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Graphical Abstract

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The territorial dynamics of fast-growing regions: Unsustainable land use change and future policy challenges in Madrid, Spain

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Research highlights

►The Madrid region of Spain has experienced remarkably dynamic land use change over the past 20 years. ►These changes can be effectively documented to a high level of detail using the CORINE land cover dataset, which forms an effective baseline dataset for regional land planning. ►Urbanization has occurred away from the capital city in an unmanaged and unsustainable way, aided by liberal land use policies and abandonment of agrarian land areas. ►Top-down political solutions are not forthcoming; integrative methodologies based on rapid sustainable development appraisals, communication and cooperation between municipalities and local groups, and participatory approaches using land use scenario modeling, offer a way forward.

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The territorial dynamics of fast-growing regions: Unsustainable land use change and future policy challenges in Madrid, Spain

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Planning policy
Integrated modeling
Participation

A B S T R A C T

The Madrid region of Spain has experienced remarkable change in the configuration use of its territory over the last 20 years, notably rapid and dispersed growth of transport networks and urban areas, accompanied by a steady decline in productive agricultural land, which has helped feed the development boom. Results of analysis of CORINE land cover data over 3 dates (1990–2000–2006) for a 77053 ha study area north-west of the Spanish capital demonstrate that 8699 ha (11.3%) of the total land area has been subject to change. Agricultural areas have shown significant reduction in area (down 1833 ha, a 10% decline) while artificial surfaces, predominantly urban areas, have increased dramatically (up 3339 ha, a 51% increase). Urban development has been intensive and poorly controlled. Investigation of these dynamics suggest serious concerns for sustainability in the territory. To move towards a more sustainable configuration, the implication of all stakeholders in the Madrid region will be required. A methodological framework is presented for implementation of sustainable development initiatives through sustainability action groups, in which integrated land use models and participatory planning activities are used to develop and test new policy initiatives.

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Introduction

Madrid: a region in transformation

The Madrid Autonomous Community (CM), an 802231 ha (8022 km^2) region in the centre of Spain and the location of the capital city, has undergone unprecedented transformation in recent years, particularly since the end of the 1980s. It is this transformation, measured here through analysis of Land Use/Land Cover change (LCC), which provides the focus of this article.

Madrid, along with Murcia and the Community of Valencia, is remarkable for its high rate of urban growth (artificial surfaces in the CM, principally urban areas, increased by 47.7% between 1990 and 2000, far beyond either national or European averages) (OSE, 2006). Subsequent urban growth has also been extremely strong (15% between 2000 and 2006). The region has seen large-scale expansion of road and rail networks, orienting new residential and commercial areas along their principal axes and in their immediate hinterland (Aldana, 2005; López de Lucio, 2003; Serrano Cambronero, Gago García, & Anton Burgos, 2002). While use of public transport is one of the highest in Europe, per capita private car ownership is rising as the capital expands, prompting sustainability concerns (García Palomares and Gutiérrez Puebla, 2007a; Hewitt & Hernández-Jiménez, 2010). Madrid's new residential areas tend to be lower density and more widely dispersed than at any time previously, and shopping and leisure activities are increasingly focused around out of town retail parks which are accessible only by car.

Nonetheless, parts of the Madrid region retain a strongly rural character, criss-crossed by livestock droveways, under both irrigated and non-irrigated arable crops, and with a rich tradition of vine and olive cultivation. In 1990 agricultural areas still comprised 41.8% of the community's surface area. By 2000 the area occupied by agriculture had fallen to 38.1%, and by 2006 36.8%.[1] Agriculture in the region is clearly in deep decline, with large areas of formerly productive land being abandoned or converted to urban use, often without appropriate environmental impact assessment, with corresponding negative effects on the rural landscape, adjacent protected areas and biodiversity. The large proportion of agrarian land remaining in the CM cautions against policies that regard it as empty space between urban blocks, awaiting its turn to be built on.

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[1] Source: Own work based on CORINE land cover 1990, 2000 and 2006.

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More enlightened approaches must be sought that allow for the continued sustainable use of these rural areas.

Madrid's transformation from compact European city in a deeply rural hinterland to a dispersed modern metropolitan region typical of US or Australian cities brings with it undoubted benefits, however, the territory and its resources (land, water, biodiversity, cultural heritage, natural areas) are not unlimited. Effective strategies for the sustainable development of the territory are therefore urgently required in order to safeguard the future well being of society and the environment on which it depends.

Background to this research

Detailed study of key land use and land planning issues in the CM was undertaken as part of the EU-funded Framework Programme 5 (FP5) Project "Time Geographical Approaches to Emergence and Sustainable Societies (TiGrESS) (EC, 2005; Winder, 2006). Recognizing problems of convergence with European Environmental and Sustainable Development legislation, TiGrESS researchers specifically identified problems of sustainability in the territory (an important step forward), and embarked on a process of consultation and engagement with regional land planning stakeholders, such as municipal governments, farmer's trade unions, ecologist's groups, consumers, and regional planners. The stakeholder engagement exercise is described in detail, together with a list of key stakeholders in the CM, by Hernández-Jiménez and Winder (2009). In order to explore potential implications of scenarios and policy interventions suggested by local stakeholders and policy makers as a result of this process, a Spatial Decision Support System (SDSS), known as the Madrid Model, was developed by the project (Hahn, Uljee, Van Der Meulen, & Vanhout, 2006; Hernández-Jiménez & Winder, 2006, 2009; Winder, 2006). The Madrid Model, which is discussed in more detail later on in this article, is an extremely powerful, and presently somewhat underexploited resource with potential to contribute substantially to practical implementation of integrated spatial planning in the region.

Following in the footsteps of this earlier research, Hewitt and Hernández-Jiménez (2010) observed that progress required not only political will from the top-down but also realistic policy actions directed at the appropriate level of governance. Since the responsibility for development control lies with the smallest unit of governance (the municipality), non-local policy initiatives, such as sustainable development, have tended to fail. Nevertheless, the picture was varied across the CM, with some areas exhibiting much greater tendencies towards unsustainability than others. These areas, denominated "Sustainability Action Areas" in this earlier article (Hewitt and Hernández-Jiménez, 2010) were identified on the basis of their response to a series of simple indicators (adoption of Agenda 21, growth of artificial areas 1990–2000, loss of agricultural and natural areas 1990–2000, growth of unemployment in the construction industry 2006–2009, growth of automobiles 1998–2008). This work served as a useful starting point for targeting key areas of attention for implementation of sustainable development initiatives.

Here, the analytical base for action is extended through in-depth study of patterns of land use change over time in one particularly dynamic part of the CM, a block of territory comprising 19 contiguous municipalities containing or immediately adjacent to the river Guadarrama, which descends north-east from the upland zone in the north-west of the CM, passing the city of Madrid to the west (Fig. 1). This area was identified as a "Sustainability Action Area" on the basis of its rapid urban growth, associated loss of natural and agricultural areas and rapid growth of private car ownership ~~(Fig. 1)~~.

The study area, (henceforth referred to as the Guadarrama area or region) presents a combination of particular dynamics which are representative of the Madrid region as a whole, while at the same time being small enough to allow detailed analysis. These key dynamics include intensive construction of second homes, areas of high natural value, strong agricultural heritage, nationally important archaeological remains, a major infrastructure corridor, and recent exclusion from rural development funding (from 2009, the regional government, in implementing national legislation, no-longer classifies this area as "rural"). The Guadarrama area is thus an appropriate candidate for a specific strategic plan for sustainable development bridging the gulf between individual municipal authorities and the regional administration. The analysis of LCC presented in this article would serve as a useful baseline dataset for future policy actions. The patterns of change observed have been used as a platform for in-depth discussion of the future management of this problematic and rapidly transforming region. Almost all of the issues discussed are the result of changing human behavior in the landscape in response to changing global conditions. This reflects a development paradigm that can be observed worldwide, the dilemmas and problems that arise when predominantly rural, agricultural societies become urban consumer-based societies (e.g. Barredo, Demicheli, Lavalle, Kasanko, & MCCormick, 2004; Brown, Johnson, Loveland, & Theobald, 2005; Tan, Li, Xie, & Lu, 2005; for general discussion of these issues see Antrop, 2004; Gutman, 2007). Here this problem is approached by observing the consequences of this transition in the landscape reflected by analysis of LCC. The patterns observed have been much debated, here emphasis is given to developing practical solutions for the sustainable future use of the territory and its precious natural resources.

Land use/land cover change and environmental monitoring

Monitoring of LCC is of crucial importance for understanding detailed change processes on the surface of the earth. Numerous recent publications in the applied geographic literature have addressed the implications and impacts of LCC. This research has tended to be focused in areas where this change is extremely dynamic and where impacts on natural resources and population welfare are particularly acute, such as Bangladesh (Dewan & Yamaguchi, 2009; Roy, 2009) and Egypt (Shalaby & Tateishi, 2007). Recent research by Brink and Eva (2009) investigated LCC modifications over the last 25 years in sub-Saharan Africa, and its serious implications on food security, natural resources, human welfare and global climate. Anthropogenic land surface change influences global climate, and LCC modifications in one area may have important implications on climate elsewhere (Marland et al., 2003). In the context of the present widespread concern about humanly modified climate change, understanding and active management of LCC is therefore increasingly important (Turner, Lambin, & Reenberg, 2007). Achieving environmentally sustainable land management practices is therefore a global concern that must be fully addressed in all areas and at all spatial scales.

The rapid parallel development of Remote Sensing (RS) technologies and Geographical Information Systems (GIS) over the last 25 years has provided researchers with better quality land resource information and more sophisticated tools for LCC analysis. In Europe, high resolution (1:100,000 scale) Land Cover data are widely available and can be obtained free of charge through the CORINE (Coordination of Information on the Environment) programme, an integrated land resource management system for the whole European community, initiated in 1985, with the aim of guiding international land resource policy across national boundaries (Briggs & Mounsey, 1989). Most areas of Europe now enjoy

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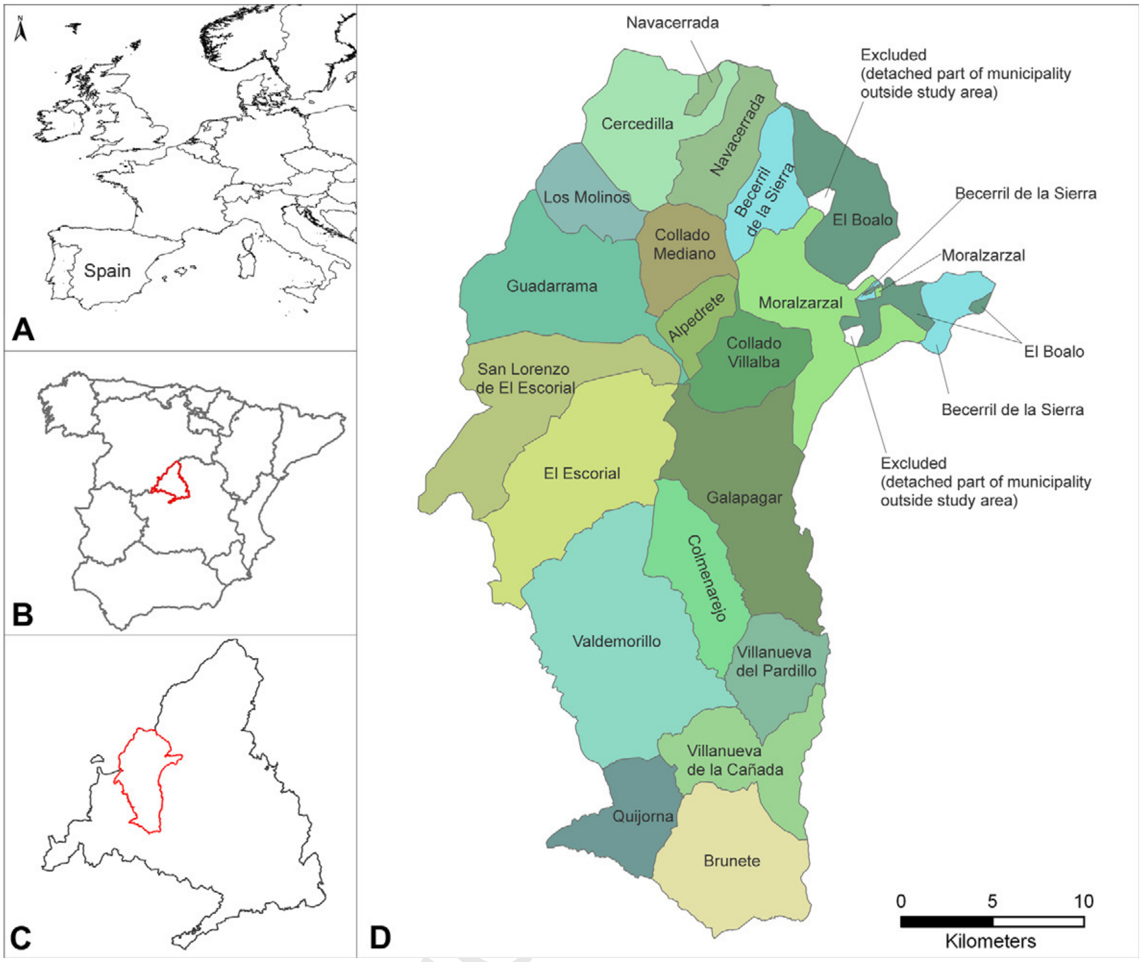

Fig. 1. A: Spain located in western Europe, B: Autonomous Communities of the Spanish Peninsula, C: Guadarrama study area, D: Municipalities of Guadarrama study area.

coverage over at least three dates (1990, 2000, 2006) enabling land cover change detection to be undertaken without recourse to separate sources of information, something that presented a serious problem in the past (see Plata Rocha, Gómez Delgado, & Bosque Sendra, 2009, with reference to the work of Aldana, 2005).

Tools for analysis of LCC are now standard components of modern desktop GIS such as IDRISI (Clark Labs, Worcester, Massachusetts, USA) and can also be obtained free of charge from a variety of sources. In this analysis, commercial GIS software ArcGIS (ESRI, Redlands, California, USA) was used to prepare data for analysis and publication outputs, but the LCC analysis was undertaken using the freeware Map Comparison Kit (MCK) developed by the Research Institute for Knowledge Systems (RIKS) in Maastricht, Netherlands.

CORINE data can be obtained from the website of the European Environment Agency (EEA, 2007a). The most recent version of the MCK (with full user documentation), can be downloaded from: http://www.riks.nl/mck/

Land use modeling

In recent years, researchers in closely related fields such as applied geography, land use policy, environmental planning and urban studies have sought to understand LCC dynamics through modeling approaches. Land use change models, according to Verburg et al. (2004) are "tools to support the analysis of the causes and consequences of land use dynamics". To explore the *consequences* of LCC, then, it is necessary to build on static descriptive work such as CORINE Land Cover to simulate possible future land use configurations from empirical data. For general overview of and use modeling in applied geography see Parker et al. (2003), Verburg et al. (2004), for detailed treatment and case studies see, for example, Barredo et al. (2004), Van Delden et al. (2010), Verburg, Veldkamp, and Fresco (1999), White and Engelen (1993).

European patterns of LCC 1990–2000

Over the last 20 years, European countries have experienced unprecedented Land use/Land cover change, notably urbanization, intensification (improvement) or extensification (abandonment) of agricultural areas, and changes to forest cover. Spain is outstanding in Europe in terms of the intensity and extent of land cover change experienced over this period. According to a recent study of land cover change flows in European landscapes by Feranec, Jaffrain, Soukup, and Hazeu (2010), 18,449 km^2 (3.64% of the country's surface area) experienced change between 1990 and 2000, the greatest surface area change in Europe. In percentage terms, land cover change across all classes was highest in Portugal (9.85% of total land area), Ireland (7.91%), Czech Republic (6.43%), the Netherlands (4.13%), Slovakia (3.96%), Latvia (3.94%), Hungary (3.90%), followed by Spain (3.64%). It can be remarked that the sum of the areas of all of these countries together less Spain comes to 485352 km^2, while Spain alone has an area of 506221 km^2 (Feranec,

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Jaffrain, Soukup, & Hazeu, 2010). Clearly, with respect to other European countries, the Spanish territory has undergone massive transformation.

LCC dynamics in the Madrid region

Dynamic landscape change within the CM and on its immediate periphery has been investigated by various authors from the early 1990s onwards (e.g. Castro & García-Abad, 1993; García-Abad, 1991; Otero, 1993; Sancho et al., 1993; Zárate, Ojeda, Rebollo, Pérez, & De Pablo, 1998). Aldana (2005) explored artificial land cover change in the CM between 1987 and 1997, clarified important patterns that had already been emerging from earlier studies, such as significant urban expansion orientated along road and rail networks and a general tendency towards dispersed urban development. García Rodríguez and Pérez González (2002) noted substantial reduction in agricultural areas and increases in urban and industrial land in south-eastern part of the Madrid region through examination of satellite images from 1987, 1999 and 2001. The inclusion of part of the study area within a national park had not impeded land use changes of mostly anthropogenic origin with consequent loss of semi-arid landscape areas of natural value. In their investigation of land use change between CORINE land cover 1990 and 2000, the Spanish Sustainability Observatory (OSE, 2006) reported rapid growth in urban, industrial and other artificial areas to the detriment of forested and agricultural areas. García Palomares and Gutiérrez Puebla (2007b) documented “extension without precedent” in recent years of residential spaces on the city’s fringe, and the ever increasing use of land for low density housing. Most recently, Plata Rocha et al. (2009) observed strong increase in urban areas between 1990 and 2000, principally low density residential units. Traditional agricultural areas had experienced substantial net losses. Losses to both forested and agricultural areas were shown to be occurring principally less than 500 m from artificial areas in 1990.

The study area and its context

In topographical terms, the Madrid region can be broadly divided into three landscape units or dynamics; (1) The Sierra de Guadarrama, the mountainous upland zone; (2) The hill and river landscape, the gentler terrain of interfluvial hills of the central part of the province, and (3) The Alcarria, a calcareous, sparsely vegetated open landscape between 700 and 1000 m in altitude in the south-eastern part of Madrid, delimited to the west by the rivers Jarama and Henares and to the south by the river Tajo (Bullón Mata, 2008). The study area (Fig. 1) comprised a contiguous block of 19 municipalities principally occupying the central part of the Sierra de Guadarrama with 4 municipalities on the interfluvial hill landscape directly to its south. These 19 municipalities form a landscape block which equates approximately to the upper and middle sections of Guadarrama river basin, including its higher tributaries, and its immediate environs. The following municipalities are located in The Sierra sector: Alpedrete, Becerril de la Sierra, Cercedilla, Collado Mediano, Colmenarejo, El Boalo, El Escorial, Galapagar, Guadarrama, Los Molinos, Moralzarzal, Navacerrada, San Lorenzo del Escorial, Valdemorillo and Villalba. The remaining municipalities of Brunete, Quijorna, Villanueva de la Cañada and Villanueva del Pardillo are located within the interfluvial hill landscape sector.

These 19 Municipalities (Fig. 1) all lie within the catchment of the middle and upper Guadarrama basin, but are remarkably different in character. The northern part of the study area, a mountainous zone with forests of *pinus sylvestris* and high-scrubland pastures contrasts sharply with the lower-lying

Table 1
CLC data details (from EEA 2007 and own sources).

Layer name	Projection	Source	Thematic accuracy	Satellite data	Geometric accuracy of satellite images	Minimum mapping unit	Time consistency
CLC1990N3	Universal Transverse Mercator (Zone 30 N)	European Environment Agency (EEA) via Spanish National Geographic Institute (IGN)	≥85% (not validated)	Landsat 4–5 TM single date (Occasionally Landsat MSS)	≤50 m	25 ha	1986–1998. (Most images for the Spanish territory are from 1987)
CLC2000N3	Universal Transverse Mercator (Zone 30 N)	European Environment Agency (EEA) via Spanish National Geographic Institute (IGN)	87.0 ± 0.8%	Landsat 7 ETM single date	≤25 m	25 ha	2000 ± 1 year
CLC2006N3	Universal Transverse Mercator (Zone 30 N)	European Environment Agency (EEA) via Spanish National Geographic Institute (IGN)	≥85%	SPOT-4 and/or IRS LISS III two dates	≤25 m	25 ha	2006 ± 1 year

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municipalities, such as Brunete, a formerly important agricultural and pastoral area on account of its abundant near-surface (freatic) water supply. All of the study area, however, is increasingly threatened by land use policies that favor urban expansion, and by the abandonment and loss of agricultural and pastoral lands. It is therefore particularly attractive for the study of landscape change, exemplifying in this way the three key conflicts within the Madrid landscape, agriculture, conservation, and urbanization.

Methodology

CORINE land cover

The investigation took as its starting point three well-known and widely accessible digital datasets, CORINE Land Cover 1990, 2000 and 2006, henceforward CLC1990, CLC2000 and CLC2006. For this investigation, CLC1990, 2000 and 2006 vector coverages distributed by the Spanish National Geographic Institute (IGN), appropriately georeferenced and projected for the Spanish mainland were used. These data are summarized in Table 1, below:

Assessments of the thematic accuracy and reliability of the CORINE Land Cover datasets are numerous (e.g. Bach et al., 2006; Gallego, 2000; Mas & Fernández, 2003). Most studies agree that CORINE is usually less precise than larger scale national land cover maps due to the unavoidable aggregation of categories owing to the scale of the CORINE dataset and the minimum mapping unit (25 ha). Aggregate error resulting from comparison of two datasets should also be considered. Cross-tabulation of two datasets will expose the results to errors present in both datasets, the intersection coverage will have a confidence level equivalent only to 72%, signifying that, potentially, 28% of the changes observed are not real changes, rather errors in thematic classification (Catalá Mateo, Bosque Sendra, & Plata Rocha, 2008, 84). Catalá et al also identified "false" land cover changes in the CORINE mapping for the Madrid region probably due to thematic classification errors, such "bare rocks" category to vegetation categories (these were predominantly rocky areas free of vegetation at both dates), changes from "agro-forestry areas" category to "beaches, dunes and sands" (there are no true beaches, dunes or sands in Madrid), and changes from natural grasslands to water bodies. This was interpreted as a difference in reservoir water levels between mapping dates rather than a genuine land cover change (Catalá Mateo et al., 2008, 93)

Aside from these known problems detailed above, the CLC1990 and CLC2000 datasets can be regarded as generally of high quality, provided they are used at the appropriate scale. For the study area investigated here, the nominal scale of 1:100,000 is clearly appropriate, though, at a more detailed level (the municipality), more precise data would be needed. The CLC2006 dataset for Spain has been available only a few months at the time of presentation of this article for publication. The reliability of the dataset in terms of thematic classification has not yet been thoroughly investigated by researchers. Aside from one or two possible classification errors, the CLC2006 dataset used here was of a generally rather lower cartographic standard comparative to previous datasets (poor edge matching with CLC2000, for example, resulting in numerous sliver polygons). While these problems made for some difficulties in presentation, they are unlikely to have affected the change analysis results to any significant degree. It is hoped that a cleaner dataset will be made available soon.

Cross-tabulation and map intersection methodology

Detailed quantification of LCC was accomplished by comparison of paired land cover maps CLC1990 and CLC2000, and CLC2000 and CLC2006 (Fig. 2a–c). After clipping the CLC coverages to the study area, coverages were converted to a raster dataset with a 100 × 100 grid cell resolution (specified nominal scale of CORINE land cover) and cross comparison was carried out. Maps were reclassified to ensure the CLC categories were correctly assigned to the maps for all dates (not all categories appear in all the maps).

The analysis was undertaken using the freeware Map Comparison Kit (MCK) developed by the Research Institute for Knowledge Systems (RIKS) in Maastricht, Netherlands, which automatically calculates the standard kappa statistic (Cohen, 1960). The statistical output takes the form of a standard contingency table (referred to as cross-tabulation or confusion matrix in some contexts), with map1 land uses reading down from the top of the table (columns) and map2 land uses reading left to right across the table (rows). This is a standard technique for making comparisons of land use change.

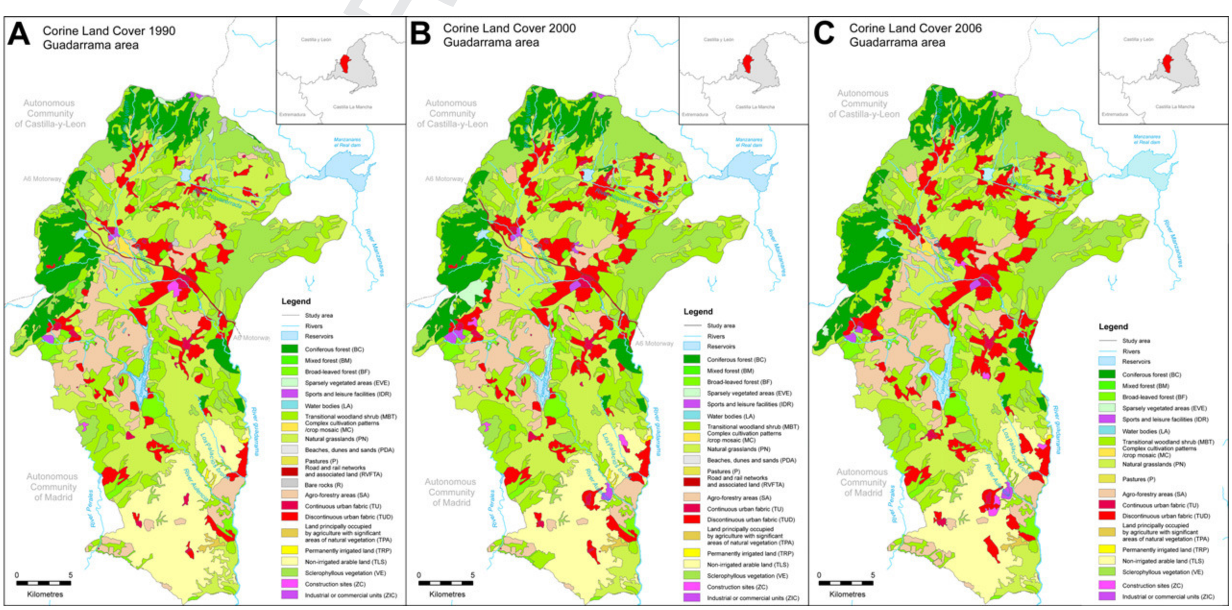

Fig. 2. Corine Land Cover, Guadarrama area. A: 1990, B: 2000, C: 2006. Note the increase in Discontinuous Urban Fabric Land Cover class across the three dates.

Table 2
Area and percentage relative to total study area of different land cover classes CLC1990, CLC2000 and CLC2006. Abbreviations relate to the title in Spanish of the original land cover class.

CLC level 3 class name	1990 (area in ha)	% Of total ha	2000 (Area in ha)	% Of total ha	2006 (Area in ha)	% Of total ha
Continuous urban fabric (TUC)	596	0.77	604	0.78	441	0.57
Discontinuous urban fabric (TUD)	5396	7	7870	10.21	8832	11.46
Industrial/Commercial (ZIC)	59	0.08	163	0.21	141	0.18
Road, rail and associated land (RTVFA)	180	0.23	206	0.27	0	0
Construction sites (ZC)	144	0.19	130	0.17	226	0.29
Sport and leisure facilities (IDR)	113	0.15	306	0.4	185	0.24
Non-irrigated arable land (TLS)	9668	12.55	8470	10.99	8217	10.66
Permanently irrigated land (TRP)	118	0.15	121	0.16	69	0.09
Pasture (P)	401	0.52	319	0.41	289	0.38
Crop mosaic (Complex cultivation patterns) (MC)	213	0.28	187	0.24	182	0.24
Land principally occupied by agriculture etc	136	0.18	136	0.18	137	0.18
Agroforestry areas (SA)	7472	9.7	7126	9.25	7302	9.48
Broad-leaved forest (BF)	2304	2.99	2382	3.09	2369	3.07
Coniferous forest (BC)	7325	9.51	7325	9.51	7423	9.63
Mixed forest (BM)	93	0.12	27	0.04	29	0.04
Natural grassland (PN)	19,853	25.77	17861	23.18	17,258	22.4
Sclerophyllus vegetation (VE)	9890	12.84	9591	12.45	9552	12.4
Transitional woodland shrub (MBT)	11,906	15.45	12849	16.67	13,469	17.48
Beaches, dunes and sands (PDA)	125	0.16	250	0.32	0	0
Bare rocks (R)	226	0.29	0	0	0	0
Sparsely vegetated areas (EVE)	156	0.2	433	0.56	46	0.06
Water bodies (LA)	678	0.88	697	0.9	888	1.15
TOTALS	77,053	100	77,053	100	77,053	100

SDSS methodology; the Madrid model

Following the LCC analysis presented in the subsequent sections, the implications of the land cover dynamics observed are discussed in some detail (Section 4.2). The results of the LCC analysis are compared with output from the Madrid Model, an SDSS developed by the EU-funded TiGrESS project to explore the impact of potential policy interventions in Madrid through modeling of future scenarios. A brief summary of the model's development is presented as follows.

Exploring the impact on the future configuration of the territory of the various policy options suggested to TiGrESS researchers by the CM's land planning stakeholders presented a practical problem, namely, the high level of complexity generated by the many conflicting decisions and counter decisions at the level of the individual land parcel.[2] To address this difficulty and allow the impact of policy interventions to be visualized, a dynamic cellular-automata based model of land use in the CM was developed. Modeling was undertaken using METRONAMICA, the land use modeling component of the GEONAMICA® application framework, a commercial environmental software developed by the Research Institute for Knowledge Systems (RIKS), in Maastricht, Netherlands (see White & Engelen, 1993, 2000 for more information on this approach). Modeling work was coordinated by Carlos Hernandez Medina, Inge Uljee and Maarten van der Meulen under the supervision of Nick Winder, coordinator of the TiGrESS project and completed in 2006 (Hahn et al., 2006). The individual scenarios developed by the model are discussed in-depth by Hernández-Jiménez (2007) and Hernández-Jiménez and Winder (2006). The model results are presented here by permission of the TiGrESS project.

The model represents land use in the CM in the form of a standard 2-dimensional cell-based (raster) map familiar to any user of GIS. Land use base mapping was produced by researchers in Madrid from remotely-sensed data across three dates, (1989, 1997 and 2002). From a starting configuration derived from a real land use map (in this example, land use in the CM in 2002), the model advances through a series of stages representing time steps. At each time step land use across the entire map is recalculated on the basis of transition rules determined for each individual cell. Transition rules for each land use cell in the model were calculated on the basis of the interaction of four key model parameters, *suitability* (physical or geographical determinants – e.g. cereals cannot normally be cultivated in mountain areas),*zoning*,(institutional suitability or model constraints – areas protected or reserved for certain land use types), a*ccessibility* (distance from roads and railways) and *dynamics* (cell neighborhood rules determined from previous empirical study of land use dynamics – e.g. repulsion of industry on housing, attraction of abandoned (vacant) land for urban use etc). Naturally, not all cells in the map will undergo transition at each stage; transition for a particular cell to a new land use type will take place only when the appropriate conditions (transition rules) for its cell neighborhood are satisfied.

The model's effectiveness at representing real land use dynamics was tested by a process known as *calibration* in which artificially generated future land use maps are compared with real land use maps for the same dates. This process was fundamental to the success of the model, and required considerable experience, not only in terms of the operation of the model software, but also in the particular dynamics of the territory under consideration and in land use modeling more generally. Scenario 0 (Business as usual) was developed by Carlos Hernández-Medina and RIKS in Madrid and Maastricht (Hernández-Jiménez & Winder, 2006). This scenario was validated to simulate land use change between the two periods of planning (1989–1997 and 1997–2002) and then extrapolated to 2025, and was intended to represent the effect of a *laissez-faire* approach to land planning in the territory (no change to current planning policy). As such it provides a crucial control land use configuration against which other future scenarios can be compared.

Scenario 0 suggested transformation of considerable amounts of land to urban use, especially in the mountainous northern part of

[2] For example, designation of areas where certain types of land use (e.g. urban development) is restricted is likely to produce knock-on effects in other areas, as land use requirements will not necessarily change if the drivers behind those land use dynamics (higher rental returns for urban land uses than for farmland) remain. This a protective "hold-the-line" approach to land planning with no thought given to complementarity may in the end produce negative outcomes in other areas something that can be easily be avoided or mitigated if the difficulty can be forseen. See Deal and Pallathucheril (2009) for an excellent illustration of this type of problem.

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Table 3a
Results of cross-tabulation exercise, CORINE land cover 1990 (columns) and CORINE land cover 2000 (rows). Yellow denotes total gain by CLC2000, orange denotes total loss by CLC2000, while green denotes no change (stable) over the study period. Units are hectares (ha).

2000 Land cover class	1990 TUC	TUD	ZIC	RTVFA	ZC	IDR	TLS	TRP	P	MC	TPA	SA	BF	BC	BM	PN	VE	MBT	PDA	R	EVE	LA	Total 2000
Continuous urban fabric (TUC)	596	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	604
Discontinuous urban fabric (TUD)	0	5379	0	0	49	0	305	9	82	0	0	199	29	0	0	1418	229	172	0	0	0	0	7870
Industrial/Commercial (ZIC)	0	17	59	0	66	0	0	0	0	0	0	4	0	0	0	4	0	0	0	14	0	0	163
Road, rail and associated land (RTVFA)	0	0	0	180	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	206
Construction sites (ZC)	0	0	0	0	30	0	56	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	130
Sport and leisure facilities (IDR)	0	0	0	0	0	113	102	0	0	0	0	69	4	0	0	0	0	18	0	0	0	0	306
Non-irrigated arable land (TLS)	0	0	0	0	0	0	8443	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	8470
Permanently irrigated land (TRP)	0	0	0	0	0	0	12	109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121
Pasture (P)	0	0	0	0	0	0	0	0	319	0	0	0	0	0	0	0	0	0	0	0	0	0	319
Crop mosaic (Complex cultivation patterns) MC	0	0	0	0	0	0	0	0	0	187	0	0	0	0	0	0	0	0	0	0	0	0	187
Land principally occupied by agriculture but with significant areas of natural vegetation (TPA)	0	0	0	0	0	0	0	0	0	0	136	0	0	0	0	0	0	0	0	0	0	0	136
Agroforestry areas (SA)	0	0	0	0	0	0	0	0	0	26	0	7082	0	0	0	18	0	0	0	0	0	0	7126
Broad-leaved forest (BF)	0	0	0	0	0	0	0	0	0	0	0	0	2241	0	0	0	0	141	0	0	0	0	2382
Coniferous forest (BC)	0	0	0	0	0	0	0	0	0	0	0	0	0	7233	0	55	28	8	0	0	0	0	7325
Mixed forest (BM)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	27
Natural grassland (PN)	0	0	0	0	0	0	408	0	0	0	0	14	19	0	0	17258	75	68	0	17	0	0	17861
Sclerophyllus vegetation (VE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	233	9088	0	0	195	76	0	9591
Transitional woodland shrub (MBT)	0	0	0	0	0	0	342	0	0	0	0	0	0	0	0	762	245	11419	0	0	80	0	12849
Beaches, dunes and sands (PDA)	0	0	0	0	0	0	0	0	0	0	0	78	10	0	0	0	0	29	125	0	0	7	250
Bare rocks (R)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparsely vegetated areas (EVE)	0	0	0	0	0	0	0	0	0	0	0	0	0	92	66	0	224	51	0	0	0	0	433
Water bodies (LA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	670	697
TOTAL 1990	**596**	**5396**	**59**	**180**	**144**	**113**	**9668**	**118**	**401**	**213**	**136**	**7472**	**2304**	**7325**	**93**	**19853**	**9890**	**11906**	**125**	**226**	**156**	**678**	**77053**

Legend
- Net gain
- Net loss
- No change

Table 3b
Results of cross-tabulation exercise, CORINE land cover 2000 (columns) and CORINE land cover 2006 (rows). Yellow denotes total gain by CLC2006, orange denotes total loss by CLC2006, while green denotes no change (stable) over the study period. Units are hectares (ha).

2006 Land cover class	2000 TUC	TUD	ZIC	RTVFA	ZC	IDR	TLS	TRP	P	MC	TPA	SA	BF	BC	BM	PN	VE	MBT	PDA	EVE	LA	Total 2006
Continuous urban fabric (TUC)	397	5	0	3	0	0	17	0	0	0	0	0	0	0	0	19	0	0	0	0	0	441
Discontinuous urban fabric (TUD)	142	7447	95	46	100	9	180	0	29	19	0	82	40	64	0	423	42	97	0	0	17	8832
Industrial/Commercial (ZIC)	12	0	65	0	0	57	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	141
Road, rail and associated land (RTVFA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction sites (ZC)	0	1	0	12	0	0	140	0	0	0	0	0	0	0	0	73	0	0	0	0	0	226
Sport and leisure facilities (IDR)	0	0	0	0	0	185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185
Non-irrigated arable land (TLS)	2	4	0	0	0	0	8136	0	0	0	0	0	7	0	0	68	0	0	0	0	0	8217
Permanently irrigated land (TRP)	0	0	0	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0	0	0	0	69
Pasture (P)	4	7	0	0	0	0	0	0	278	0	0	0	0	0	0	0	0	0	0	0	0	289
Crop mosaic (Complex cultivation patterns) MC	0	0	0	0	0	0	0	0	0	157	0	0	0	0	0	25	0	0	0	0	0	182
Land principally occupied by agriculture but with significant areas of natural vegetation (TPA)	0	0	0	0	0	0	0	0	0	0	137	0	0	0	0	0	0	0	0	0	0	137
Agroforestry areas (SA)	9	23	1	18	0	0	0	0	0	12	0	7047	44	0	0	0	0	139	0	0	9	7302
Broad-leaved forest (BF)	2	66	0	4	0	0	0	0	0	0	0	0	2280	0	0	9	0	0	0	0	8	2369
Coniferous forest (BC)	8	25	0	0	0	0	0	0	0	0	0	0	0	7226	0	0	140	23	0	0	1	7423
Mixed forest (BM)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	29
Natural grassland (PN)	14	191	7	67	0	56	1	0	14	0	0	1	0	0	0	16892	0	2	0	0	13	17258
Sclerophyllus vegetation (VE)	0	40	0	37	30	1	0	0	0	0	0	0	0	40	0	0	9343	48	0	0	13	9552
Transitional woodland shrub (MBT)	2	44	0	22	0	0	0	51	0	0	0	0	23	1	0	324	29	12539	0	429	5	13469
Beaches, dunes and sands (PDA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparsely vegetated areas (EVE)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	0	0	0	0	46
Water bodies (LA)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	241	0	642	888
TOTAL 2000	**592**	**7853**	**168**	**209**	**130**	**308**	**8481**	**120**	**321**	**188**	**137**	**7130**	**2394**	**7331**	**29**	**17833**	**9600**	**12853**	**241**	**429**	**708**	**77055**

Legend
- Net gain (yellow)
- Net loss (orange)
- No change (blue)

the territory, where housing demand was thought to be increasing (Hernández-Jiménez & Winder, 2006). This observation is clearly of key relevance to the current study area, which deals with the western part of precisely this area. Scenario 0 also indicated that cropland would become surrounded by urban land or by forested areas, with conversion to urban use of shrubland borders. Other indications provided by this model scenario, such as the spread of irrigated crops and destruction of crop mosaic areas by urbanization, are of less direct relevance to the study area under discussion in this article.

For the purposes of this article the model was stopped at 2006, generating a map for the business as usual scenario 0 (Fig. 8) for this year. The scenario 0 simulation result for 2006 was then compared with the CLC2006 dataset for the group 1 Corine land cover classes (Artificial surfaces; urban land use in the Madrid Model) using the MCK and ESRI GIS software. These results are discussed in Section 4.2. This simple simulation and map comparison exercise was not intended as an in-depth study, but rather to complement the results of the LCC analysis and to illustrate of the power and utility of this type of SDSS as an aid to land planning.

Results of LCC Analysis

Land cover change 1990–2000–2006

The reader is referred throughout to Tables 2, 3a and 3b (above), and to Figs. 3–6. All detailed information is given in the tables and the most significant patterns of change observed are discussed in the following section entitled "summary of changes 1990–2000–2006". Land cover change between CLC1990 and CLC2000 is referred to as period 1, between CLC2000 and CLC2006 as period 2.

Total change

Period 1 1990–2000. In period 1, 6356 ha out of the total 77053 ha (8.25%) that comprised the study area were subject to some kind of land cover change between the two maps, while 70607 ha (91.75%) remained unchanged. Gains and losses for period 1 are shown in Fig. 6.

Period 2 2000–2006. In period 2, 4186 ha (5.43%) out of 77,055 ha were subject to change. 72,869 ha (94.57%) remained unchanged. Total land cover change was therefore significantly less in period 2 than in period 1. Gains and losses for period 2 are shown in Fig. 7.

One important difference between this mapping and the two previous years is complete disappearance of the road, rail and associated land category, which occupied 209 ha in CLC2000. This is probably a response to criticism (e.g. Catalá Mateo et al., 2008) of poor mapping of infrastructures in previous editions of CORINE land cover.

Whole period 1990–2006. Over the whole period 1990–2006, 8699 ha (11.3%) of the total land area has been subject to change. Agricultural areas decreased (down 1833 ha, a 10% decline) while artificial surfaces, predominantly urban areas increased (up 3339 ha, a 51% increase).

Summary of changes 1990–2000–2006

Artificial areas. The majority of new artificial areas comprised discontinuous urban fabric developed on non-irrigated arable land or natural grasslands, so-called "greenfield" development. These two land cover classes occupy together 35% of the whole study area, (25% alone classified as natural grassland), thus the apparent preference observed is probably only a function of the relative availability of development land. There is little evidence from this

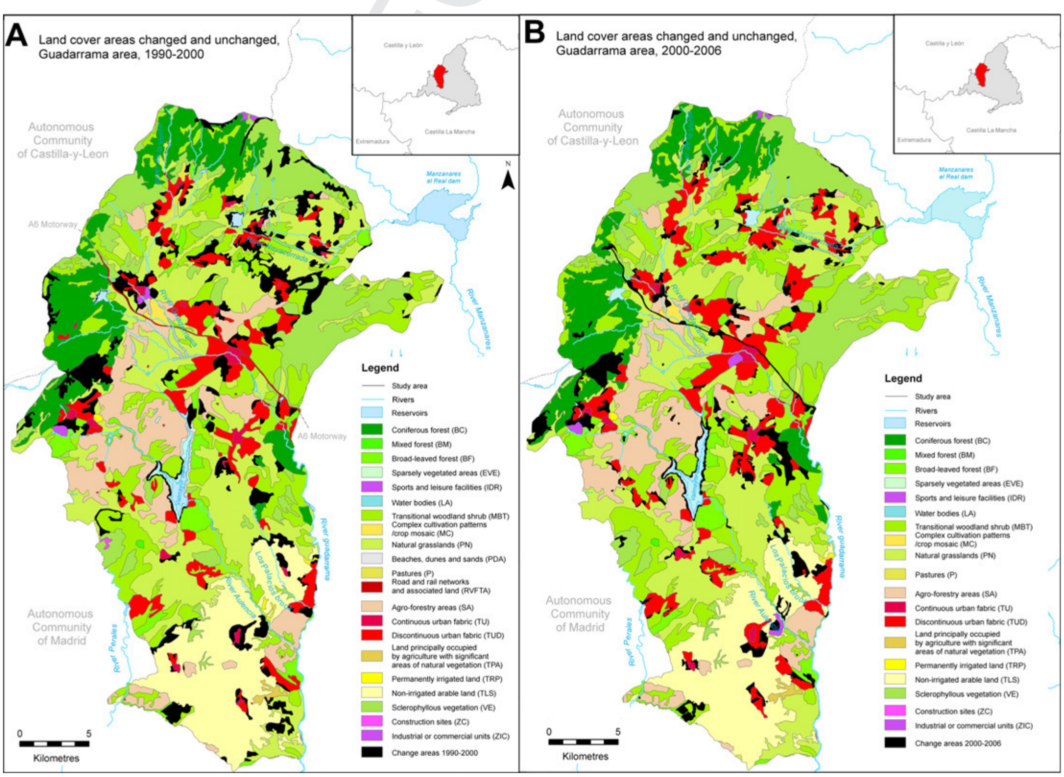

Fig. 3. Land Cover change, Guadarrama area. Changed areas in black, unchanged areas in color: A: Land cover areas changed and unchanged between CLC1990 and CLC2000, B: Land cover areas changed and unchanged between CLC2000 and CLC2006.

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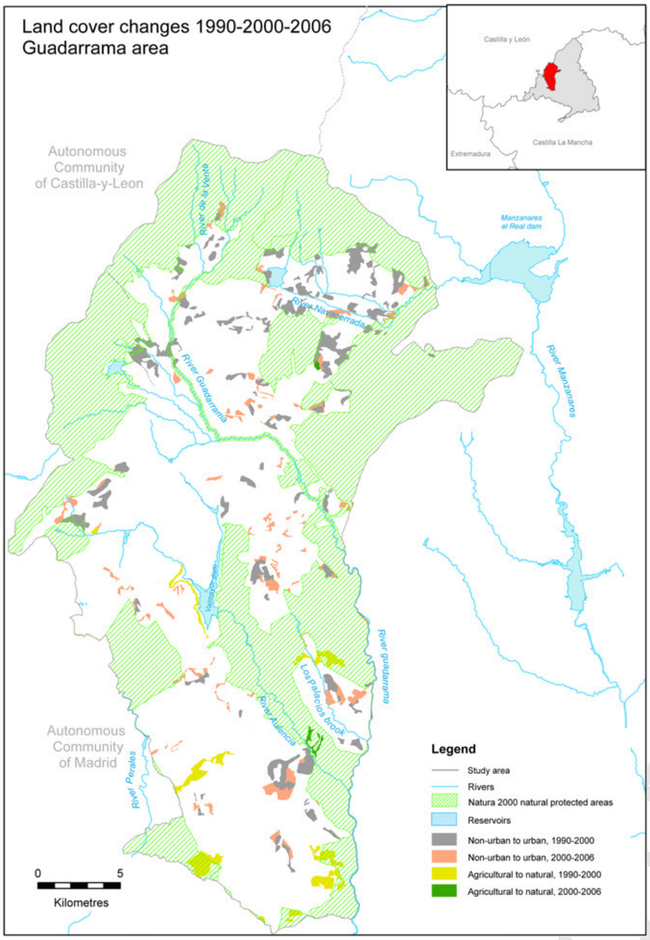

Fig. 4. Land cover changes 1990–2000–2006, showing natural protected areas.

analysis of any policy aimed at controlling urban expansion or limiting urban growth to specific land cover types. Examination of the change matrix (Tables 3a and 3b) reveals urban development on almost all land cover classes. Thus it seems likely that previous land use was not an important factor in the determination of urban planning applications for the study area for the period studied.

Agricultural areas. Non-irrigated arable land saw dramatic loss in period 1, being reduced in area by 12.5%, a total deficit of around 1200 ha. Very little of the land lost (12 ha, <1%) came under irrigated cultivation. The majority of the losses to non-irrigated arable land (750 ha out of 1225 ha lost; 61%) were to grassland and transitional woodland shrub, probably indicating abandonment. (463 ha of 1225 ha lost, 38%) converted to discontinuous urban fabric. In period 2, loss of non-irrigated arable land to natural land cover classes ceased entirely, but this land cover continued to decline severely in surface area, losing 344 ha (100% of total ha lost and 4% of its surface area in 2000) to artificial land cover classes across the period. Remembering that period 2 represents a shorter time period than period 1, it can be observed that urban development on non-irrigated arable land in fact increased in intensity in period 2 (a minimum of 46 ha lost to artificial surfaces per year in period 1, compared to a minimum of 57 ha per year in period 2).

Natural areas. Natural forested areas experienced relatively little change over the whole time period studied, and in fact increased slightly (9722 ha in 1990 up to 9821 ha in 2006). Though broad-leaved forest and coniferous forest increased slightly, mixed forest declined by $^{2}/_{3}$ over the study period (93 ha down to 29 ha). Give the very limited area originally given over to this land cover this does not seem very significant, though loss of mixed forested areas might result in reduced biodiversity.

A strong pattern of decline was observed in the natural grasslands category over the period studied. Changes to this land cover class have serious implications for the study area, as natural grasslands comprised around 26.8% of all land cover in the study area in CLC1990, reduced to 22.4% by CLC2006. Despite the conversion of 408 ha of non-irrigated arable land to grassland in period 1, the land cover shows marked decline over the whole period. Natural grassland has seen more urban development than any other land cover class except non-irrigated arable land. This is likely to be due to its natural characteristics and geographical location (flatter, closer to existing urban areas), as well as the large overall proportion of land area which it occupies. Transitional woodland shrub, also following the pattern observed in the previous study period, has continued to increase in area, principally as a result of tree growth in areas previously bare or sparsely covered by vegetation. The degree of movement within the natural vegetation category may in some cases be due to difficulty of distinguishing categories in remote sensing software, rather than real land use change.

Discussion – the transforming landscape of Guadarrama

Urbanization

The study area, which incorporates some of the most important natural areas of the Sierra de Guadarrama (Fig. 4), has seen intensive urbanization between 1990 and 2006, principally in the form of low density residential development (discontinuous urban fabric). Development appears to have occurred indiscriminately on a wide variety of land cover types. This suggests that Land use/Land cover have not been material considerations in determination of urban planning applications. Moreover, examination of the location of the new urban development (Fig. 5) reveals that much of it is located directly adjacent to the natural protected areas in the Sierra de Guadarrama (East of the Navacerrada reservoir on the river of the same name). Some of this development actually falls inside the protected area itself (Fig. 4). While these protected areas were not formally enshrined in law until 1998, not all of the development encroaching on the protected area belongs to period 1 (CLC1990 – CLC2000). Further south, the municipalities of Villanueva de la Cañada and Villanueva del Pardillo have seen large blocks of low density residential development. In Colmenarejo, the town has seen substantial expansion at its outskirts, while in the neighboring municipality of Galapagar urbanization seems to have been more haphazard, with a variety of developments emerging all over the municipality, at first (period 1) as a series of compact blocks, later (period 2) as smaller, widely scattered units. Proximity to natural spaces is of course part of the attraction – property advertisements for luxury detached villas at Navata, 3 km from the town of Galapagar, begin: "¡vive en un parque natural protegido!" ("live in a natural protected park!").

Overall, it seems that urban development has climbed to the top of the land use hierarchy, taking precedence over virtually any other land use. This implies that land planning in the sense of achieving a best fit between competing land uses has not been successful in this area during the study period. In terms of location, natural protected areas have, with some exceptions, generally been respected, though substantial urban development has taken place directly outside the boundaries of the protected areas. There is no indication of any attempt to control urban form, with new urban areas growing up more or less indiscriminately wherever they can be fitted in.

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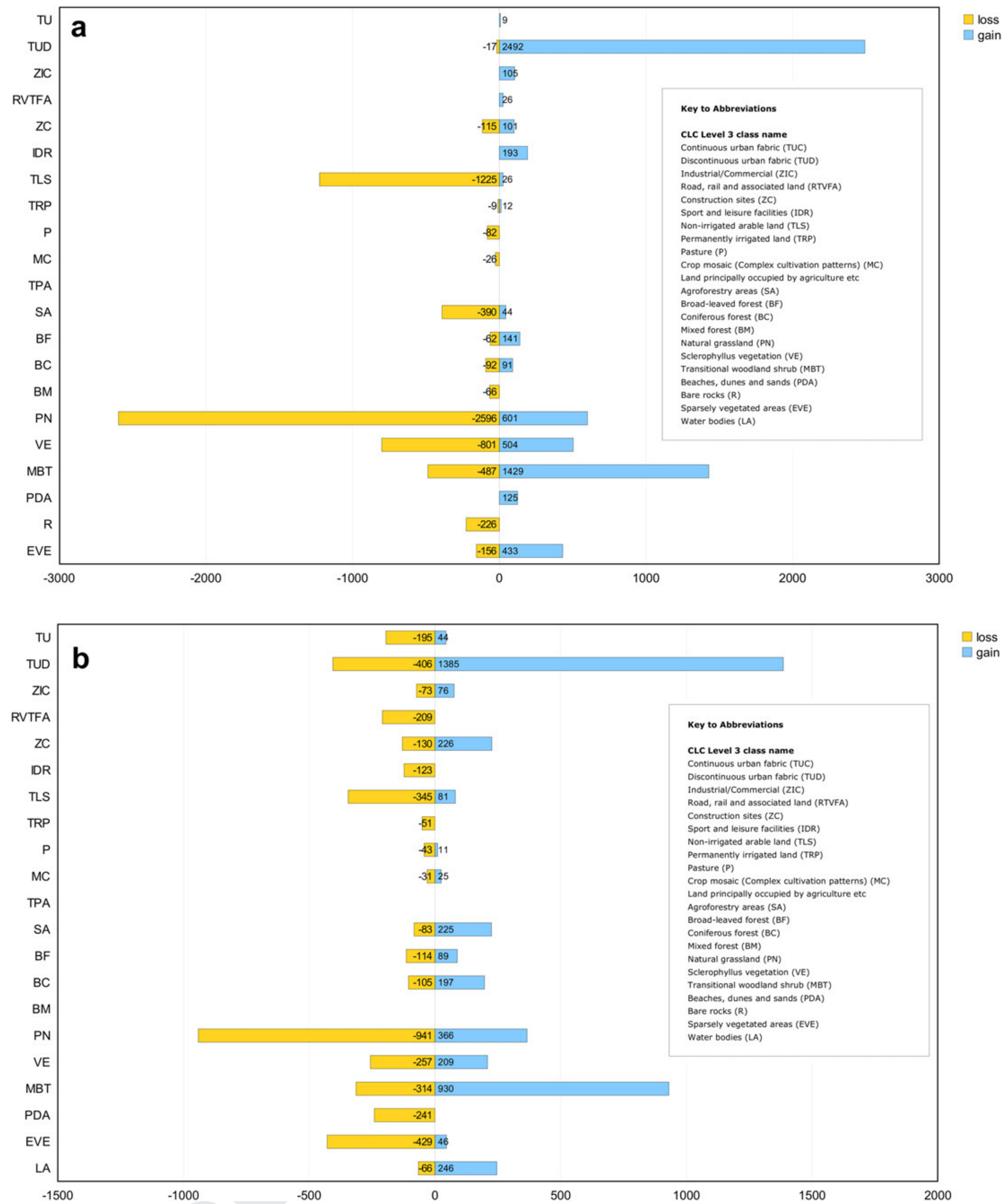

Fig. 5. a: Gains and losses, 1990–2000. b: Gains and losses, 2000–2006.

Agricultural decline

Agricultural land in the study area saw substantial decline in period 1. There was no evidence of changes due to intensification (e.g. irrigation of formerly non-irrigated land), rather urbanization and extensification (change of agrarian land to natural land, probably representing abandonment) were responsible. The extensification process, represented in period 1 by changes from agrarian land areas to natural areas such as grasslands or transitional woodland shrub, did not continue into period 2. This difference is probably due to adjustments to the European Common Agricultural Policy (CAP) in favoring rural conservation and regeneration actions after 2000. Of course, detection of apparently cultivated land in satellite images does not necessarily indicate agricultural productivity; all available statistics for traditional agriculture in Madrid present a picture of an industry in irreversible decline. In 2007, only 0.41% of the population of the Madrid region was employed in agriculture, compared with 8.73% in industry, 10.02% in construction, and 80.84% in services (Institute of Statistics for Madrid). By 2009, according to the Institute for National Statistics (INE) this figure had fallen to only 0.35% (INE, 2007–10).

Reversibility and land use

The prevailing land cover dynamics are non-reversible. No artificial land cover has converted into any non-artificial land cover type. This underlines the fact that not all forms of land occupation can really be considered as land *use*, urbanization is really *consumption* of land, while natural and agricultural areas are generally more interchangeable (within limitations), and fit better with the concept of land *use*.

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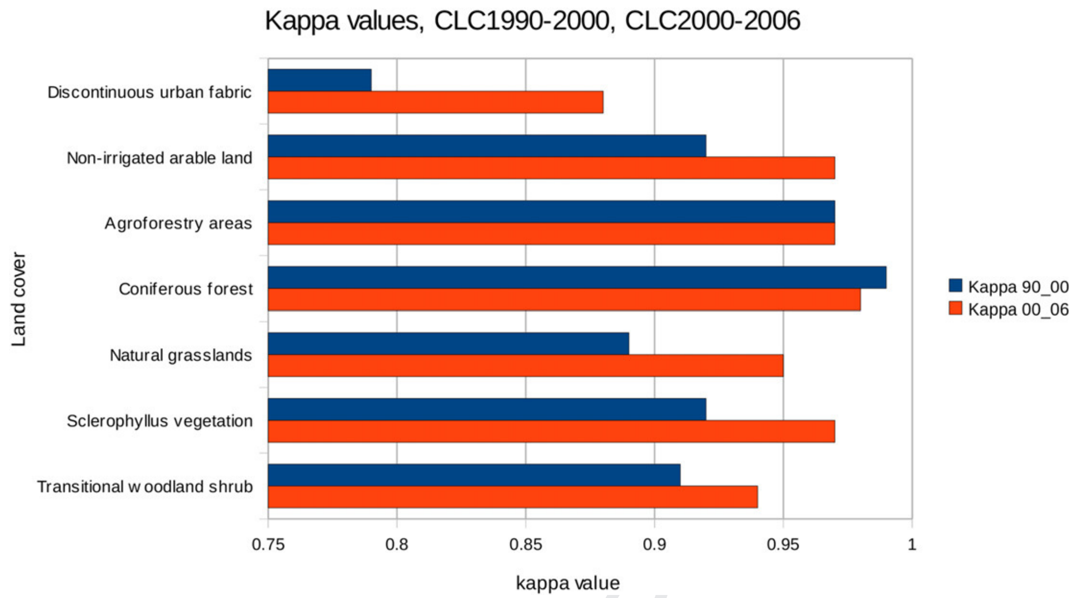

Fig. 6. kappa index of agreement across 7 largest land cover categories, 2000–2006. This statistic takes into account the change between each pair of maps relative to all other land uses in the maps. Longer bars indicate greater similarity (less dynamism) for each land cover class across the pair of maps. Since the statistic is based on ratio scores, comparison is only of interest for the same class between the two dates, not between classes.

CORINE land cover as a tool for land planning

The study area, a group of 19 contiguous municipalities, all occupying the Guadarrama river basin and immediate environs is an appropriate unit for the development of sub-regional spatial planning strategies for sustainable development. The intensity of the land cover changes seen in this study indicates that implementation of such strategies is an important priority for better management of the area.

Despite the known limitations of CORINE Land Cover, the CLC database at the level 3 classification scale is sufficient to develop analyzes in sub-regional contexts. Analysis of CLC data allows us to detect the main land cover changes within the study area and observe important tendencies in the occupation of the territory.

The future: planning for change in Madrid

The data presented above from the CORINE land cover programme demonstrate that even in areas not directly adjacent to the capital city, dramatic land use change is occurring. Problems of urban sprawl, decline and depopulation of agricultural areas and loss of areas of natural value are likely to intensify in the region unless progress can be made in a number of important directions. The remainder of this article is therefore devoted to discussion of what are considered to be the key priorities for future planning policy in the region. The following section outlines some practical methods for the implementation of sustainable development.

Land cover change monitoring and baseline data

Development planning in Madrid needs to be, as far as possible, objective and data-driven. Along with basic physical land information such as geology and soil mapping, land use and LCC information should be considered indispensable at all levels of policy making. Data-driven analytical approaches encourage transparency and repeatability. As we have demonstrated in the analytical

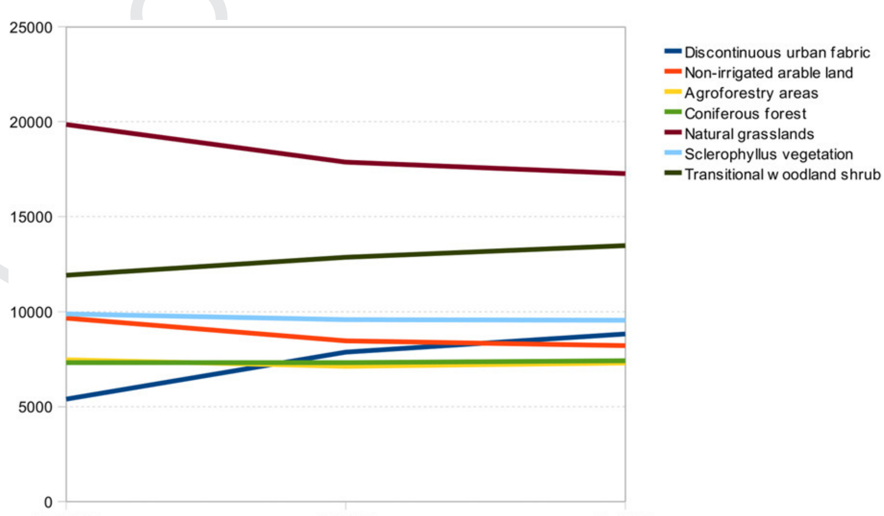

Fig. 7. Graph of land cover change trends across 7 largest land cover categories, 2000–2006. Y-axis value in hectares (ha).

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section of this article, CORINE land cover data is a powerful tool for elucidating change flows in the territory, allowing patterns of change to be managed as part of an integrated system. Where information at a greater spatial scale than that supplied by CORINE is required, government databases such as the Geographical Information System for Agrarian Parcels (SIGPAC), which contains large-scale land use information, could also be usefully adapted for change analysis. It should be emphasized that availability of high quality cartographic data is not the issue – Geographic Information is abundantly available from a variety of sources. These data need to be properly incorporated into formal decision making procedures (Spatial Decision Support Systems, SDSS), and all planning stakeholders, even the smallest municipality, should have access to the same datasets. CORINE land cover, on grounds of its widespread acceptance throughout Europe and its accessibility to all territorial stakeholders with a computer and internet connection, is a good place to begin.

SDSS and land use scenario modeling

Complexity, dynamism and scenario modeling

In a ~~complex and~~ highly dynamic region such as Madrid, it is difficult to explore the effect in the landscape of the complex interaction of different drivers of land use change such as land prices, access to employment and leisure activities, transport and policy decisions using static maps. To overcome these difficulties, various kinds of SDSS, (many based on land use models and incorporating CORINE land cover) are increasingly used by planners all over the world for exploring possible future land use configurations based on the interaction between these various dynamics (e.g. Rutledge et al., 2008; Van Delden et al., 2010; White & Engelen, 2000). In these models, patterns of land use change observed in existing datasets are projected forward to show possible future land use configurations based on the complex interaction the various agents of landscape change. The basic premise of these tools is not to accurately “predict the future” (which is of course impossible), but to show the long term implications in the territory of particular patterns of change, such as urban sprawl. Not only do these models show the implications of non-intervention (“business-as-usual” scenarios), they also allow innovative policy scenarios to be tested. Scenario modeling of this kind was employed for research into urban sprawl in Europe, in which Madrid was described as “a sprawled region with a weak spatial planning framework” (EEA, 2006). Hypothetical future development patterns were investigated, to “form the basis for decisions facing the city planners in delivering a more sustainable Madrid”. (EEA, 2006).

The Madrid model

Fig. 8 shows the indicative non-intervention scenario (business as usual, scenario 0) for the year 2006, developed by the Madrid Model (Sections 1.2 and 2.3, above). In this figure, only urban areas (corresponding to CLC artificial areas category) are shown. The top row shows (A) the 1:200,000 scale land use map for 2002 used in the model (the most recent available at the time of the TiGrESS project), and (B) the “business-as-usual” scenario generated by the

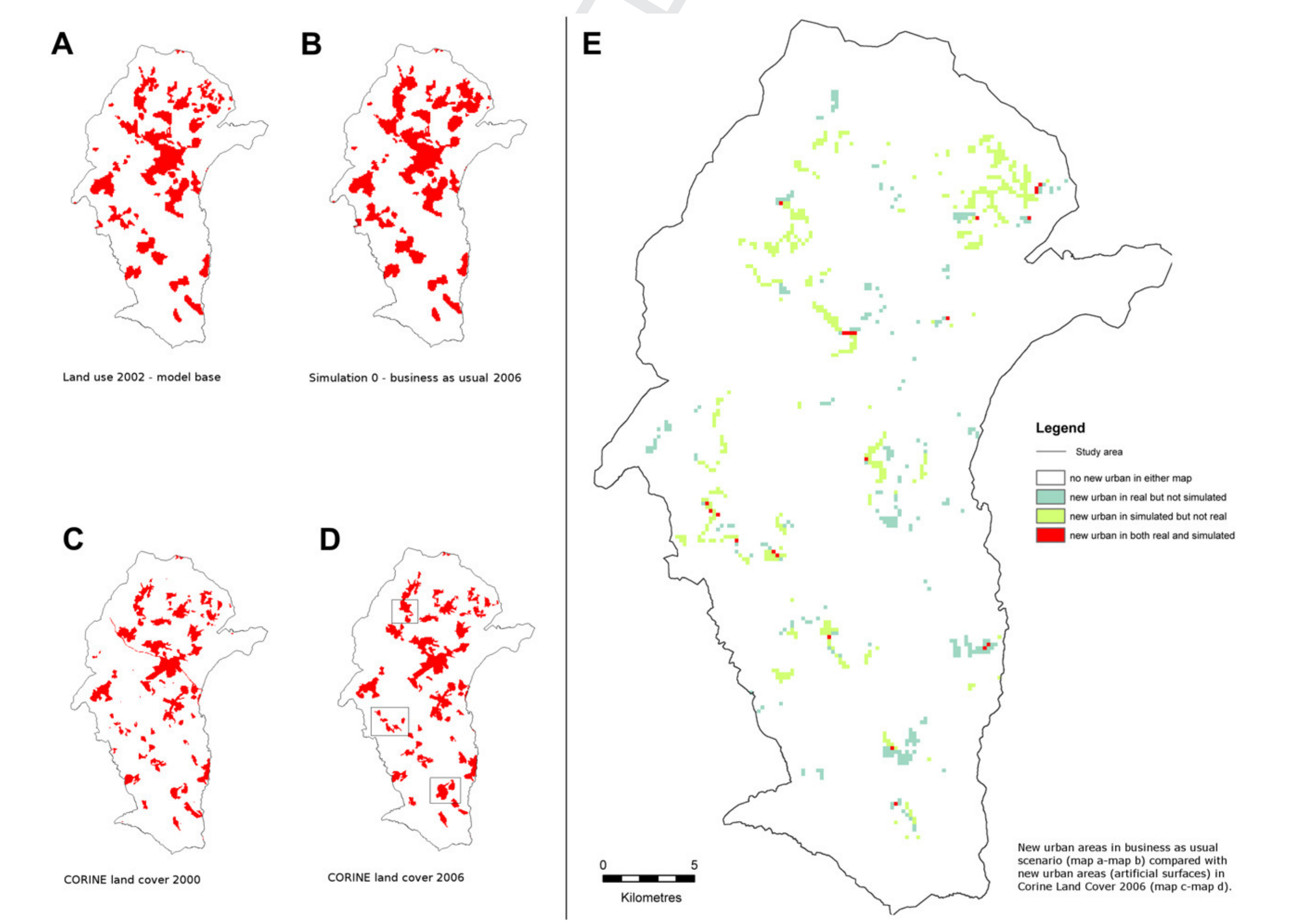

Fig. 8. Some outputs from the Madrid Model, developed by the TiGrESS project (Winder, 2006; Hahn et al., 2005; Hernández-Jiménez, 2007). Q5

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model showing urban land use for the year 2006. The amount of urban growth for the forecast year was derived from the rate of urban growth observed over previous years (in this case 1989 and 1997), which was then used to produce the urban land budget, allocated according to the model's cell transition rules (see Section 2, above). At the bottom of the figure, two of the land use maps used in the analysis presented in this article are shown, CLC2000 and CLC2006. Allowing for the difference in scale between the CORINE dataset and the model maps (CORINE, at 1:100,000 scale, has mapped the urban areas more precisely), on close inspection it can be seen that the model has successfully identified areas where urban growth did eventually take place (compare the real changes between maps C and D with the forecast changes in maps A to B). To aid comparison, the largest map (map E), shows new urban areas in 2006 (the differences between the two pairs of maps; A–B and C–D) for the model scenario and for CLC2006. Simulation 0 originally suggested (across the total simulation period 2002–2025), that substantial urban growth would take place in the mountainous northern region of the CM, along with encroachment of urban and forested land surrounding or enclosing existing cropland and shrubland (Hernández-Jiménez & Winder, 2006). This does indeed seem to have been the case, and though the match is not exact, the model does accurately predict growth in areas where growth later occurred (red areas in Fig. 8E). Discrepancies between the model and the real data for 2006 are intriguing. For example, in the northeast corner of the study area, the model predicts more urban growth than actually occurred, while in the south more growth has occurred than predicted. It may be that adjustment of certain variables that were not manifest or were not adequately modeled in the first place (e.g. the attractiveness to urban use of non-irrigated arable land) would more closely replicate the actual pattern.

While it should be emphasized that very close comparison with CORINE land cover is probably unwise (for one thing, the Madrid Model used a nominal scale of 1:200,000, half the scale of Corine), it is notable that the model does seem to have provided very specific information about the future development of the region, and seems broadly to pass the test of cross comparison with an independent mapping source not previously available at the time of the model's development (Model development ceased in 2006, Corine land 2006 did not become available until 2010). In the case discussed here, therefore, a scenario of non-intervention generated by the model can be shown to bear resemblance to real land use change. By introducing constraints (no growth permitted in certain areas), the growth budget determined from comparison of real land use change maps must be allocated by the model in other areas, in this way, planning restrictions can be tested and evaluated by stakeholders before being put into practice.

Despite the evident practical utility of these models, in the CM, as in many other regions, they have so far remained largely within the domain of research. Convincing policy makers to adopt these approaches in practice is more challenging in some regions than others, something that seems to be largely due to political priorities; the impetus needs to come from planners themselves. In Vitoria-Gasteiz, in the Basque Region of northern Spain, municipal planners commissioned a dynamic spatial land use model to explore the effects of alternative policy scenarios. The model incorporated 6 land use indicators and employed various scenarios related to land use, transport and zoning for the future development of the city and its environs up to the year 2030 (van Delden, Uljee, & Dominguez, 2006). In the CM, in spite of the research discussed here, these kinds of approaches have yet to be seriously considered by planning departments. The problem is the inability or unwillingness to recognize (for political reasons or otherwise) the urgent need for integrated spatial planning in the Madrid region.

Identifying areas for action

The Guadarrama study area selected for analysis in this article was initially defined in response to basic indicators of unsustainable development outlined in an earlier article (Hewitt & Hernández-Jiménez, 2010). This article took as its starting point the classic Brundtland report definition of sustainable development - "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). In Madrid, natural resource use is increasing in a way *unknown at any time previously* (Hewitt & Hernández-Jiménez, 2010, 12). Sustainability is therefore clearly an important concern; our earlier article was dedicated to an analysis of those areas of the CM that seemed most out of step with this guiding principle. Municipalities that had not successfully implemented the Agenda 21 process and that showed the highest rate of urban growth 1990–2000, the greatest decline in natural and agricultural areas 1990–2000, the highest rate of growth in construction sector unemployment 2006–2009 and the greatest per capita increase in private car ownership 1998–2008 were deemed the most unsustainable. Concerns about unsustainable development in the CM with respect to most of these criteria have already been voiced in the literature, e.g. López de Lucio (2003), García Palomares and Gutiérrez Puebla (2007a, 2007b) and Naredo (2008), so the basic indicators selected can be regarded as uncontroversial.

Once the indicators had been determined, analysis was straightforward, involving little more than simple statistical comparisons of easily accessible data sources (CORINE land cover, map of municipalities, national and regional statistical sources, e.g. INE, InEM, anuario económico de la Caixa). Such analyzes are easily repeatable by practically anyone with access to the internet and some standard desktop software. Procedure should take the form of a rapid appraisal. Long-drawn out evaluation procedures using many complex indicators should be avoided; it is important at this stage only to be able to identify basic dynamics in the territory to be able to group together municipalities sharing similar challenges. Action areas defined in our previous work are shown in Table 4.

Joint municipal strategies for sustainable territorial development – communication between municipalities

Sustainability Action Areas like those above can then be used to group municipalities together based on shared characteristics or challenges in their combined territories. These Sustainability Action Groups could then be charged with drafting sub-regional plans for sustainable development, or Territorial Sustainable Development Strategies (TSDS). These should, as noted above, be based on measurable patterns of land use change in the respective territories and should all use the same agreed baseline datasets and SDSS. The territorial unit is itself unimportant, as long as all municipalities in Madrid are incorporated into one or other, the unit has at least some common landscape characteristics, and enough municipalities (around 15–30) are included to adequately pool resources and ensure a broad enough perspective. TSDS should take the form of brief documents, supported by appropriate statistics and graphics. Inclusion of land use model scenarios and SDSS outputs, preferably tested through participatory sessions with community stakeholders would form a key part of such documents. TSDS should presenting practical plans and recommendations for the medium to long term sustainable development of the territory covered. It is important to note that these are not Local Plans or Agendas, and neither are they top-down strategy or central planning directives. Local interests would need to be subservient to broader interests within the wider landscape unit, but should strive to achieve a compromise between all local agents without interference from

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Table 4
Sustainability action areas.

Action area n°	Action area name	Indicator	Municipalities
1	Urban fringe West	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000	Arroyomolinos Mostoles Villaviciosa de Odon Boadilla del Monte Majadaonda Las Rozas Villanueva de la Canada
2	CM West	Strong increases in construction unemployment 2006–2009 Agenda 21 not initiated by 2009 Strong growth in automobiles per capita since 1998	Rozas de Puerto Real Navegamella Valdemorillo Robledo de Chavela Colmenar de Arroyo Aldea del Fresno Villa del Prado San Martin de Valdeiglesias Villamaqueda Navas del Rey
3	CM South East	Strong increases in construction unemployment 2006–2009 Agenda 21 not initiated by 2009	Municipalities bisected by and cast of a line drawn between Los Santos de la Humosa and Aranjuez
4	Urban fringe and Corridor South	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000 Agenda 21 not initiated by 2009	Fuenlabrada Pinto Valdemoro Getafe San Martín de la Vega Titulcia
5	Guadarrama Valley	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000 Agenda 21 not initiated by 2009 Strong growth in automobiles per capita since 1998	Torrelodones Moralzarzal El Boalo Becerril de la Sierra Collado Mediano Alpedrete
6	Urban fringe and Corridor East	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000 Strong growth in automobiles per capita since 1998 Agenda 21 not initiated by 2009	Coslada Alcala de Henares Torrejon de Ardoz Meco Ajalvir
7	Urban fringe and Corridor North	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000 Agenda 21 not initiated by 2009	Alcobendas, San Sebastian dc los Reyes Algete Tres Cantos
8	CM North	Agenda 21 not initiated by 2009	Municipalities bisected by and north of a line drawn between Torrelaguna and Rascafria
9	CM Centre North	Strong increase artificial areas 1990–2000 Decline natural/agricultural areas 1990–2000 Strong increases in construction unemployment 2006–2009 Agenda 21 not initiated by 2009	La Cabrera Torrelaguna Venturada Navalafuente

the autonomous community. Only once such a strategy is approved, should such a document be regarded as binding or legally enforceable by the autonomous community.

The model proposed here is at present hypothetical (Fig. 9), but as almost all of its elements are already in existence (appropriate territorial groups, adequate and accessible datasets, relevant skills base in civil society) the only practical impediment to implementation of this kind of model is the political will to do so. To be successful, the necessary impetus needs be found at the lowest administrative level, with appropriate support at the level of the autonomous government. Since municipalities are largely self-funded, appropriate grants for development of TSDS would also need to be in place.

Participatory planning and stakeholder engagement

The poor level of engagement of civil society in planning in Madrid has drawn much comment in recent years (e.g. Fernández Muñoz, 2008; Hernández-Jiménez & Winder, 2009). Recent and ongoing research projects such as the EU-funded ISBP project (Winder et al., 2009) have focused on trying to broaden the range of stakeholders involved and the extent to which they participate in the process. Nonetheless, traditional top-down "planning for the people" approaches still seem to prevail. Participatory planning is a key part of the process if sustainable management strategies are ever to be adopted in practice. One of its great strengths is the opportunity it provides for distributing decision making away from the hands of technocrats and officials, where it is traditionally concentrated, to the community influenced by such decisions. It is therefore particularly appropriate for evaluation of different policy scenarios, such as those generated from dynamic models of the kind discussed previously. Different development scenarios can be explored by community groups together with planners and researchers, often resulting in a highly constructive learning process for all participants. (See, for example, Deal & Pallathucheril, 2009; Paez, 2005; Paez, Bishop, & Williamson, 2006)

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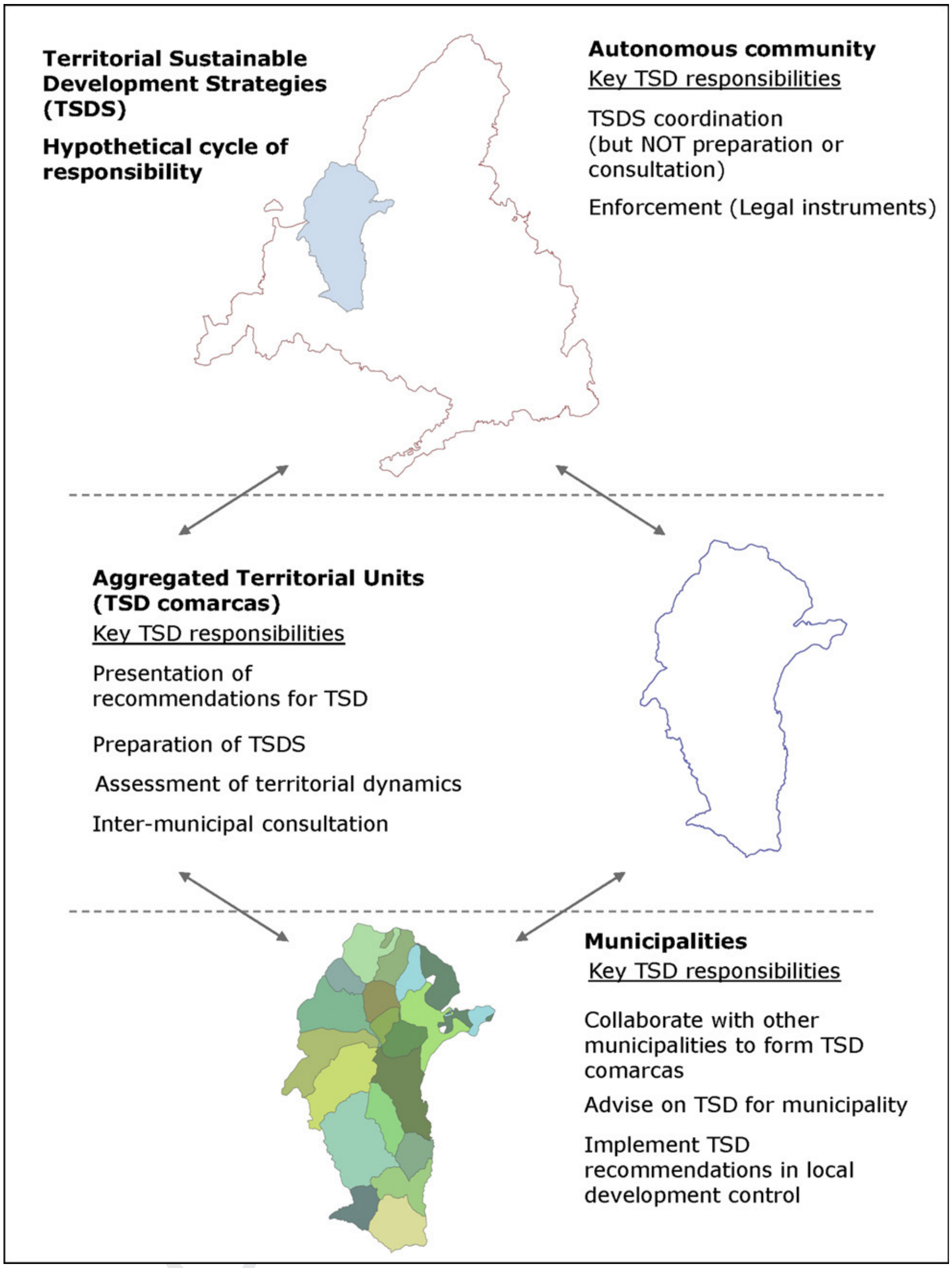

Fig. 9. Territorial sustainable development strategies: hypothetical cycle of responsibility.

Conclusions: a brighter future?

Towards sustainable development in Madrid

The investigations presented in this paper indicate that even outside of urban fringe areas of Madrid, where strong growth might be expected in such a fast-developing region, urbanization has been extensive and largely unchecked by systematic development control procedures. Urban form has not been respected and natural areas are under threat. The easy availability of former agricultural land and a liberal approach to land use policy over the years has exacerbated the problem.

Agricultural land has declined sharply, particularly in the southern part of the study area, reflecting wider trends both regionally and nationally. In a rapidly changing and increasingly urban and consumer-orientated society, rural areas are transforming as never before. Even where exploitation of agricultural land becomes uneconomic, it retains important values in terms of ecosystem services, biodiversity and natural beauty. Unfortunately, in Madrid, rural land is sometimes perceived by planners as having no value at all; in effect, as empty space to be "filled" by urban development.[3]

Only a combination of integrated approaches driven by all agents in the territory (civil society, planners, politicians) is likely to

[3] Nowhere is this view more cogently expressed than in the words of the current president of the CM, Esperanza Aguirre, in a television interview of 2003: "Así, una vez que se sepa que no hay nada que proteger…se podrá construir". *In this way, once we know that there is nothing to protect..we will be able to build."* (TeleMadrid, 2003). The implication is not only that protected areas are an inconvenience to be overcome, but that land lacking protection is automatically appropriate for urban use.

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succeed in the elusive goal of delivering sustainable development in Madrid. Some consensus has already been reached regarding the extent of the problems the territory faces (Hewitt & Hernández-Jiménez, 2010), but agreement surrounding the issues is not enough unless it can be resolved into concrete actions. This article has proposed a basic methodology for sustainable development planning in the CM. This methodology is summarized as follows:

1. Systematic use of the same baseline datasets, such as CORINE land cover, at all levels of governance for transparent, data-driven spatial planning.
2. Application of SDSS to model the complex interaction of drivers for land use change and test policy scenarios.
3. Establishment of supra-municipal action groups responsible for evaluation and implementation of sustainable development within their territory. The study area, comprising 19 contiguous municipalities in a single landscape unit (the upper and middle Guadarrama river valley) and clearly facing shared threats, is an example of the possible configuration of one such group.
4. Participation of civil society in planning decisions. Scenario-based land use models offer the opportunity to incorporate citizen's groups to test the validity and desirability of future scenarios, based on important local knowledge which planners may not have.

This methodology is intended as a constructive platform for practical action. Further research into dynamic land use modeling as a tool for evaluation of future policy scenarios in the CM is currently underway, and the authors continue to collaborate with the recently established land use and planning policy group, The Observatory for a Culture of the Territory (OCT). OCT works closely with universities and NGO's as well as the regional and national government to develop methodologies, tools and strategies for sustainable development and cooperation in the territory.

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EEA, 2007b; Feranec et al., 2007; Inem, 2007–10.

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