Chapter 15
Modeling Land-Use Scenarios in Protected Areas of an Urban Region in Spain

M. Gallardo and J. Martínez-Vega

Abstract Land use change due to human activity can have serious, often irreversible effects on the environment. It affects ecosystem functions and the sustainability of protected natural areas. Problems such as fragmentation, low habitat connectivity or a decline in a territory's ability to capture carbon are some of its consequences. By studying past land use trends we can simulate future land uses, and modeling such trends is essential if a preventive approach to the management of protected areas is to be adopted. The aim of this chapter is to simulate different change scenarios in protected natural areas in the urban region of Madrid, from National and Nature Parks to Special Areas of Conservation and Special Protection Areas. To this end we study land use changes both inside and around these protected areas. CORINE Land Cover maps from 1990, 2000 and 2006 are used. Cross-tabulation techniques are applied in order to study trends in land use change. Three scenarios are designed: a baseline or trend scenario, an economic crisis scenario and a green scenario. The CLUE model (based on logistic regression) is used. LCM (based on neural networks) is also used but only in the trend scenario. Biophysical, socio-economic and accessibility factors and incentives and restrictions are considered. FRAGSTATS and GUIDOS are used to analyse the effect of infrastructure and built-up land growth on connectivity and fragmentation. In recent decades, the region of Madrid has experienced intense urban and infrastructure development (48,332 ha). Protected areas have been affected by this urbanization process. Built-up areas have grown at an average annual rate of 5.52% in protected areas and around them. According to the trend scenario, the built-up area will increase by 28,000 ha over the period 2006–2025 to 7.6% of the study area. No fragmentation processes are expected in the National Park. However, fragmentation of agricultural and natural habitats around protected areas is expected to increase by

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M.T. Camacho Olmedo et al. (eds.), *Geomatic Approaches for Modeling Land Change Scenarios*, Lecture Notes in Geoinformation and Cartography,
https://doi.org/10.1007/978-3-319-60801-3_15

7.2% during this period. These findings should alert land use planners and the managers of protected areas to the potential threats.

Keywords Simulations · Land use scenarios · Protected areas · Region of Madrid · Spain

1 Introduction

According to the World Database on Protected Areas, from 2003 to 2014 the number of protected sites increased from 84,577 to 217,294. In 1990, protected areas covered 8.6% of the land area. Since 2012, these areas have grown by 1.6 million km^2 as a result of new declarations. Today, they occupy 15.4% of the land area and of continental and inland waters, 3.4% of the global ocean area, 8.4% of marine areas covered by national jurisdictions and 10.9% of coastal waters (Juffe-Bignoli et al. 2014). In order to reach Aichi Target 11 (Strategic Plan for Biodiversity 2020), the Convention on Biological Diversity recommends that by 2020 at least 17% of terrestrial and inland water surfaces and 10% of coastal and marine areas be protected. In Europe, protected areas occupy 13.6% of the land mass and of continental waters (Deguignet et al. 2014). In Spain, from 1990 to 2013 the number of protected natural areas multiplied by 7 and their surface area tripled (EUROPARC-España 2014). In the world and European contexts, Spain has an important role to play in the conservation of biological diversity. Today, over 27% of the surface occupied by terrestrial ecosystems are protected by national, European or worldwide networks. Within the EU, Spain is the largest contributor to the Natura 2000 network.

In spite of their importance, Protected Areas (PAs) are increasingly under threat from factors such as climate change (Ruiz-Mallén et al. 2015), land use changes (Martínez-Fernández et al. 2015), deforestation (FRA 2010), forest fires (Chuvieco et al. 2013), habitat fragmentation (Dantas de Paula et al. 2015), loss of biodiversity (Sastre et al. 2002), propagation of invasive species (Lei et al. 2014), urban pressure (McDonald 2013) and public use (López Lambas and Ricci 2014).

Land-use change is a matter of concern for the scientific community. Spatio-temporal analysis can be used for a number of purposes (Lambin et al. 2001; Moreira et al. 2001; Améztegui et al. 2010; Viedma et al. 2015): (1) to observe land use changes in the past and explore the factors explaining them, (2) to simulate possible environmental and socio-economic impacts, and (3) to assess the influence of political alternatives in order to improve planning.

A vast number of studies and projects related to Land Use and Cover Change (LUCC) have been carried out. Of importance at a global level is the Land-Use and Land-Cover Change Science/Research Plan (Turner et al. 1995), a core project of the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimension Programme on Global Environmental Change (IHDP). In Europe, one of the most interesting programmes is CORINE Land Cover, CLC

(Feranec et al. 2007). The results of these projects and studies can help managers take decisions and enable the objectives of the aforementioned strategic plan to be achieved.

However, little is known about LUCC trends at different protection levels. Recent studies have focused on analysing changes in protected areas of differing importance and in the unprotected areas around them (Sastre et al. 2002; Romero-Calcerrada and Perry 2004; Ruiz Benito et al. 2010; Hewitt and Escobar 2011; Martínez-Fernández et al. 2015; Martinuzzi et al. 2015). It is important to simulate future land-use scenarios so that a dual approach can be adopted in preventive planning for protected areas and their surroundings (Martinuzzi et al. 2015). Such scenarios are important firstly for predicting threats associated with increased built-up land and the risk of forest fires stemming from growth in the Wildland-Urban Interface. They may also be a source of opportunities. New naturalised areas resulting from the abandonment of agricultural land might be included in buffer zones or ecological corridors that would improve connectivity among PA cores.

In short, although the perceptions of scientists and manager differ (Rodríguez-Rodríguez and Martínez-Vega 2016), LUCC would seem to be a basic component for evaluating the efficiency of PAs (Rodríguez-Rodríguez and Martínez-Vega 2012).

Our research is in line with previous approaches. The simulated scenarios and initial knowledge of their consequences for landscape structure could be a good starting-point for discussion and for reaching agreements between local communities and managers of protected areas.

The main goal of this research is to simulate land use in 2025 in PAs and their surrounding areas in the region of Madrid using two simulators, one based on logistic regression and the other on artificial neural networks. A secondary goal is to analyse the LUCC that took place between 1990 and 2006 and the changes expected by 2025 in order to determine trends and threats arising inside and around PAs. A third goal is to analyse the changes that have taken place or are expected in landscape structure and in a selection of landscape ecology indices.

2 Test Area and Data Sets

The Madrid region covers an area of 8,027 km^2 and in 2015 had a population of 6,436,996 inhabitants.[1] It is the most densely populated region in Spain with about 800 inhabitants/km^2. The region has a continental Mediterranean climate. Forest and semi-natural areas occupy about 48% of the total area, agricultural land 37%, built-up areas 14% and wetlands and water bodies 0.84%, according to CORINE Land Cover 2006 (CLC06).

[1] http://www.madrid.org/iestadis (last accessed March 3, 2016).

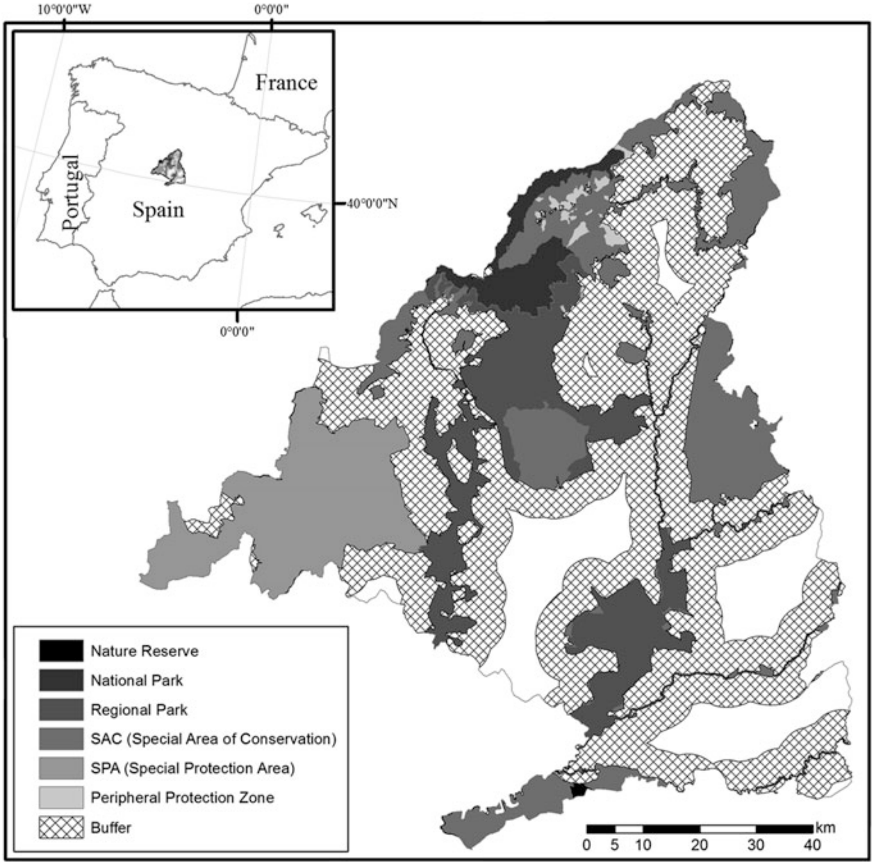

Fig. 1 Test area: Madrid region, Spain

In the region of Madrid, PAs occupy 329,164 ha, equivalent to 41% of the region's total surface area (Fig. 1). Table 1 shows their main characteristics, listing them in order of protection—from greatest to least. 15% of the Madrid Region is protected in SACs (Special Areas of Conservation), 12% in Regional Parks (RP), 10% in an SPA (Special Protection Area), about 3% belongs to a National Park (NP) and the remaining 1% is occupied by the Peripheral Protection Zone (PPZ) around this National Park and by a Nature Reserve (NR). All the PAs studied contain terrestrial ecosystems typical of the Mediterranean biogeographic region.

We also took into account a 5 km buffer zone around all the PAs in the region, which has no protection from the point of view of biodiversity. It occupies 372,865 km^2 equivalent to 46% of the region's area. Its aim is to mitigate threats to the PAs and as such it plays a strategic role in the conservation of biodiversity. About 13% of the region's land surface falls outside the scope of the study. Most of it is occupied by the city of Madrid and by other towns within the metropolitan area.

Table 1 Main characteristics of the protected areas considered in the study

Protected area	Designation year	Designation target	Main ecosystems
El Regajal-Mar de Ontígola Nature Reserve	1994	Fauna (Lepidoptera; birds), botanical	Scrub; semi-natural wetland (dam)
Sierra de Guadarrama National Park	2013	Ecological, geomorphology, landscape, scientific, cultural, education	Montane scrub and alpine grasslands; pine forests (*P. sylvestris*); deciduous forests (*Q. pyrenaica*); wetlands; peatlands
Cuenca Alta del Manzanares Regional Park	1985	Environmental, cultural, agricultural and landscape, ecologicalcorridor	Montane; deciduous forests (*Q. pyrenaica*); evergreen forests (*Q. rotundifolia, P. sylvestris*); pasturelands
Sureste Regional Park	1994	Ecological, palaeontological and archaeological	Unirrigated cropland; pine forests (*P. halepensis*); riparian forests; artificial wetlands; scrub
Curso medio del río Guadarrama Regional Park	1999	Natural and cultural, water ecosystems, landscape, ecological corridor, tourism	Evergreen forests (*Q. rotundifolia, P. pinea*); riparian forests; scrub; unirrigated cropland
Cuenca del río Lozoya y Sierra Norte SAC	1998/ 2014[a]	Ecological, habitats	Montane; deciduous forests (*Q. pyrenaica*); evergreen forests (*T. baccata*); scrub (*G. purgans*)
Cuenca del río Manzanares SAC	1998/ 2014[a]	Ecological, fauna, hábitats	Evergreen forests (*Q. ilex, Q. rotundifolia*); riparian forests (*Salix and Populus alba*); Sclerophillous grazed forests (dehesas); substeppes (*Thero-Brachypodietea*)
Cuenca del río Guadalix SAC	1998/ 2014[a]	Ecological, fauna, hábitats	Evergreen forests (*Q. ilex, Q. rotundifolia*); Arborescent matorral with *Juniperusspp*; riparian forests (*Salix and Populus alba*); Sclerophillous grazed forests (dehesas); substeppes
Cuencas de los ríos Jarama y Henares SAC	1998/ 2011[a]	Ecological, fauna, hábitats	Cereal steppes; riparian forests (*Salix and Populus alba*); Arborescentmatorral with *Juniperus spp.*
Vegas, Cuestas y Páramos del Sureste de Madrid SAC	1998/ 2014[a]	Ecological, fauna, hábitats	Wetlands; salt and gypsum inland steppes; riparian forests (*Salix and Populus alba*)

(continued)

Table 1 (continued)

Protected area	Designation year	Designation target	Main ecosystems
Encinares de los ríos Alberche y Cofio SPA	1990	Ecological, fauna, hábitats	Evergreen forests (*Q. ilex*, *Q. rotundifolia*, *P. pinea*, *P. pinaster*); Sclerophillous grazed forests (dehesas); scrub
Peripheral Protection Zone Guadarrama National Park	2013	Ecological	Montane; pine forests (*P. sylvestris*); pasturelands

[a]For the SACs, two dates are given in the "Designation year" field. The first refers to the year when the regional government proposed to the EU that the area be declared an SAC. This marked the beginning of their commitment to preventive protection in order to conserve the biodiversity of the area's habitats. The second date is the actual date of the declaration, after which the corresponding management plans were approved

We have selected two sets of geographical data. First, we downloaded all the updated perimeters and their corresponding attributes for the Nationally Designated Protected areas (NDP) in the Madrid region.[2] We also downloaded the Natura 2000 Network areas (Nn2000).[3]

This information comes from the Nature Data Bank of the Spanish Ministry for the Environment, the national contact point. In order to find the dates for final approval of the SACs, we linked the cartography with the Common Database on Designated Areas (CDDA) of the European Environment Agency.[4] We then downloaded land use/land cover maps from the CLC project for the years 1990, 2000 and 2006.[5] We did not consider the most recent map (CLC 2012) because it is still under review.

Finally, we took into account a collection of auxiliary geographic data in order to map the driving factors and the restrictive and incentive factors during design of future land use scenarios. We considered roads, rivers and railway stations (Numerical Cartographic Base 1:100,000, obtained from the Spanish National Geographical Institute) when drawing up accessibility maps that take into account the cost of transport and distances to the city of Madrid, to other cities, to the airport and to the roads themselves. We used a Digital Elevation Model (raster 30 m GMES RDA, EU-DEM) to generate altitude and slope maps, the lithological map

[2]http://www.magrama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/cartografia_informacion_disp.aspx (last accessed March 21, 2016).

[3]http://www.magrama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/red_natura_2000_inf_disp.aspx (last accessed March 21, 2016).

[4]http://www.eea.europa.eu/data-and-maps/data/natura-6#tab-european-data (last accessed March 21, 2016).

[5]http://centrodedescargas.cnig.es/CentroDescargas/buscadorCatalogo.do?codFamilia=02113 (last accessed March 21, 2016).

of Madrid, the map of public-utility forest areas (Regional Government of Madrid), PA zoning in the region (Autonomous Body for National Parks) and specific legislation on land and territorial planning (General Urban Land Plan for Madrid for 1997, Law 9/2001 of 17 July on land in the Region of Madrid, Law 9/1995 of 28 March on measures for territorial policy, land and planning, and Law 3/1991 of 7 March on roads in the Region of Madrid).

3 Methodology and Practical Application to the Data Sets

Our research follows the workflow shown in Fig. 2. We used ArcGIS v10.3 (ESRI Inc.) for vector processing of the downloaded data and to draw up the buffer. For LUCC analyses, we used IDRISI-Selva (Eastman 2012). We also used CLUE (Verburg and Overmars 2007) and the IDRISI-Selva Land Change Modeller (LCM) for designing the scenarios. Finally, we used GUIDOS-MSPA (Soille and Vogt 2009) to analyse the spatial landscape pattern, and FRAGSTATS 4.0 (McGarigal et al. 2002) to evaluate trends in landscape metrics depending on the type of PA and trends in their surrounding areas.

Firstly, we selected the PAs to be considered in the study. Areas where several types of protection overlap are classified as areas of greatest protection. In descending order, the level of priority is as follows: (1) Nature Reserve,

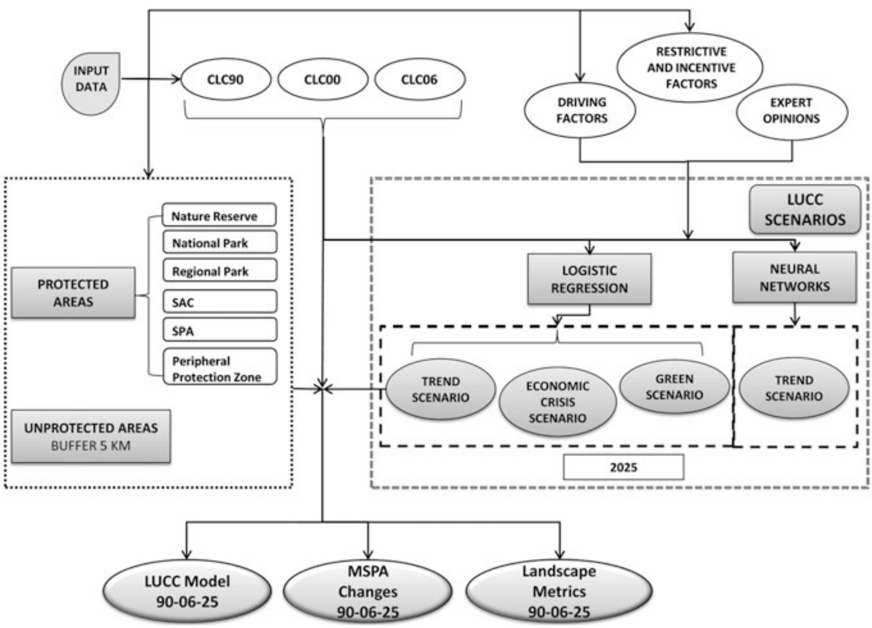

Fig. 2 Framework

(2) National Park, (3) Regional Park, (4) SAC, (5) SPA, (6) Peripheral Protection Zone in *Sierra de Guadarrama* National Park.

We then established an unprotected area around each PA, joining up areas that are adjacent to each other. From this buffer we excluded land that might be protected for other reasons (public-utility forest, public waters, roads, etc.). In line with the literature, we began using a 10-km buffer (Martínez-Fernández et al. 2015; Martinuzzi et al. 2015). However, in the end we opted for a 5-km buffer which is more appropriate for the characteristics of this triangular urban region. This means that 13% of the region is outside the PAs and the buffers analyzed. Their ecosystems are very different to those inside the PAs.

Second, we transformed the CLC vector maps to a raster format with a 50 × 50 m pixel size. From the CLC legend we made three different groupings. The first is a simplification of level 3 in seven categories: (1) urban fabric, (2) industrial and commercial, (3) arable land and permanent crops, (4) heterogeneous agricultural areas, (5) forests, (6) shrubs and herbaceous vegetation, and (7) others (open spaces with little vegetation, wetlands and water bodies). We used this grouping to simulate future scenarios and to analyse temporal trends in landscape metrics. In the second we grouped land uses into three types: (1) built-up surfaces, (2) agricultural areas and (3) natural areas. This classification (Martinuzzi et al. 2015) was used to evaluate land-use changes according to the type of PA and in their surrounding areas. Finally, in order to assess the dynamics of landscape structure we took level 1 of the CLC legend into account. We reclassified the maps in binary format. We considered class 1 as background, and combined classes 2, 3, 4 and 5 into a single target category (agricultural and natural areas) linked to the habitats represented in PAs in the region of Madrid.

Third, using CLUE we simulated land use in 2025 in three different scenarios: (a) trend scenario, (b) economic crisis scenario and (c) green scenario. The first one, the trend scenario or "business as usual" shows what would happen if the past trend in 1990–2000–2006 were to continue until 2025. The crisis scenario shows what would happen if the economic crisis in Spain and the region of Madrid were to continue until 2025. To draw up this scenario, we carried out 117 surveys with experts (scientists, land and protected area managers, ecologists and representatives of non-governmental organisations, neighbourhood associations, etc.); they were asked about how much the different land use types could grow or decrease under an economic crisis scenario and where these land use changes could preferentially be located (see Gallardo 2014; Gallardo et al. 2016). Finally, the green scenario shows what would happen if there were more active reforestation policies and if greater importance were placed on the natural environment. It does, however, take into account that Madrid is an urban region and that built-up areas will continue to grow. This means on the one hand, that greater protection is offered to natural uses than in the past and, on the other, that greater growth is assigned to built-up land. We used LCM to design the trend scenario in order to compare its results with those of CLUE.

In the models drawn up with CLUE, we related land use and driving factors by means of logistic regressions (LR). In the model simulated with LCM, we used a multi-layer perceptron neural network (MLP). Previously, we performed a

Pearson's correlation analysis to observe the correlations between the selected variables. We eliminated highly correlated variables as they did not make a significant contribution (see Gallardo 2014; Gallardo et al. 2016). In CLUE, we assigned the demand for each land use specifying the number of hectares for each land use in 2025, based on what had happened in previous years. In LCM, this was determined by a transition matrix indicating the probability of change from one use to another (see Gallardo 2014).

We calibrated the model in order to improve the scenario results. Taking the sequence of maps 1990–2000 as a base, we simulated a land-use model in 2006 and compared it with the real map for 2006. We varied the amount of land-use change, the driving factors used and/or the size or weight of the neighbourhood in order to obtain a better result. For validation, we carried out comparisons in terms of quantity and location; the former considered the proportion of each category of land use appearing on one map and whether this was similar to the proportion for that same category on the other; the latter compared the position of each category on the two maps. We used Kappa statistics, K Location (location) and K Histogram (quantity) (Pontius 2000; Van Vliet 2009) and we compared them with a null model and a random model. We obtained values and maps of hits, misses and false alarms (Eastman 2012; Sangermano et al. 2012).

Fourth, we drew up cross-tabulation matrices (Pontius et al. 2004) to obtain values and maps of changes between 1990–2006 and 2006–2025. We then compared the results with the protected areas depending on their level of priority and with the 5-km buffer. The aim was to find some of the main processes of land-use change that had already taken place and that could be expected in different scenarios: urbanisation, naturalisation and disturbances and exchanges in natural areas (Stellmes et al. 2013; Martínez-Fernández et al. 2015).

Fifth, we calculated an index for fragmentation of agricultural and natural habitats and for temporal variations in terms of their size and spatial pattern. The MSPA algorithm in the GUIDOS software (Soille and Vogt 2009) classified each pixel by its geometric position on the matrix being analysed, distinguishing between seven entities: (1) cores, (2) islets, (3) perforations, (4) edges, (5) loops, (6) bridges and (7) branches. We took into account the following parameters: analysis of pixel connectivity in 8 directions (cardinal and diagonal) = 1; transition pixels = 1; distinction between external and internal edges (perforations) in the core class. We calculated a Habitat Fragmentation Index (Chuvieco et al. 2013), in our case the sum of agricultural and natural habitats (HFI) in each type of PA and in its corresponding buffer. This goes from 1 (greatest fragmentation) to 2 (least fragmentation). It assigns a different weight to each of the entities mapped in terms of the relations between resilience and spatial coherence (Opdam et al. 2003, 2006). There is a constant gradation from the core (greatest weight) to the islets (least weight). The index relates the number of pixels in each category or fragmentation entity to their weights.

Finally, we calculated temporal variations in some landscape metrics. Following the recommendations of Aguilera and Botequilha-Leitão (2012) for a Mediterranean region with similar processes to those of Madrid, we selected six

FRAGSTATS indices that give us an estimate of fragmentation (NP) of the landscape patches, their size (LPI and AREA_CV), the complexity of their shape (FRAC_AM), their closeness (CONTIG_AM) and their isolation (ENN_AM).

4 Results

Table 2 shows the LUCC that took place between 1990 and 2006 by zone (types of PA and their surroundings), a period of intense change. Globally, the built-up surface expanded by 41,000 ha, equivalent to 11.23% of the total study area. Over these 16 years, more than 9% of the buffer land and 2% of PAs were sealed. There are large differences depending on the degree of protection enjoyed by the different PAs. The Nature Reserve and Regional Parks were the most affected by land-use changes. In general, agricultural areas contributed most to the growth of urban areas. Although in relative terms persistence is very high inside the PAs, the increase in built-up area is a worrying process from an ecological point of view. In short, almost half the surface area that changed its use inside the PAs in the region was urbanized. Naturalisation of abandoned agricultural land is less worrying from the ecological and surface area points of view. Revegetation affected over 10,000 ha, about 3% of the area studied. Both processes occurred with greater intensity in the areas around the PAs.

Map CLC06, reclassified in 7 categories, and the three scenarios are represented in Fig. 3. The result obtained with LCM for the trend scenario is not shown because the result was fairly similar to that obtained with CLUE.

The trend scenario (Fig. 3b) shows that extensive growth of urban, industrial and commercial areas can be expected in the region. In both CLUE and LCM, these areas will grow by more than 30% compared to 2006 levels. Urban areas will spread in a compact way around the metropolis, especially to the south and south-east along the main transport routes. Industrial and commercial areas will spread towards the south and south-east of the capital. Heterogeneous agricultural areas and forests will remain stable, with slight gains of less than 0.1% over 2006.

Table 2 Land use cover change that took place between 1990 and 2006 in protected areas and in their surroundings

	LUCC CLC90-CLC06													
	NR		NP		RP		SAC		SPA		PPZ		BUFFER	
LUCC	ha	%	ha	%	ha	%	Ha	%	ha	%	ha	%	ha	%
FBA	36	5.8	0	0	1,486	1.54	440	0.4	678	0.8	3	0.1	11,156	3.0
ABA	10	1.6	0	0	1,775	1.84	1,460	1.2	533	0.6	21	0.4	23,502	6.3
AFA	1	0.2	0	0	1,870	1.93	1,124	0.9	789	0.9	4	0.1	6,291	1.7

NR Nature Reserve, *NP* National Park, *RP* Regional Park, *SAC* Special Area of Conservation, *SPA* Special Protection Area, *PPZ* Peripheral Protection Zone, *FBA* Forest to built-up areas, *ABA* Agricultural to built-up areas, *AFA* Agricultural to forest areas

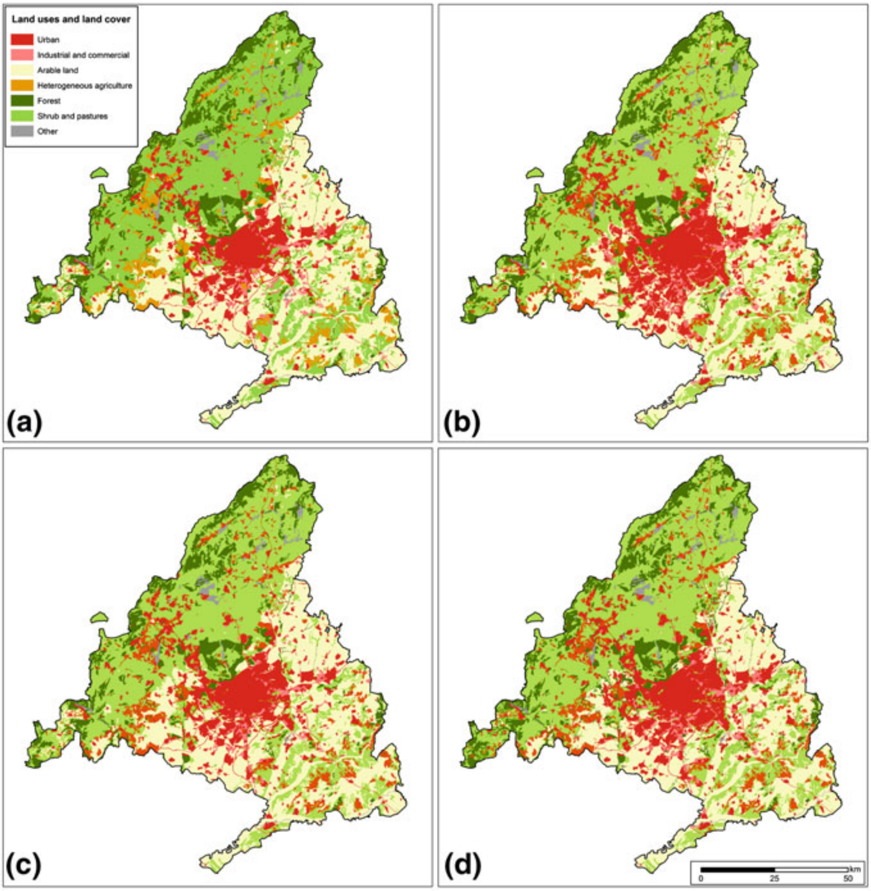

Fig. 3 LUCC trend in the region of Madrid between 2006 and 2025: **a** CLC map for 2006; the other quadrants show the scenarios modelled using CLUE in 2025: **b** trend scenario, **c** economic crisis scenario, **d** green scenario

The greatest losses will be in arable land and permanent crops. In short, the current processes will be reinforced, that is, anthropization of natural habitats and to a lesser extent naturalisation of agricultural habitats.

In the economic crisis scenario (Fig. 3c), growth in built-up areas will be much more restrained, 6 times less than in the trend scenario. It would be located to the south-east of Madrid, where the large urban patch would spread in a compact way. Forests, shrubs, and herbaceous vegetation will remain stable.

In the green scenario (Fig. 3d), growth in built-up areas will be half that forecast in the trend scenario. While in the previous scenarios, shrub and pastures record losses, here there will be a slight gain. Following the same trend, forests will see marked growth compared to 2006 (+13.72%).

Table 3 Projected Change 2006–2025 in protected areas and their buffers

	NR		NP		RP		SAC		SPA		PPZ		BUFFER	
LUCC CLC06-SCEN25 TREND														
LUCC	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
FBA	3	0.5	0	0	820	0.9	53	0.1	14	0.1	0	0	6,341	1.7
ABA	5	0.8	0	0	218	0.2	88	0.1	1	0.0	0	0	20,828	5.6
AFA	0	0	0	0	1	0.0	55	0.1	4,372	5.3	0	0	169	0.1
LUCC CLC06-SCEN25 CRISIS														
LUCC	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
FBA	3	0.5	0	0	364	0.4	21	0.0	13	0.0	0	0	2,417	0.7
ABA	5	0.8	0	0	120	0.1	24	0.0	0	0	0	0	2,021	0.5
AFA	0	0	0	0	2	0.0	60	0.1	2,050	2.5	1	0.0	63	0.0
LUCC CLC06-SCEN25 GREEN														
LUCC	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
FBA	3	0.5	0	0	193	0.2	26	0.0	14	0.0	0	0	2,897	0.8
ABA	5	0.8	0	0	211	0.2	106	0.1	0	0	0	0	11,283	3.0
AFA	0	0	0	0	1,788	1.9	455	0.4	5,656	6.8	9	0.2	5,914	1.6

NR Nature Reserve, *NP* National Park, *RP* Regional Park, *SAC* Special Area of Conservation, *SPA* Special Protection Area, *PPZ* Peripheral Protection Zone. *FBA* Forest to built-up areas, *ABA* Agricultural to built-up areas, *AFA* Agricultural to forest areas

Table 3 summarises the projected change between 2006 and 2025 by scenario and zone (types of PA and their surroundings). Although in the region as a whole a growing trend in soil sealing will continue, this will be slightly mitigated in comparison with the first period. Overall, in the trend scenario the built-up area will grow by 28,000 ha (7.6% of the study area). The buffer will increase its built-up land by 7.29%, and PAs by 0.36%.

The latter result is to some extent the product of the design of the three scenarios and takes into account the restrictions set out in the management plans for the different natural areas. The Regional Parks and the Nature Reserve will continue to be the most affected by this process. In the economic crisis scenario, the expansion of new urban zones will drop sharply in the buffer (+1.19%) and inside PAs (+0.16%). In the green scenario the built-up area will increase in the buffer (+4%) but only very slightly in the PAs (+0.16%). As in the first period, most of the new urban zones will be developed on abandoned agricultural land. The process of naturalisation will take place in the SW of the region, in the *Encinares de los ríos Alberche y Cofio* SPA. In this scenario, 60% of the area affected by land use change in PAs will be naturalised.

Figure 4 shows a representative window of what will happen in the centre-south of the region, around the city of Madrid and its metropolitan area. It represents the processes of urbanisation and naturalisation that will affect the PAs and the buffer, in the three scenarios. If restrictions on the construction of new urban and industrial buildings and of new infrastructure are complied with, most of the PAs will be unaffected by urbanisation.

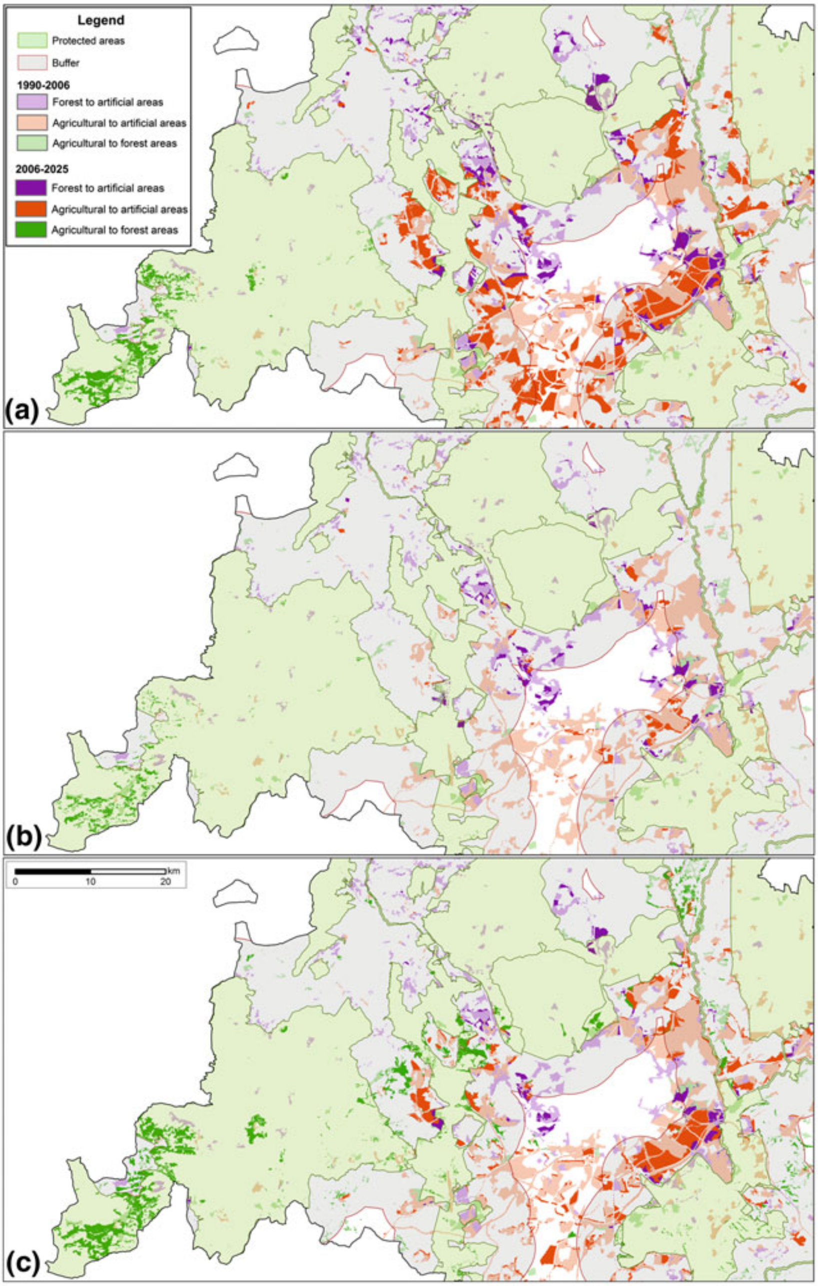

Fig. 4 Processes of urbanisation and naturalisation that took place in the centre-south sector of the region of Madrid during the period 1990–2006 (*light colours*) and projected changes 2006–2025 (*dark colours*), for **a** the trend scenario, **b** the economic crisis scenario and **c** the green scenario

All the same, in the trend scenario (Fig. 4a), medium and small residential areas will be built in the *Cuenca Alta del Manzanares* Regional Park along the A6 and M607 motorways. This is one of the protected areas that suffered most from urban sprawl during the first period. Most of the new urban developments will take place in the unprotected territorial matrix outside the buffer zone and, especially, in the buffer zones around the three regional parks and the SACs in the east and south of the region.

In the crisis scenario (Fig. 4b), the threat of urban development will be much more moderate as a result of the economic situation that has affected Spain since 2008. The green scenario (Fig. 4c) shows an intermediate situation. Soil sealing will be mitigated in the buffers of PAs, and new urban development inside protected areas will be insignificant. Forestation of agricultural land will be more extensive and will affect the *Encinares de los ríos Alberche y Cofío* SPA and the three regional parks. This will be the response to the incentives for revegetation included in the PA management plans.

Regarding validation, we obtained Kappa values of 0.868 and 0.892 for the trend scenarios designed using CLUE and LCM, respectively, and K Location and K Histogram values of 0.869 and 0.998 for CLUE and of 0.927 and 0.962 for LCM. Values for the null model were 0.879 and K Location and K Histogram values of 0.951 and 0.925.

Table 4 shows trends in landscape fragmentation categories in each type of PA and in their respective buffers, in two periods (1990–2006 and 2006–2025) and taking the trend scenario designed using CLUE. A clear difference exists between the National Park and its PPZ in comparison with the other types of protection. The National Park has remained intact and there has been no change. Its HFI was still 2.00 in 2006. The forest habitats survive today and will persist in their current condition bearing in mind the severe restrictions imposed by the land management plans to be approved this year. Habitat fragmentation in the buffer zone increased by 0.40% during the first period. Very minor changes are expected in the future.

There has been little fragmentation in the agricultural and natural habitats in the Natura 2000 Network areas. In 1990, the SACs and SPAs studied had an HFI of 1.98. During the first period, their fragmentation increased by 2.34 and 1.39% respectively, and these figures are expected to reach 2.51 and 2.01% by 2025.

Although quantitatively there have not been great changes, there has been a striking loss of core zones of high ecological value because of the construction of roads and new associated urban areas. Ecologists are especially worried about the case of the *Encinares de los ríos Alberche y Cofio* SPA. 26 years after its declaration, it is still not covered by any plan that clearly and specifically regulates land use.

The Regional Parks are also a source of worry. Although they are covered by plans, management has not been as efficient as expected. In 2006, the fragmentation index was 1.89, almost 5% greater than 16 years before, and 1.6% lower than the

Table 4 Trend over time of the spatial landscape pattern of PAs in and around Madrid

CLC90										
	Backgr	Core	Islet	Perfor	Edge	Loop	Bridge	Branch	Total	HFI90
NR	45	466	0	2	89	0	18	0	620	1.81
NP	2	21,572	0	0	32	0	0	0	21,606	2.00
RP	3571	89,576		1514	1434	294	90	183	96,662	1.94
SAC	1542	117,988	2	1258	626	91	37	44	121,588	1.98
SPA	1095	80,406	0	1026	45	18	0	39	82,629	1.98
PPZ	20	5461	0	60	0	1	0	4	5546	1.99
Buffer	39,024	313,985	27	8725	7874	1577	447	1080	372,739	1.86
CLC06										
	Backgr	Core	Islet	Perfor	Edge	Loop	Bridge	Branch	Total	HFI06
NR	66	430	0	19	102	0	3	0	620	1.75
NP	2	21,571	0	1	32	0	0	0	21,606	2.00
RP	6767	84,077	8	1853	3106	248	261	342	96,662	1.89
SAC	3429	114,758	14	1916	1153	159	34	125	121,588	1.95
SPA	1860	79,095	0	1524	45	36	0	69	82,629	1.96
PPZ	23	5431	0	85	0	3	0	4	5546	1.98
Buffer	72,045	274,367	131	9349	12,411	1598	830	2008	372,739	1.76
SCEN25-TREND										
	Backgr	Core	Islet	Perfor	Edge	Loop	Bridge	Branch	Total	HFI25
NR	95	401	0	0	110	2	10	2	0	1.71
NP	3	21,582	0	4	33	0	3	0	125	2.00
RP	8158	82,446	51	1564	3635	134	250	428	28	1.87
SAC	3524	114,486	8	1792	1383	155	88	141	442	1.95
SPA	2264	78,584	1	1644	61	21	0	93	115	1.96
PPZ	44	5370		99	0	4	0	15	14	1.98
Buffer	99,525	246,424	995	9011	10,425	2162	1215	2695	645	1.68

expected figure for 2025. The *Sureste* and *Curso medio del río Guadarrama* Regional Parks have been crossed by new motorways and occupied by new urban zones, which have increased the background category and the edges associated with perforations.

The Nature Reserve is a particularly striking case. Even though it falls under the category for maximum protection, in 1990 it was the most fragmented zone in the region (HFI of 1.81). Between 1990 and 2006, its fragmentation index grew by 5.6% and is expected to reach an accumulated figure of 10% by 2025. A new motorway (R4), crosses the reserve parallel to a previous one (A4) so encouraging urban growth around the historic town of Aranjuez. It is true, however, that this is a small protected area covering less than 0.2% of the total PAs in the region.

Unexpectedly, there are no great differences between this nature reserve and the extensive buffer (46% of the regional surface area) around all the protected areas in the Madrid Region. This area is the second most affected by the general process of built-up land growth over this short period (average annual increase of 0.63% in the fragmentation index). In 2006, its HFI was 1.76 and this process of landscape fragmentation is expected to reach 1.67 by 2025.

Comparison of the left and right parts of Fig. 5 shows an increase in the background and in perforation in the core of agricultural and forest habitats in the region of Madrid during the period of most intensive growth in built-up land (1990–2006). The urban areas and new corridors opened up by motorways and railway lines are perfectly visible. At the other extreme and as already stated, there has been revegetation associated with the abandonment of agricultural lands in the *Encinares de los ríos Alberche y Cofio* SPA. However, this phenomenon does not compensate for the loss of habitats in the buffer, the nature reserve and the regional parks that are closest to the capital.

The landscape metrics reinforce the key ideas expressed above. In the buffer the number of urban patches (NP) increased by 26% between 1990 and 2006, and is expected to rise over the base year by 142% by 2025. The percentage occupied by the largest urban patches is also increasing. During the first period, the largest patch index (LPI) doubled and is expected to quadruple by 2025. With the increase in the number and surface area of urban patches, their contiguity is almost at maximum level (ENN_AM = 0.93). A similar, albeit less intensive, process has taken place in industrial and commercial uses.

In the Nature Reserve, the increase in the number and surface area of built-up patches stems from the widening of roads, as stated above, and from new urban and industrial developments linked to improved accessibility. A similar progression is expected up to 2025 which will be reflected in increased contiguity of patches with this type of land use.

In the Regional Parks, the number of urban patches grew by 60% between 1990 and 2006, and additional growth of 36% is expected by 2025. The index for the largest patch within this category is very low but it doubled during the first period and quadrupled during the second. The average distance between urban patches (ENN_AM) has also grown. This may indicate the isolation of such zones among large forest patches in the search for more scenic landscape. This has already happened in the *Manzanares* and *Guadarrama* Regional Parks. Great changes are not apparent in the metrics of other categories, probably because of internal exchanges between the forest and agricultural classes.

Nor are there great changes in forest areas within SACs. In the SPA there is an incipient process of regeneration of arboreal vegetation. In 2025 the number of forest patches will be three times greater than in 1990. Built-up land growth has had no effect on the National Park and its PPZ, with no appreciable change in indices.

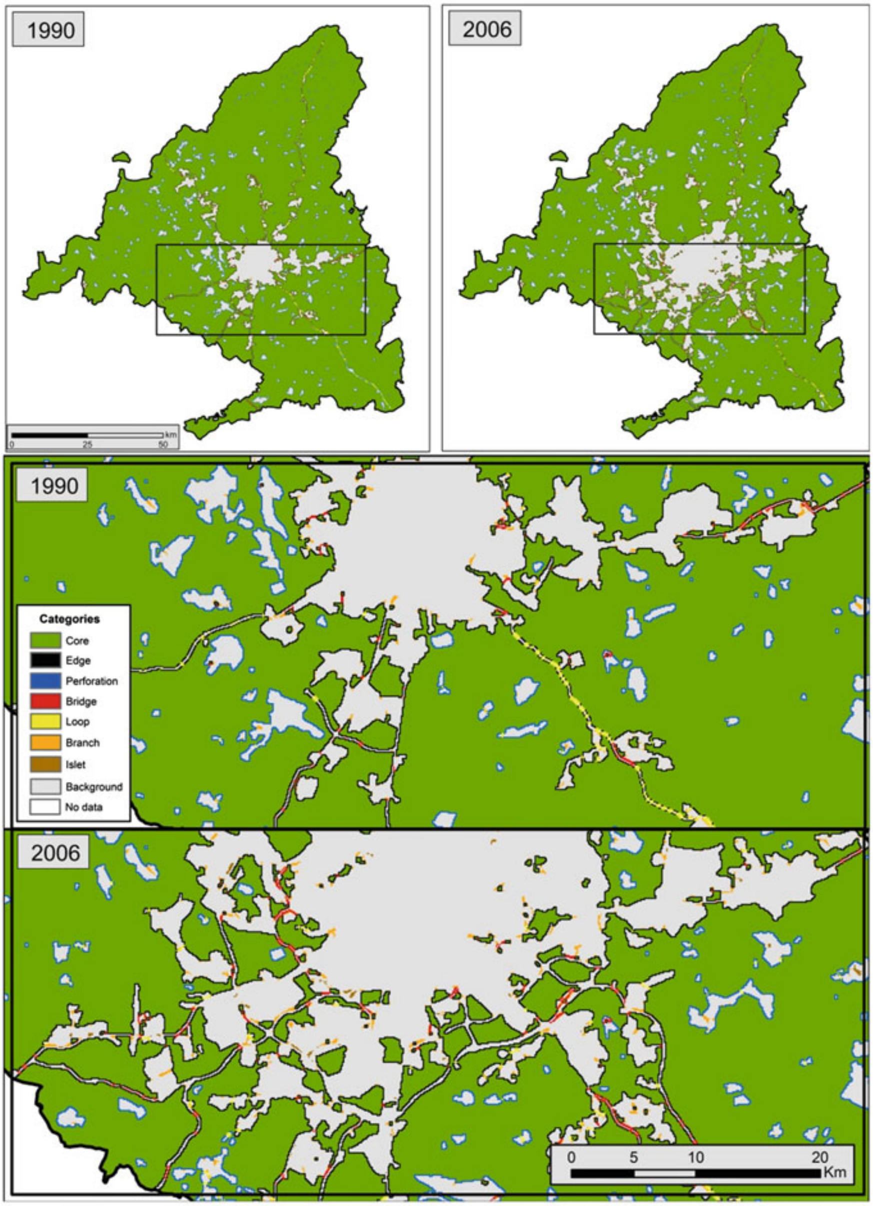

Fig. 5 Trends in fragmentation of agricultural and natural habitats in the region of Madrid since 1990 (*left*) and 2006 (*right*). Expanded view of a window of the southern part of the city of Madrid and its metropolitan area

5 Discussion of Results

We consider CLC to be a valid source of information for this research. This cartography is available throughout Europe, so the study could be replicated in other areas. The scale 1:100,000 is appropriate for studying regional and national PA networks. In order to update our study, it would be very useful to have access to CLC 2012 but, as already stated, it will be some months before the errors detected in it can be corrected. In fact, in our study site errors were also found in the previous CLC, especially in CLC00 (Catalá Mateo et al. 2008) and CLC06 (Hewitt and Escobar 2011; Díaz-Pacheco and Gutiérrez 2013; Martínez-Fernández et al. 2015; Gallardo et al. 2016). A lot of effort was made to correct these errors to avoid generating false land use change values.

A more detailed scale could be used for this type of study at the level of PAs or of specific ecosystems. The Information System on Land Cover in Spain (SIOSE), on a scale of 1:25,000, might be a good alternative. However, its complex legend including mixed classes and the lack of a historical series make it inappropriate for this research. Another good alternative might be the Spanish Forest Map (MFE2012) on a scale of 1:50,000. It combines with the SIGPAC covering the agricultural surface area and is updated using photointerpretation of SPOT images and with support from the National Plan for Aerial Orthophotography (PNOA). However, the coverage for 1990 does not have the same level of detail to enable us to analyse changes in land use.

Going further back in time, an effort needs to be made to interpret the aerial photographs made in 1956–57 and build an earlier land use map to start the time series. However, experts in the simulation of future use scenarios recommend that the initial and final maps be built on data from similar sources and using the same methods. In addition, such a long series would include some very different and even opposing trends. For all these reasons, it is advisable to use a more recent, shorter time period (Candau et al. 2000).

Another topic for discussion is the size of the buffer. A width of 10 km is often used in the literature, (Bruner et al. 2001; Figueroa and Sánchez-Cordero 2008; Martinuzzi et al. 2015). In the USA, Mexico and other countries this might be suitable because of the smaller size of protected areas. But a 10 km buffer would include 94% of Spain (Martínez-Fernández et al. 2015). We must remember that Spain plays an important role in biodiversity conservation and that 27% of its territory is protected. In the case of the region of Madrid, a 10 km buffer would be a complex solution because, with the territorial distribution of its PAs, much of the regional surface area would be within that buffer and it would include ecosystems that are very different to those represented in the PAs that were urbanised many decades ago. The buffer would therefore no longer be an effective means of controlling what happens inside and outside the PAs.

Regarding the design of future scenarios, in spite of the variety of simulation techniques, we opted for logistic regression because it is easy to use. And although there are technical differences between CLUE and LCM, the results obtained in the trend scenarios with both models are fairly similar.

Regarding validation of the results, the goodness of fit of the models depends on whether these values are due to good prediction or to the fact that there is high persistence in the study area (Pontius and Millones 2011). This phenomenon occurs with the K Histogram in CLUE. Its fit is almost perfect because real values for land use demand are taken.

The results obtained in our research are in line with the findings of previous studies on land use change in similar or nearby areas (Ruiz Benito et al. 2010, Hewitt and Escobar 2011; Díaz-Pacheco and Gutiérrez 2013; Díaz-Pacheco and García-Palomares 2014; Gallardo and Martínez-Vega 2016). They are also in line with the results of future scenarios in protected areas and their surroundings in the region of Madrid (Ruiz-Benito et al. 2010) and in the USA (Martinuzzi et al. 2015). The results on habitat fragmentation in regional parks and in the nature reserve are also in line with the findings of Rodríguez-Rodríguez and Martínez-Vega (2013).

Finally, although new episodes of built-up land growth are not expected inside Madrid's protected areas, threats to their peripheral zones are still a matter of concern. Those in charge of preserving biodiversity should remain on the alert for breaches of management plans or land use changes inside PAs approved on the basis of, for example, considerations of general interest. This type of reasoning and the impotence of managers were behind the high rates of built-up land growth and the increase in habitat fragmentation that took place in the period 1990–2006. We propose an exercise in collective reflection, comparing the results of the three scenarios proposed with a new trend scenario in which there are no restrictions on use changes in PAs and no incentives. The graphic and statistical results indicate clearly what might happen if the authorities were to sit back and allow economic agents to adopt an aggressive attitude.

6 Conclusion

Clearly land use changes linked to processes of anthropization and soil sealing are amongst the main threats to biodiversity, the preservation of natural resources and the production of environmental goods and services. For this reason, the analysis of land use changes during recent periods and the simulation of future scenarios can facilitate effective preventive planning for protected areas. Sustainable development can only be achieved when we understand the full implications of land use changes.

In urban areas such as the Madrid region the spill-over effect of protected areas should be monitored. It is clear that they attract urban developments to less protected areas around them. Transformation of their agricultural and natural habitats may have irreversible effects on biodiversity. Fragmentation brings with it longer exterior and interior edges. It can also create external threats for protected areas such as invasion by exotic species or the propagation of forest fires. These threats increase the potential ecological vulnerability of these spaces.

Acknowledgements This research received funding from the Spanish National R&D project "DISESGLOB: Design of a Methodology for Monitoring and Assessing the Overall Sustainability of National Parks and the Influence of Expected Changes of Use" (CSO2013-42421-P). Marta Gallardo was sponsored by a JAE-Predoc Grant from the Spanish National Research Council (CSIC). We specially thank Pilar Echavarría (CSIC) for her assistance in designing the cartographic figures.

References

Aguilera F, Botequilha-Leitão A (2012) Selección de métricas de paisaje mediante análisis de componentes principales para la descripción de los cambios de uso y cobertura del suelo del Algarve, Portugal. GeoFocus 12:93–121

Améztegui A, Brotons L, Coll L (2010) Land-use changes as major drivers of mountain pine (Pinusuncinata Ram.) expansion in the Pyrenees. Glob Ecol Biogeogr 19(5):632–641. doi:10.1111/j.1466-8238.2010.00550.x

Bruner AG, Gullison RE, Rice RE, da Fonseca GAB (2001) Effectiveness of parks in protecting tropical biodiversity. Science 291:125–128

Candau J, Rasmussen S, Clarke KC (2000) A coupled cellular automaton model for land use/land cover dynamics. 4thInternational Conference on Integrating GIS and Environmental Modeling (GIS/EM4): problems, prospects and research needs Banff. http://www.geog.ucsb.edu/~kclarke/ucime/banff2000/529-jc-paper.htm

Catalá Mateo R, Bosque Sendra J, Plata Rocha W (2008) Análisis de posibles errores en la base de datos Corine Land Cover (1990–2000) en la Comunidad de Madrid. Estudios Geográficos 264:81–104. doi:10.3989/egeogr.2008.i264.80

Chuvieco E, Martínez S, Román MV, Hantson S, Pettinari L (2013) Integration of ecological and socio-economic factors to assess global vulnerability to wildfire. Glob Ecol Biogeogr 23(2):245–258. doi:10.1111/geb.12095

Dantas de Paula M, Groeneveld J, Huth A (2015) Tropical forest degradation and recovery in fragmented landscapes. Simulating changes in tree community, forest hidrology and carbon balance. Glob Ecol Conserv 3:664–677. doi:10.1016/j.gecco.2015.03.004

Deguignet M, Juffe-Bignoli D, Harrison J, MacSharry B, Burgess N, Kingston N (2014) 2014 United Nations list of protected areas. UNEP-WCMC, Cambridge

Díaz-Pacheco J, Gutiérrez J (2013) Exploring the limitations of CORINE Land Cover for monitoring urban land-use dynamics in metropolitan areas. J Land Use Sci. doi:10.1080/1747423X.2012.761736

Díaz-Pacheco J, García-Palomares JC (2014) A highly detailed land-use vector map for Madrid region based on photo-interpretation. J Maps 10(3):424–433. doi:10.1080/17445647.2014.882798

Eastman JR (2012) IDRISI Selva. Clark University, Worcester, Guía para SIG y procesamiento de imágenes

EUROPARC-España (2014) Anuario 2013 del estado de las áreas protegidas en España. Fundación Fernando González Bernáldez, Madrid

FRA (2010) Global ForestResourcesAssessment 2010. FAO, Rome http://www.fao.org/docrep/013/i1757e/i1757e.pdf. Accessed 22 March 2016

Feranec J, Hazeu G, Christensen S, Jaffrain G (2007) CORINE land cover change detection in Europe (case studies of the Netherlands and Slovakia). Land Use Policy 24:234–247. doi:10.1016/j.landusepol.2006.02.002

Figueroa F, Sánchez-Cordero V (2008) Effectiveness of natural protected areas to prevent land use and land cover change in Mexico. Biodivers Conserv 17:3223–3240. doi:10.1007/s10531-008-9423-3

Gallardo M (2014) Cambios de usos del suelo y simulación de escenarios en la Comunidad de Madrid (Changes in land use and simulation scenarios in the region of Madrid). Universidad Complutense, Madrid. http://eprints.ucm.es/25253/. Accessed 22 March 2016
Gallardo M, Martínez-Vega J (2016) Three decades of land-use changes in the region of Madrid and how they relate to territorial planning. Eur Plan Stud 24(5):1016–1033 doi.10.1080/09654313.2016.1139059
Gallardo M, Gómez I, Vilar L, Martínez-Vega J, Martín MP (2016) Impacts of future land use/land cover on wildfire occurrence in the Madrid region. Reg Environ Change 16(4):1047–1061. doi:10.1007/s10113-015-0819-9
Hewitt R, Escobar F (2011) The territorial dynamics of fast-growing regions: unsustainable land use change and future policy challenges in Madrid. Spain. Appl Geogr 31(2):650–667. doi:10.1016/j.apgeog.2010.11.00
Juffe-Bignoli D, Burgess ND, Bingham H, Belle EMS, de Lima MG, Deguignet M, Bertzky B, Milam AN, Martinez-Lopez J, Lewis E, Eassom A, Wicander S, Geldmann J, van Soesbergen A, Arnell AP, O'Connor B, Park S, Shi YN, Danks FS, MacSharry B, Kingston N (2014) Protected Planet Report 2014. UNEP-WCMC, Cambridge. https://portals.iucn.org/library/sites/library/files/documents/2014-043.pdf. Accessed 22 March 2016
Lambin EF, Turner BLI, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skänes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. Glob Environ Change 11:261–269. doi:10.1016/S0959-3780(01)00007-3
Lei C, Lin Z, Zhang Q (2014) The spreading front of invasive species in favorable habitat or unfavorable habitat. J Differ Equ 257:145–166. doi:10.1016/j.jde.2014.03.015
López Lambas ME, Ricci S (2014) Planning and management of mobility in natural protected areas. Procedia Soc Behav Sci 162:320–329. doi:10.1016/j.sbspro.2014.12.213
Martínez-Fernández J, Ruiz-Benito P, Zavala MA (2015) Recent land cover changes in Spain across biogeographical regions and protection levels: Implications for conservation policies. Land Use Policy 44:62–75. doi:10.1016/j.landusepol.2014.11.021
Martinuzzi S, Radeloff VC, Joppa LN, Hamilton CM, Helmers DP, Plantinga AJ, Lewis DJ (2015) Scenarios of future land use change around United States' protected areas. Biol Conserv 184:446–455. doi:10.1016/j.biocon.2015.02.015
McDonald RI (2013) Implications of Urbanization for Conservation and Biodiversity Protection. In: Levin SA (ed) Encyclopedia of biodiversity, 2nd edn. Academic Press, Amsterdam, pp 231–244
McGarigal K, Cushman SA, Neel MC, Ene E (2002) FRAGSTATS: spatial pattern analysis program for categorical maps. University of Massachusetts, Amherst. http://www.umass.edu/landeco/research/fragstats/fragstats.html. Accessed 22 March 2016
Moreira F, Rego FC, Ferreira PG (2001) Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence. Landsc Ecol 16(6):557–567
Opdam P, Verboom J, Pouwels R (2003) Landscape cohesion: an index for the conservation potential of landscapes for biodiversity. Landsc Ecol 18:113–126
Opdam P, Steingrover E, Rooij SV (2006) Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landsc Urban Plan 75(3–4):322–332. doi:10.1016/j.landurbplan.2005.02.015
Pontius RG Jr (2000) Quantification error versus location error in comparison of categorical maps. Photogramm Eng Remote Sens 66:1011–1016
Pontius RG Jr, Shusas E, McEachern M (2004) Detecting important categorical land changes while accounting for persistence. Agr Ecosyst Environ 101:251–268. doi:10.1016/j.agee.2003.09.008
Pontius RG Jr, Millones M (2011) Death to Kappa: Birth of quantity disagreement and allocation disagreement for accuracy assessment. Int J Remote Sens 32:4407–4429. doi:10.1080/01431161.2011.552923

Rodríguez-Rodríguez D, Martínez-Vega J (2012) Proposal of a system for the integrated and comparative assessment of protected areas. Ecol Ind 23:566–572. doi:10.1016/j.ecolind.2012.05.009

Rodríguez-Rodríguez D, Martínez-Vega J (2013) Results of the implementation of the System for the Integrated Assessment of Protected Areas (SIAPA) to the protected areas of the Autonomous Region of Madrid (Spain). Ecol Ind 34:210–222. doi:10.1016/j.ecolind.2013.04.019

Rodríguez-Rodríguez D, Martínez-Vega J (2016) What should be evaluated from a manager's perspective? Developing a salient protected area effectiveness evaluation system by managers and scientists. Ecol Ind 64:289–296. doi:10.1016/j.ecolind.2016.01.011

Romero-Calcerrada R, Perry GLW (2004) The role of land abandonment in landscape dynamics in the SPA Encinares del rio Alberche y Cofio, Central Spain, 1984–1999. Landsc Urban Plan 66:217–232. doi:10.1016/S0169-2046(03)00112-9

Ruiz Benito P, Cuevas JA, Bravo de la Parra R, Prieto F, García del Barrio JM, Zavala MA (2010) Land use change in a Mediterranean metropolitan region and its periphery: assessment of conservation policies through CORINE land cover data and Markov models. For Syst 13 (3):315–328

Ruiz-Mallén I, Corbera E, Calvo-Boyero D, Reyes-García D (2015) Participatory scenarios to explore local adaptation to global change in biosphere reserves: experiences from Bolivia and Mexico. Environ Sci Policy 54:398–408. doi:10.1016/j.envsci.2015.07.027

Sangermano F, Toledano J, Eastman JR (2012) Land cover change in the Bolivian Amazon and its implications for REDD + and endemic biodiversity. Landsc Ecol 27:571–584. doi:10.1007/s10980-012-9710-y

Sastre P, Lucio JV, Martínez V (2002) Modelos de conectividad del paisaje a distintas escalas. Ejemplos de aplicación en la Comunidad de Madrid. Ecosistemas 11(2). http://revistaecosistemas.net/index.php/ecosistemas/article/viewFile/288/283. Accessed 22 March 2016

Soille P, Vogt P (2009) Morphological segmentation of binary patterns. Pattern Recogn Lett 30 (4):456–459. doi:10.1016/j.patrec.2008.10.015

Stellmes M, Röder A, Udelhoven T, Hill J (2013) Mapping syndromes of land change in Spain with remote sensing time series, demographic and climatic data. Land Use Policy 30(1):685–702. doi:10.1016/j.landusepol.2012.05.007

Turner BL, Skole D, Sanderson S, Fischer G, Fresco L, Leemans R (1995) Land-use and Land-cover change: science/research plan. International Geosphere-Biosphere Programme, Stockholm

Verburg PH, Overmars KP (2007) Dynamic simulation of land-use change trajectories with the CLUE-s model. In: Koomen E, Stillwell J, Bakema A, Scholten HJ (eds) Modelling land-use change. Progress and applications. Springer, Heidelberg, pp 321–335. doi:10.1007/978-1-4020-5648-2_18

Van Vliet J (2009) Assessing the accuracy of changes in spatial explicit land use change models. In: 12th AGILE international conference on geographic information science, Leibniz Universität, Hannover, 2–5 June 2009

Viedma O, Moity N, Moreno JM (2015) Changes in landscape fire-hazard during the second half of the 20th century: agriculture abandonment and the changing role of driving factors. Agr Ecosyst Environ 207:126–140. doi:10.1016/j.agee.2015.04.011