized SDSS that planners employed.

## Conclusions

Preservation of agricultural land is a current topic on the agenda of many States and regions of the European Union, for a variety of reasons. This work proposed the development of an objective system to define the boundaries of protected agricultural land adaptable to the estimated demand for agricultural land at the municipal or parish level. The system integrates information variously related to the productivity and ecological importance of agricultural land, while requiring minimal input data sources. Nevertheless, it is far from our intention to present it as a model to be followed strictly. Other variables, different weighting applied to them, or different means of analysis could be successfully employed in other geographic areas.

It is remarkable that the influence of subjective decisions (the estimation of weights for the different groups of variables) upon the final result is relatively low, which suggests that the approach is robust enough for the system to be trustworthy both for planning technicians and local inhabitants. Two other innovative features are should be highlighted as well. First, the parcel-based nature of the process, as opposed to a raster-based approach is a rare feature that contributes to the applicability of the system in a practical context. Second, the combination of object-oriented classification with the use of textural features for the classification of historical black and white aerial photographs is also innovative, rendering very high accuracy values while offering easy applicability via the use of commonly-used, readily available software.

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## References

- Androkovich, R.A. (2013), 'British Columbia's agricultural land reserve: Economic, legal and political issues', *Land Use Policy*, 30 (1), 365–372.
- Baldock, D., Beaufoy, G., Brouwer, F. & Godeschalk (1996), *Farming at the margins: abandonment or redeployment of agricultural land in Europe*. Institute for European Environmental Policy, London/The Hague.
- Bengston, D. N., Fletcher, J. O. & Nelson, K. C. (2004), 'Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States', *Landscape and Urban Planning* 69, 271–286.

- Bojórquez-Tapia, L. A., Díaz-Mondragón, S. & Ezcurra, E. (2001), 'Gis-based approach for participatory decision making and land suitability assessment', *International Journal of Geographical Information Science* 15(2), 129–151.
- Bouhier, A. (1979), *La Galice: essai géographique d'analyse et d'interprétation d'un vieux complexe agraire*, Ph.D. Thesis, University of Poitiers.
- Brabec, E. & Smith, C. (2002), 'Agricultural land fragmentation: the spatial effects of three land protection strategies in the eastern United States', *Landscape and Urban Planning* 58(2), 255–268.
- Bunce, M. (1998), 'Thirty years of farmland preservation in North America: discourses and ideologies of a movement', *Journal of Rural Studies* 14(2), 233–247.
- Calvo, S., Méndez, G. & Díaz, R. A. (2011), 'Los paisajes culturales de agras en Galicia y su dinámica evolutiva', *Journal of Depopulation and Rural Studies* 10, 7-38.
- Carmel, Y. & Kadmon, R. (1998), 'Computerized classification of Mediterranean vegetation using panchromatic aerial photographs', *Journal of Vegetation Science* 9, 445–454.
- Ceballos-Silva, A. & López-Blanco, J. (2003), 'Delineation of suitable areas for crops using a multi-criteria evaluation approach and land use/cover mapping: a case study in central Mexico', *Agricultural Systems* 77, 117–136.
- Collantes Gutiérrez, F. & Pinilla Navarro, V. (2011), *Peaceful surrender: The depopulation of rural Spain in the Twentieth Century*. Cambridge Scholars Publishers.
- Corbelle-Rico, E., Crecente-Maseda, R. & Santé-Riveira, I. (2012), 'Multi-scale assessment and spatial modelling of agricultural land abandonment in a European peripheral region: Galicia (Spain), 1956–2004', *Land Use Policy*, 29(3), 493-501.
- Cots Folch, R., Aitkenhead, M. J. & Martínez Casanovas, J. A. (2007), 'Mapping land cover from detailed aerial photography data using textural and neural network analysis', *International Journal of Remote Sensing* 28(7), 1625–1642.
- Daniels, T. L. & Reed, D. E. (1988), 'Agricultural zoning in a metropolitan county: An evaluation of the Black Hawk County, Iowa, program', *Landscape and Urban Planning* 16(4), 303–310.
- Díaz-Fierros Viqueira, F. & Gil Sotres, F. (1984), *Capacidad productiva de los suelos de Galicia*, Universidade de Santiago de Compostela.
- DLG (2005), *Land abandonment, biodiversity and the CAP*, Dienst Landelijk Gebied (Government Service for Land and Water Management of the Netherlands), Utrecht.
- EEA (2004), *High nature value farmland. Characteristics, trends and policy challenges*, European Environment Agency. Report No 39 (1/2004), Luxembourg.
- EEA (2006), *Land accounts for Europe 1990-2000. Towards integrated land and ecosystem accounting*, European Environment Agency. Report No 11/2006, Copenhagen.
- FAO (1976), *A framework for land evaluation*, Food and Agriculture Organization of the United Nations. Soils Bulletin 32.
- Gellrich, M., Baur, P., Koch, B. & Zimmermann, N. E. (2006), 'Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis', *Agriculture, Ecosystems and Environment* 118, 93–108.
- Geneletti, D. (2007), 'An approach based on spatial multicriteria analysis to map the nature conservation value of agricultural land', *Journal of Environmental Management* 83, 228–235.
- Geneletti, D. & van Duren, I. (2008), 'Protected area zoning for conservation and use: a combination of spatial multicriteria and multiobjective evaluation', *Landscape and Urban Planning* 85(2), 97–110.
- Gorry, G.A. & Morton, M.S. (1971), *A framework for management information systems*. Massachusetts Institute of Technology.
- Haralick, R.M., Shanmugam, K. & Dinstein, I. (1973), 'Textural features for image classification', *IEEE Transactions on Systems, Man and Cybernetics*, 3(6), 610-621.
- Höchtel, F., Lehringer, S. & Konold, W. (2005), '“Wilderness”: what it means when it becomes a reality - a case study from the Southwestern Alps', *Landscape and Urban Planning* 70, 85–95.

- Hornik, K., Zeileis, A., Hothorn, T. & Buchta, C. (2009), RWeka: an R interface to Weka. R package version 0.3-15. URL: <http://CRAN.R-project.org/>
- Hutchinson, C.F., Unruh, J.D. & Bahre, C.J. (2000), 'Land use vs. climate as causes of vegetation change: a study in SE Arizona', *Global Environmental Change*, 10, 47-55.
- INE (1963), Primer Censo Agrario de España. Año 1962. Resultados provisionales. Segunda parte: datos municipales, Spanish National Statistics Institute (INE), Madrid, 1964.
- INE (2010a), Agricultural Census 1999, Spanish National Statistics Institute (INE). URL: <http://www.ine.es>
- INE (2010b), Population Census, Spanish National Statistics Institute (INE). URL: <http://www.ine.es>
- Johansen, K., Coops, N.C., Gergel, S.E. & Stange, Y. (2007), 'Application of high spatial resolution satellite imagery for riparian and forest ecosystem classification', *Remote Sensing of Environment*, 110, 29-44.
- Kadmon, R. & Harari-Kremer, R. (1999), 'Studying long-term vegetation dynamics using digital processing of historical aerial photographs', *Remote Sensing of Environment* 68, 164-176.
- Koomen, E., Dekkers, J. & van Dijk, T. (2008), 'Open-space preservation in the Netherlands: planning, practice and prospects', *Land Use Policy* 25, 361-377.
- Laliberte, A. S., Rango, A., Havstad, K. M., Paris, J. F., Beck, R. F., McNeely, R. & González, A. L. (2004), 'Object-oriented image analysis for mapping shrub encroachment from 1937 to 2003 in southern New Mexico', *Remote Sensing of Environment* 93(2), 198-210.
- Lichtenberg, E. & Ding, C. (2008), 'Assessing farmland protection policy in China', *Land Use Policy* 25(1), 59-68.
- MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutiérrez Lazpita, J. & Gibon, A. (2000), 'Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response', *Journal of Environmental Management* 59, 47-69.
- MacGregor, R. (1980), 'The vanishing land', *Maclean's Magazine*, 12, 46-47.
- Makowski, M. & Wierzbicki, A.P. (2000), Architecture of decision support systems, in: Wierzbicki, A.P., Makowski, M. & Wessels, J. (Eds.), *Model-based decision support methodology with environmental applications*. Kluwer Academic Publishers, Dordrecht, pp. 47- 70.
- Malczewski, J. (1999), *GIS and multicriteria decision analysis*, John Wiley and Sons, Toronto.
- Malczewski, J. (2000), 'On the use of weighted linear combination method in GIS: Common and best practice approaches', *Transactions in GIS* 4(1), 5-22.
- Malczewski, J. (2006), 'Gis-based multicriteria decision analysis: a survey of the literature', *International Journal of Geographical Information Science* 20(7), 703-726.
- Marignani, M., Rocchini, D., Torri, D., Chiarucci, A. & Maccherini, S. (2008), 'Planning restoration in a cultural landscape in Italy using an object-based approach and historical analysis', *Landscape and Urban Planning* 84(1), 28-37.
- Matthews, K. B., Shwarz, G., Buchan, K., Rivington, M. & Miller, D. (2008), 'Wither agricultural DSS?', *Computers and Electronics in Agriculture* 61, 149-159.
- McCown, R.L. (2002), 'Changing systems for supporting farmers' decisions: problems, paradigms, and prospects', *Agricultural Systems* 74, 179-220.
- Millington, J. D. A. (2007), *Modelling Land-Use/Cover Change and wildfire regimes in a Mediterranean Landscape*, Ph.D. dissertation, King's College, London.
- Moreira, F., Rego, F. C. & Ferreira, P. G. (2001), 'Temporal (1958-1995) pattern of change in a cultural landscape of Northwestern Portugal: implications for fire occurrence', *Landscape Ecology* 16, 557-567.
- Mottet, A., Ladet, S., Coqué, N. & Gibon, A. (2006), 'Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees', *Agriculture, Ecosystems and Environment* 114, 296-310.
- National Agricultural Lands Study (1980), *Where Have all the Farmlands Gone*. Washington, DC.

- Nellis, L. & Maca, M. N. (1986), 'The effectiveness of zoning for agricultural lands protection: a case study from Cache County, Utah', *Landscape and Urban Planning* 13, 45–54.
- Ontario Institute of Agrologists (1975), *Foodland Preservation or Starvation: A Statement on Land Use Policy*. Executive Committee of the Council of Ontario Institute of Agrologists.
- Pillai, R. B., Weisberg, P. J. & Lingua, E. (2005), 'Object-oriented classification of repeat aerial photography for quantifying woodland expansion in central Nevada', 20<sup>th</sup> Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment, October 4-6, Weslaco, Texas.
- Pinto Correia, T. & Breman, B. (2008), Understanding marginalisation in the periphery of Europe: a multidimensional process, in F. Brouwer, T. van Rheenen, S. S. Dhillion & A. M. Elgersma, Eds., 'Sustainable land management. Strategies to cope with the marginalisation of agriculture', Edward Elgar Publishing Limited, Cheltenham.
- R Development Core Team (2008), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. URL: <http://www.R-project.org>
- Romero Calcerrada, R. & Perry, G. L. W. (2004), 'The role of land abandonment in landscape dynamics in the SPA Encinares del río Alberche y Cofio, Central Spain, 1984-1999', *Landscape and Urban Planning* 66, 217–232.
- Singer, M. J., Tanji, K. K. & Snyder, J. H. (1979), Planning uses of cultivated cropland and pastureland, in M. T. Beatty, G. W. Petersen & L. D. Swindale, eds, 'Planning the uses and management of land', Agronomy series, n. 21, American Society of Agronomy, pp. 225–272.
- Skinner, M. W., Kuhn, R. G. & Joseph, A. E. (2001), 'Agricultural land protection in China: a case study of local governance in Zhejiang province', *Land Use Policy* 18(4), 329–340.
- Soliva, R. (2006), 'Landscape stories: Using ideal type narratives as a heuristic device in rural studies', *Journal of Rural Studies* 23, 62–74.
- Steiner, F.R., Pease, J.R., Coughlin, R.E., Eds. (1994), *A Decade with LESA: The Evolution of Land Evaluation and Site Assessment*, Soil and Water Conservation Society, Ankeny.
- Suárez Seoane, S., Osborne, P. E. & Baudry, J. (2002), 'Responses of birds of different biogeographic origins and habitat requirements to agricultural land abandonment in northern Spain', *Biological Conservation* 105, 333–344.
- Tan, R., Beckmann, V., van den Berg, L. & Qu, F. (2009), 'Governing farmland conversion: comparing China with the Netherlands and Germany', *Land Use Policy* 26(4), 961–974.
- Tulloch, D. L., Myers, J. R., Hasse, J. E., Parks, P. J. & Lathrop, R. G. (2003), 'Integrating GIS into farmland preservation policy and decision making', *Landscape and Urban Planning* 63, 33–48.
- UNESCO (2008), *Operational guidelines for the implementation of the World Heritage Convention*, United Nations Educational, Scientific and Cultural Organization. Intergovernmental Committee for the Protection of the World Cultural and Natural Heritage. URL: <http://whc.unesco.org/archive/opguide05-en.pdf>
- Uran, O. & Janssen, R. (2003), 'Why are spatial decision support systems not used? Some experiences from the Netherlands', *Computers, Environment and Urban Systems* 27, 511–526.
- Witlox, F. (2005), 'Expert systems in land-use planning: an overview', *Expert Systems with Applications*, 29, 437- 445.