A twenty year GIS-based assessment of environmental sustainability of land use changes in and around protected areas of a fast developing country: Spain

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1. Introduction

Global socioeconomic improvements in the last decades (United Nations, 2015) have run in parallel to an unprecedented decline of biodiversity and ecosystem services (Butchart et al., 2010), despite substantial international efforts to maintain healthy ecosystems (UNESCO, 1971, 1972; CMS, 1979; EEC, 1979; CBD, 1992; EEC, 1992; OSPAR, 1992; United Nations, 1994). Protected areas (PAs) have been widely advocated and used as the main global policy to stop the loss of biodiversity for a long time (CBD, 1992), although evidence of their effectiveness at conserving species and natural habitats varies (Gaston et al., 2008; Craigie et al., 2010; Geldmann et al., 2013; Davis et al., 2014; Spracklen et al., 2015). Moreover, active discussions are in place on accurate techniques for measuring the effectiveness of PAs as a result of existing biases (Andam et al., 2008; Pfeifer et al., 2012; Spracklen et al., 2015).

Spain experienced massive social and economic transformations in the last decades of the XXth century, with large increases in average income (de la Fuente, 2017) and life expectancy (Cleries et al., 2009). Similarly to other transition economies worldwide, such positive socioeconomic changes have had clear impacts on biodiversity and landscapes (Jiménez, 2009; Sun et al., 2010). Three main territorial trends have occurred in Spain since the 1960s. On the one hand, large rural emigration to cities, which continues today, results in the abandonment of some traditional farming activities that in some cases benefit biodiversity (van der Zanden et al., 2017), and in the subsequent ‘naturalisation’ and homogenisation of the Spanish rural landscape (Jiménez, 2012). On the other, remaining farming practices...
have become more intensive, resulting in greater water, fertilizer and pesticide use in search of profitability (Zorrilla-Miras et al., 2014; Custodio et al., 2016). Finally, increasing population and tourist figures boosted intense‘anthropisation’ of the Spanish countryside especially around big cities and along the coast (Barbero-Sierra et al., 2013; García-Ayllón, 2015). These artificial changes have been especially intense in the 2000–2008 period, where massive residential and infrastructural construction took over across the country (Jiménez, 2012) as a result of abundant credit, deficient regulations and expansive mindsets (In’t Veld et al., 2014).

As a result of those territorial processes, negative impacts on Spanish biodiversity have been identified or foreseen on farmland birds, waterfowl (Jiménez, 2012; SEO, 2014), vascular plants, freshwater fish species, amphibians (CBD, 2017), butterflies (Stefanescu et al., 2004), and mammals, including recent extinctions (Pérez et al., 2002). Environmental impacts from development are especially relevant in a biodiversity rich country like Spain (Médail and Quézel, 1999; Williams et al., 2000; López-López et al., 2011; CBD, 2017; Mújica et al., 2017).

The administrative responses to the biodiversity crisis in Spain have been uneven. In terms of in situ protection of biodiversity, PA coverage has expanded greatly in recent years. The 1958 nationally designated PAs and 1865 Natura 2000 sites (Sites of Community Importance, Special Areas of Conservation and Special Protection Areas; EEC, 1992) cover approximately 28% of the terrestrial area of the country, the largest absolute area of any country in the European Union (European Commission, 2016). That national PA coverage largely exceeds global PA coverage targets, at 17% by 2020 (CBD, 2010), and nearly doubles global figures at 14.7% (Bhola et al., 2016). Although efforts are being made to make adequate management plans for such areas, both PA management and evaluation still need much improvement in most PAs in the country (Rodríguez-Rodríguez et al., 2015). Research attention has also been paid to areas surrounding PAs given their influence on PAs' conservation outcomes (Radelf of et al., 2010). Thus, the environmental sustainability trends of Spanish PAs and the wider countryside remain an active research subject (Martínez-Fernández et al., 2015; Hewitt et al., 2016; Rodríguez-Rodríguez and Martínez-Vega, 2017, 2018a).

Satellite images are ideal sources of information to analyse LULC changes in and around PAs through a BACI design (Rodríguez-Rodríguez and Martínez-Vega, 2018a). Their recurrent spatial coverage (Chuvieco and Huete, 2010) is highly appreciated by PA managers (Dimobe et al., 2017; Ramachandran et al., 2018) and planners to achieve sustainable development. Additionally, they facilitate the making of spatially-explicit models, which are useful tools to quantify driving forces of change and simulate future land uses under different scenarios (Veldkamp and Lambin, 2001; Gallardo and Martínez-Vega, 2018). The BACI design (Green, 1979) has been long applied to statistically evaluate environmental and ecological impacts (Smith, 2002). However, despite its highly valid outcomes, it has scarcely been used by the remote sensing community (Blackman, 2013; Meroni et al., 2017; Staenzel et al., 2018).

In this study we used remote sensing products to: 1) assess environmental sustainability trends in and around different PA networks with clear legal and managerial characteristics in Spain during a period of intense environmental transformation in the country: 1987–2006 (Jiménez, 2012); 2) compare sustainability trends among PA networks; 3) test the validity of different spatial-statistical techniques at ascertaining causality; and 4) make recommendations for the adequate planning, management and conservation of the country's protected biodiversity.

2. Methods

2.1. Study area

Spain’s land territory covers 505,370 km\(^2\) that expand across four biogeographic regions: Alpine, Atlantic, Mediterranean and Macaronesian (EEA, 2016). Four PA networks with clear legal and managerial characteristics across the country were analysed (Table 1): NRs, NPs, SCIs and SPAs.

Table 1

| Area (ha) | Legal stringency | Management in the study period | IUCN Management Category * |
|----------|------------------|-------------------------------|---------------------------|
| NRs      | High             | Yes                           | Ia & Ib                   | 9,957                      |
| NPs      | Medium           | Yes                           | V                         | 1,660,858                 |
| SCIs     | Medium           | No                            | IV                        | 6,447,010                 |
| SPAs     | Medium           | No                            | IV                        | 2,432,914                 |
| Total    |                  |                               |                           | 10,550,828                |

Note: NRs (Nature Reserves), NPs (Nature Parks), SCIs (Sites of Community Importance), SPAs (Special Protection Areas).

* Based on Atauri et al. (2008).

The actual time when each CLC data were taken was considered by spatially overlapping each PA network and all the CLC satellite scenes for Spain for 1987 and 2006. CLC-1990 and 2006 scenes were provided by Tragrae Ltd. Those scenes specifying the exact dates when remote data were taken for each territorial ‘window’ allowed us to select only those PPs that had been designated after their overlapping CLC scenes for the initial time point (t1; “Before”, around 1987) and those PPs that had been designated at least 3 years before the second time point (t2; “A efter”, around 2005). That way, we made sure that baseline LULC data was consistently older than the analysed PPs, and that enough time was given to PAs designated before 2005 to have some environmental effect, thus minimising temporal confounding. Two buffer zones (“Controls”) were generated for each PP: a proximal buffer of 1 km from PPs boundaries, and a distant buffer of 5 km. Both controls were assigned the PA category of the PP they were created from (e.g. 1 km, NR buffer).

We analysed our data using two models of increasing validity. Model 0 (M0) considered all PP and buffer areas. PAs from different networks (e.g. Biosphere Reserves) designated until the end of 2006 or other regulated areas that restrict LULC changes, including the public hydraulic domain (IGN, 2012) and the public coastal domain (IGN, 2015), were excluded from control areas in Model 1 (M1), as their protection status was likely to introduce confusion at ascertaining causality (Rodríguez-Rodríguez and Martínez-Vega, 2018a).

Cross-tabulation matrices (Pontius et al., 2004) were created for each PA network and related controls, for both models. We aimed at...
identifying the most relevant LULC change processes by class between 1987 and 2006. Twenty-seven such processes were analysed (Table 3). In addition to the descriptive statistics generated by the matrices: absolute and relative change, class persistence, gains, losses, net change, etc., we calculated the Annual Rate of Change ($r_t$) for each reclassified LULC class in cases and controls. For this, we used the following equation (Rodríguez Eraso et al., 2013):

$$r_t = \frac{1}{t_2-t_1} \times \ln\left(\frac{A_t}{A_i}\right) \times 100$$

### Table 2
Reclassification of CORINE Land Cover level 3 classes.

| CORINE Land Cover class code | Description                                                                 | Grouped LULC class code | Description                      |
|------------------------------|------------------------------------------------------------------------------|-------------------------|----------------------------------|
| 111, 112, 121, 122, 123,    | Continuous urban fabric, Discontinuous urban fabric, Industrial or commercial | ASU                     | Artificial surfaces              |
| 124, 133                    | units, Road and rail networks, Port areas, Airports and Construction sites  |                         |                                  |
| 131, 132                    | Mineral extraction sites and Dump sites                                      | MDS                     | Mine and dump sites              |
| 141, 142                    | Green urban areas and Sport and leisure activities                           | GUA                     | Green urban areas                |
| 211                         | Non-irrigated arable land                                                    | NIL                     | Non-irrigated arable land        |
| 212, 213, 231               | Permanently irrigated land, Rice fields and Pastures                       | ILA                     | Irrigated land                   |
| 221, 222, 223               | Vineyards, Fruit trees and berry plantations and Olive groves               | PCR                     | Permanent crops                  |
| 241, 242                    | Annual crops associated with permanent crops and Complex cultivation patterns| HAA                     | Heterogeneous agricultural areas  |
| 243                         | Land principally occupied by agriculture with significant areas of natural vegetation| ALV                     | Agricultural land with vegetation |
| 244                         | Agro-forestry areas                                                         | AFA                     | Agro-forestry areas              |
| 321                         | Natural grassland                                                           | GRA                     | Natural grasslands               |
| 322, 323                    | Moors and heathland and Sclerophyllous vegetation                           | SHR                     | Shrubs                           |
| 324                         | Transitional woodland-shrub                                                  | TWS                     | Transitional woodland-shrubs     |
| 311, 312, 313               | Broad-leaved, coniferous and mixed forest                                   | FOR                     | Forests                          |
| 331                         | Beaches, dunes, sands                                                       | BDS                     | Beaches, dunes, sands            |
| 332                         | Bare rocks                                                                  | BRO                     | Bare rocks                       |
| 333                         | Sparserly vegetated areas                                                   | SVA                     | Sparsely vegetated areas         |
| 334                         | Burnt areas                                                                 | BUA                     | Burnt areas                      |
| 335                         | Glaciers and perpetual snow                                                 | GPS                     | Glaciers and perpetual snow      |
| 411, 412, 421, 422, 423     | Wetlands                                                                    | WET                     | Wetlands                         |
| 511                         | Water courses                                                               | WAC                     | Water courses                    |
| 512                         | Water bodies                                                                | WAB                     | Water bodies                     |
| 521, 522, 523               | Marine waters                                                               | MWA                     | Marine waters                    |
Table 3
Cross tabulation matrix between the simplified land-use land-cover classes of 1990 (in rows) and 2006 (in columns). The main processes of LULC change are indicated with an alphabetic and color key. (For interpretation of the references to colour in this Table legend, the reader is referred to the web version of this article.)

| LULC (15 classes) | Description | LULC AS | MD5 | GU | NIL | IL | PC | HAA | ALV | AFA | GRAS | SHR | TWS | FOR | BDS | BR | SVA | BA | GS | WET | WC | WB | MW |
|-------------------|-------------|---------|-----|----|-----|----|----|-----|-----|-----|------|-----|-----|-----|-----|----|----|-----|----|-----|-----|-----|
| 111, 121, 122, 123 | Artificial surfaces | AS | P | IMP | EDF | | | | | | | | | | | | | | |
| 131, 132 | Mine and dump sites | MD5 | | | | | | | | | | | | | | | | |
| 141, 142 | Green urban areas | GU | IMP | P | | | | | | | | | | | | | | | |
| 211 | Non-irrigated arable land | NIL | P | IMP | P | | | | | | | | | | | | | | |
| 212, 213, 214 | Irrigated land | IL | IMP | P | | | | | | | | | | | | | | | |
| 221, 222, 223 | Permanent crops | PC | | | | | | | | | | | | | | | | |
| 241, 242 | Heterogeneous agricultural areas | HAA | EDF | P | | | | | | | | | | | | | | | |
| 243 | Agricultural land with forest vegetation | ALV | ENIL | EDF | | | | | | | | | | | | | | | |
| 244 | Agro-forestry areas | AFA | P | | | | | | | | | | | | | | | |
| 321 | Natural grassland | GRAS | | | | | | | | | | | | | | | | |
| 322, 323 | Shrubs | SHR | | | | | | | | | | | | | | | | |
| 324 | Transitional woodland-shrub | TWS | | | | | | | | | | | | | | | | |
| 331, 332, 333 | Forests | FOR | | | | | | | | | | | | | | | | |
| 333 | Sparse-vegetated areas | SVA | ENIL | EDF | | | | | | | | | | | | | | | |
| 334 | Burnt areas | BA | P | | | | | | | | | | | | | | | |
| 335 | Glaciers and perennial snow | GS | | | | | | | | | | | | | | | | |
| 4 | Wetlands | WET | ENIL | EDF | | | | | | | | | | | | | | | |
| 511 | Water courses | WC | ENIL | | | | | | | | | | | | | | | |
| 512 | Water bodies | WB | ENIL | | | | | | | | | | | | | | | |
| 521, 522, 523 | Marine waters | MW | | | | | | | | | | | | | | | | |

P: Persistence; IMP: Improbable; LD1: Land development of other artificial zones; LD2: Land development of agricultural areas; LD3: Land development of forest and natural areas; LD4: Land development of wetlands and water bodies; RC: Reservoir construction; CR: Crop reconversion; INIL: Intensification of non-irrigated arable land; ENIL: Expansion of non-irrigated arable land on forests; ENIW: Expansion of non-irrigated land on wetlands; III: Intensification of irrigated land; EIFL:Expansion of irrigation in forest land; EIWF: Expansion of irrigation in wetlands; FR: Forest regression; BAA: Burnt agricultural areas; BA2: Burnt arable areas; BA3: Burnt forest areas; CC: Climate Change; CW: Colonization of vegetation in wetlands; ANIC: Abandonment of non-irrigated crops; AIC: Abandonment of irrigated crops; FS: Forest succession; ARBA: Agricultural restoration of burned areas; FRBA: Forest restoration of burned areas; WR: Wetlands restoration; MZR: Mining zone restoration; EGU: Expansion of green urban areas.

Where $A_1$, $A_2$ are the areas (in ha.) of the assessed LULC class in the initial year (t1) and final year (t2), respectively. We considered only LULC changes that affected at least 0.1% of each PA network area or control zone area (‘noticeable changes’). Among these LULC changes, we considered ‘relevant changes’ those affecting at least 1% of each PA network or control zone.

The environmental interpretation of LULC changes is straightforward only in few cases (e.g., changes towards artificial LULCs; Rodríguez-Rodríguez and Martínez-Vega, 2017). Many other LULC transitions are difficult to interpret from an environmental sustainability point of view (Rey-Benayas et al., 2007; Queiroz et al., 2014), especially GLC intra-class transitions (Gregor et al., 2016; Hewitt et al., 2016). In order to facilitate the interpretation of LULC changes, we followed the interpretation of LULC changes used previously (Rodríguez-Rodríguez and Martínez-Vega, 2017). We assumed that those changes and processes that increased ‘naturalisation’ (i.e., the trend towards ecosystem complexity and climax) were positive. Therefore, some processes such as abandonment of crops and related forest succession were deemed positive, even though agricultural areas and other semi-natural ecosystems provide key habitats for a number of endangered species in Spain (Araújo et al., 2007; Rodríguez-Rodríguez and Martínez-Vega, 2018b). The twenty-seven resulting LULC change processes were aggregated in 16 main ones for eased explanation as shown in Table 4.

The steps taken in the study are summarised in Fig. 2. Spatial analyses were made with ArcGIS v10.3 whereas matrix data analyses were made using Microsoft Excel.

3. Results

All the results shown here refer to those from Model 1. Results from Model 0 are shown only in the Appendices on space grounds.

3.1. LULC changes

There was high persistence ($P$) of existing LULCs in all PA networks (> 90%). NRs were the most dynamic PA category ($P = 93.06$). Fig. 3 summarises net LULC changes for the four PA networks and their control areas. Appendix 1 Supplementary data shows all the results of cross-tabulations for all PA networks, control areas, and models. Relevant net positive changes occurred in transitional woodland-shrub and agro-forestry areas in all PA networks. Noticeable net positive LULC changes in artificial surfaces and water bodies occurred in all PA networks except in NRs. The LULCs with the greatest losses and net negative changes inside PAs were: shrub, agricultural land with vegetation and non-irrigated arable land.

In proximal control areas, persistence of LULCs was smaller than in PAs, although greater than 90% in all networks. The smallest persistence occurred in NRs’ proximal buffers. In this network, permanently irrigated land increased very relevantly, whereas in the other networks, relevant increases of artificial areas occurred, except in the SCI network where those areas increased very noticeably. In proximal buffer areas, noticeable losses of forests, transitional woodland shrub, shrubs, grasslands and sparsely vegetated areas also occurred.

In distant control areas, persistence was lower than in proximal buffer areas, although still high, around 90%, except around NRs ($P = 81.65$%). In these areas, former sparsely vegetated areas turned to irrigated lands very noticeably. In all networks’ distant controls (e.g. 1.84% around NPs). Burnt areas increased very noticeably around managed PAs (> 0.28%). Non-irrigated arable lands experienced net negative relevant changes in all distant control areas, whereas...
forest areas, shrubs and grasslands experienced noticeable negative changes in those areas.

Artificial surfaces, mine and dump sites and green urban areas had the greatest inside PAs and in their control areas, except in NRs.

3.2. LULC change processes

Natural succession trends prevail inside PAs, especially inside NRs. However, forest regression processes have also affected SCIs relevantly. Actually, forest regression outstands as the prevailing negative LULC change process in NPs, SCIs and SPAs. In NRs’ control areas, the dominating process was new irrigated areas, affecting distant controls very relevantly. Land development was the prevailing LULC change process around NPs and SPAs, and the second most important process around NRs. In contrast, positive processes towards forest succession dominated around SCIs. Burned areas were only noticeable inside SCIs.

Fig. 2. Methodological flux diagram of the study.
NRs (Nature Reserves), NPs (Nature Parks), SCIs (Sites of Community Importance), SPAs (Special Protection Areas), PAs (Protected Areas), PP (protected polygon), CLC (CORINE Land Cover), LULC (Land Use-Land Cover).

| Environmental interpretation | Aggregated LULC change process code | Description | LULC change process code* |
|-----------------------------|------------------------------------|-------------|---------------------------|
| −                           | LD                                 | Land development | LD1 + LD2 + LD3 + LD4 |
| RC                          | Reservoir construction             |             | RC                        |
| ENIA                        | Expansion of non-irrigated arable land |             | ENILF + ENIW               |
| INIL                        | Intensiﬁcation of non-irrigated arable land |             | INIL                      |
| CR                          | Crops reconversion                 |             | CR                        |
| NIA                         | New irrigated areas                |             | IIL + EIFL + EIW          |
| FR                          | Forest regression                  |             | FR                        |
| BA                          | Burned areas                       |             | BAA + BFA                 |
| CC                          | Climate change                     |             | CC                        |
| CVW                         | Colonization of vegetation on wetlands |         | CVW                      |
| AC                          | Abandonment of crops               |             | ANIC + AIC                |
| +                           | FS                                 | Forest succession | FS                      |
| RBA                         | Restoration of burned areas        |             | ARBA + FRBA               |
| ROA                         | Restoration of other areas         |             | MZR + WR                  |
| EGU                         | Expansion of green urban areas     |             | EGU                       |
| IMP                         | Improbable                         |             | IMP                       |
| P                           | Persistence                         |             | P                         |

* Codes from Table 3.
with no such process occurring in NRs or in their proximal controls. In all networks, there was generally an increasing gradient of burned areas from PAs’ boundaries, except for SPAs. Forest regression exceeded forest succession around NPs. Table 5 summarises the main LULC change processes that have taken place in PAs and their control areas.

3.3. Comparison of both spatial-statistical models

The environmental balance of all LULC changes around PAs was less negative for M0 than for M1 in all PA networks except in SCIs (Table 6).

4. Discussion

4.1. Main LULC changes and processes of change

The major LULC increases inside PAs were experienced by agro-forestry areas and transitional woodland-shrub, whereas artificial surfaces, permanently irrigated land and burned areas prevailed in the proximal and distant controls. Conversely, the area of non-irrigated arable land decreased inside and around Spanish PAs. In addition, all the LULC classes associated with forest areas—forests, transitional woodland-shrub, shrubs, natural grasslands and sparsely vegetated areas—registered negative net changes in the proximal and distant controls. These land use dynamics relate to similar ones that have occurred in Spain (Jiménez, 2012; Martínez-Fernández et al., 2015) and in other Mediterranean (Brunori et al., 2016) and European areas (EEA, 2017; van der Zanden et al., 2017), and reveal greater environmental sustainability of LULC changes inside Spanish PAs than outside (Martínez-Fernández et al., 2015; Rodríguez-Rodríguez and Martínez-Vega, 2017).

The main LULC processes of change inside and around Spanish PAs: forest succession, land development, and new irrigated areas largely relate to the three major LULC processes across Spanish landscapes in recent times (Stellmes et al., 2013): farmland abandonment (Vidal-Macua et al., 2018), intensification of farming practices (Custodio et al., 2016) and land development (Jiménez, 2012). LULC change processes related to land development and farming were far more environmentally sustainable inside Spanish PAs than outside (Martínez-
Table 5
Main land use-land cover change processes.

| Environmental sign | LULCs change process | % total NRs | % total B1K_NRs | % total B5K_NRs | % total NPs | % total B1K_NPs | % total B5K_NPs | % total SCIs | % total B1K_SCIs | % total B5K_SCIs | % total SPAs | % total B1K_SPAs | % total B5K_SPAs |
|--------------------|----------------------|-------------|----------------|----------------|-------------|----------------|----------------|-------------|----------------|----------------|-------------|----------------|----------------|
| −                  | Land development     | 0.00        | 1.90           | 1.77           | 0.15        | 1.92           | 2.13           | 0.08        | 0.88           | 0.92           | 0.21        | 1.46           | 1.53           |
| −                  | Reservoir construction| 0.00        | 0.00           | 0.12           | 0.34        | 0.18           | 0.14           | 0.05        | 0.06           | 0.05           | 0.11        | 0.02           | 0.02           |
| −                  | Expansion of non-irrigated arable land | 0.05        | 1.47           | 1.43           | 0.65        | 0.83           | 0.84           | 0.46        | 0.68           | 0.68           | 0.74        | 0.65           | 0.77           |
| −                  | Intensification of non-irrigated arable land | 0.59        | 0.00           | 0.41           | 0.08        | 0.45           | 0.37           | 0.07        | 0.25           | 0.30           | 0.03        | 0.12           | 0.21           |
| −                  | Crops reversion      | 0.10        | 1.73           | 0.37           | 0.03        | 0.27           | 0.66           | 0.07        | 0.35           | 0.41           | 0.09        | 0.28           | 0.31           |
| −                  | New irrigated areas  | 0.00        | 3.08           | 11.85          | 0.11        | 0.73           | 1.06           | 0.10        | 0.66           | 0.66           | 0.13        | 0.64           | 1.09           |
| −                  | Forest regression    | 0.00        | 0.00           | 0.42           | 0.67        | 1.52           | 1.31           | 1.48        | 0.96           | 1.05           | 0.79        | 0.65           | 0.59           |
| −                  | Burned areas         | 0.00        | 0.00           | 0.39           | 0.05        | 0.08           | 0.30           | 0.17        | 0.15           | 0.17           | 0.08        | 0.10           | 0.04           |
| −                  | Climate change       | 0.00        | 0.00           | 0.00           | 0.00        | 0.00           | 0.00           | 0.00        | 0.00           | 0.00           | 0.00        | 0.00           | 0.00           |
| −                  | Colonisation of vegetation on wetlands | 0.00        | 0.00           | 0.00           | 0.02        | 0.04           | 0.04           | 0.01        | 0.02           | 0.01           | 0.03        | 0.04           | 0.01           |
| +                  | Abandonment of crops | 0.00        | 0.81           | 0.74           | 0.12        | 0.36           | 0.49           | 0.39        | 0.66           | 0.56           | 0.28        | 0.60           | 0.61           |
| +                  | Forest succession    | 6.20        | 0.67           | 0.83           | 1.21        | 1.26           | 1.11           | 1.66        | 1.18           | 1.22           | 1.17        | 0.68           | 0.75           |
| +                  | Restoration of burned areas | 0.00        | 0.00           | 0.00           | 0.06        | 0.00           | 0.02           | 0.26        | 0.14           | 0.15           | 0.34        | 0.12           | 0.10           |
| +                  | Restoration of other areas | 0.00        | 0.00           | 0.00           | 0.01        | 0.14           | 0.07           | 0.01        | 0.01           | 0.02           | 0.03        | 0.00           | 0.01           |
| +                  | Expansion of green urban areas | 0.00        | 0.00           | 0.00           | 0.01        | 0.00           | 0.00           | 0.00        | 0.00           | 0.00           | 0.00        | 0.00           | 0.01           |

Summary of processes

| Negative change processes | 0.74 | 8.18 | 16.77 | 2.11 | 6.03 | 6.85 | 2.50 | 4.01 | 4.24 | 2.20 | 3.98 | 4.58 |
| Positive change processes | 6.20 | 1.48 | 1.58 | 1.39 | 1.75 | 1.69 | 2.32 | 2.00 | 1.95 | 1.92 | 1.41 | 1.48 |
| Balance                 | 5.46 | −6.70 | −15.19 | −0.72 | −4.27 | −5.15 | −0.18 | −2.01 | −2.29 | −0.28 | −2.57 | −3.10 |
| Persistence (%)         | 93.06 | 90.33 | 81.65 | 96.45 | 92.17 | 91.43 | 95.47 | 93.96 | 93.79 | 95.84 | 94.60 | 93.92 |

The LULC change processes are expressed in % with regard to the total area of each PA network or control area. NRs (Nature Reserves), NPs (Nature Parks), SCIs (Sites of Community Importance), SPAs (Special Protection Areas), B1k (1 km-buffer), B5k (5 km-buffer).
Fernández et al., 2015; Rodríguez-Rodríguez and Martínez-Vega, 2018a). Such processes are very relevant territorial-wise. Agricultural land covered half the terrestrial territory of Spain, contributed 2.75% of the country’s GDP, and accounted for 75% of consumed water in 2005 (Jiménez, 2007). Unsustainable agricultural processes such as intensification of non-irrigated arable land, crops reconversion and, especially, new irrigated areas generally proliferated much less in PAs than in their surroundings, as expected due to regulation (Martínez-Fernández et al., 2015). Our results also show lesser abandonment of crops inside PAs, which appear to better maintain agricultural practices thus likely contributing to endangered species’ conservation (Rodríguez-Rodríguez and Martínez-Vega, 2018b) and also probably being more socioeconomically sustainable for the agricultural guild than outer unregulated areas, in contrast to common European farmers’ claims (Kati et al., 2015; Blicharska et al., 2016). Notwithstanding worrisome land development processes in most PA networks, the good territorial performance of PAs and other sectoral legislation at reducing land development in Spain (Rodríguez-Rodríguez and Martínez-Vega, 2018a) seem to have partially offset insufficient territorial planning (Jiménez, 2010) in a country that increased its artificial areas almost double than the European Union-15’s mean in the 1987–2000 period (Jiménez et al., 2005).

4.2. Environmental sustainability of PA networks

The four PA categories were more environmentally sustainable than their surroundings in the 1987–2006 period, as expected and shown previously (Jiménez, 2012; Martínez-Fernández et al., 2015). This is reflected by their greater LULC persistence and more positive LULC change balances. However, there was a gradient in the overall environmental sustainability of LULC change processes among the four PA networks: NRs > SCIs > SPAs > NPs. This result adds to evidence that different PA categories perform differently according to their legal and managerial characteristics (Seiferling et al., 2012; Linardi et al., 2013; Terra et al., 2014; Castro et al., 2015; Martínez-Fernández et al., 2015) and that grouping PA categories based on untested assumptions may lead to inaccurate results in PA effectiveness studies (Rodríguez-Rodríguez and Martínez-Vega, 2018a).

The relatively low effectiveness of NPs, where negative LULC change processes were dominant, indicates that PA management does not seem to have played a clear role in the sustainability of LULC changes in Spanish PAs, in contrast to common assumptions (Hockings et al., 2006; Dudley, 2008) and suggestions (Martínez-Fernández et al., 2015). In turn, multiple-use ‘paper parks’ (i.e., unmanaged SCIs and SPAs) performed moderately well environmentally, and better than NPs in general terms. The combination of legal stringency and management (as for NRs) resulted in high sustainability values, as shown previously for land development (Rodríguez-Rodríguez and Martínez-Vega, 2018a). In spite of good PA performance, environmentally negative LULC changes, including destructive, irreversible land development processes (McKinney, 2002), exceeded positive changes in all PA networks except in NPs, which cast reasonable doubts on the long-term conservation of biodiversity in those areas, should the drivers of those changes remain.

Negative agricultural LULC change processes were the smallest in SCIs and the largest in SPAs. Our results also show lesser abandonment of crops inside PAs, especially in managed PAs, which appear to best maintain farming practices and thus be also more socially sustainable than Natura 2000 sites, at least for the primary sector. Martínez-Fernández et al. (2015) found that Natura 2000 sites occupied more farmland area than nationally designated PAs and experienced greater agrarian abandonment in the studied period. The perurban location of many NPs is likely to have influenced greater persistence of agrarian activities with regard to more rural Natura 2000 sites (Rodríguez-Rodríguez and Martínez-Vega, 2018a), which are probably more affected by decreasing labour force due to emigration and ageing (Collantes and Pinilla, 2004).

Although LULC persistence was the lowest in NRs, LULC changes in that network were overwhelmingly positive, thus increasing its environmental sustainability. Good performance of legally stringent reserves (IUCN management categories Ia or Ib; Dudley, 2008) at conserving natural habitats have been shown in tropical areas (Linardi et al., 2013; Sims, 2014; Terra et al., 2014) and in temperate areas, including Spain (Castro et al., 2015; Rodríguez-Rodríguez and Martínez-Vega, 2018a), when compared to multiple-use PAs. In all the other networks assessed here, including managed NPs, environmental sustainability decreased in the assessed period. Natura 2000 sites (SCIs and SPAs) behaved similarly in terms of LULC persistence, sign and magnitude of LULC balance, and main LULC change processes, although SCIs were notably more sustainable than SPAs. In both categories forest succession and regression processes prevailed, respectively. However, largely destructive and irreversible land development and reservoir construction processes (McKinney, 2002) were much greater in SPAs, whereas less environmentally negative intensification of non-irrigated arable land and forest fires were much more relevant in SCIs. Forest fire-related processes were far greater in both Natura 2000 sites than in NPs and, especially, NRs, which suggests positive managerial influence on this important threat to Spanish PAs (Rodríguez-Rodríguez and Martínez-Vega, 2017).

4.3. Environmental sustainability of areas surrounding PAs

Control areas experienced chiefly unsustainable LULC change patterns, mirroring the developmental trends of the whole country in that period (Jiménez, 2012). However, LULC persistence values and LULC change balance values were consistently less negative in proximal controls than in distant ones, suggesting a ‘protection spillover’ from Spanish PAs (Sánchez-Azofeifa et al., 2003; Rodríguez-Rodríguez and Martínez-Vega, 2018a) through which the four PA networks ‘irradiated’ environmental sustainability to the rest of the territory.

New irrigated areas, land development and forest regression were the dominant LULC change processes in both control zones, although forest succession dominated around SCIs. This is worrisome, as surrounding pressures are likely to affect PAs’ environmental effectiveness (Radloff et al., 2010). Unsustainable territorial trends have been shown around the Spanish network of national parks (Rodríguez-Rodríguez and Martínez-Vega, 2017) and suggest the need for more intense environmental measures around Spanish PAs. A gradient of environmental sustainability of control areas was evident: SCIs > SPAs > NPs > NRs. Interestingly, the areas surrounding NRs and NPs were much more unsustainable than those around Natura 2000 sites, which tend to be located in rural areas. NPs and NRs were found to be
the closest and most distant PA categories to main cities in Spain, respectively (Rodríguez-Rodríguez and Martínez-Vega, 2018a). This likely explains unsustainable LULC change processes around NPs. Interestingly, land development is also widespread around more rural NRs, whereas the other relevant LULC processes of change affect individual sites, for instance, expansion of new irrigated areas on the coast around Punta Entinas-Sabinar NR (Almeria), or expansion of non-irrigated arable land around Hoces del Cabriel NR.

Endowing areas surrounding PAs some sort of territorial regulation buffering external impacts emerges as a meaningful recommendation to territorial planners. Existing regulations for buffering external impacts to PAs in Spain exist for National Parks (Spanish Government, 2014). Those buffer areas experienced fewer LULC changes than unprotected areas although forest fires affected both zones similarly (Rodríguez-Rodríguez and Martínez-Vega, 2017). Such external protection would most likely enhance sustainability and also increase connectivity across the heavily fragmented Spanish landscape (Torres et al., 2016), as nature conservation regulations state (EEC, 1992; Spanish Government, 2007).

4.4. Methodological remarks

As expected (Rodríguez-Rodríguez and Martínez-Vega, 2018a), MI LULC change balances in control areas were more negative than in M0, after erasing additional territorial protection, which confirms previous claims on the improvable validity of default surrounding buffer areas used as controls in PA effectiveness studies (Andam et al., 2008; Spracklen et al., 2015).

Our study provides substantial improvements regarding previous studies on LULCs in PAs in Spain. Firstly, our study discriminates a larger number of CLC classes (22), possible LULC changes (484), and processes of change (15) than previous studies (Martínez-Fernández et al., 2015; Rodríguez-Rodríguez and Martínez-Vega, 2017). Here, we also distinguished effects of four specific PA networks rather than aggregated PA categories, which likely masks results. Moreover, we applied a more accurate method, both spatially (through the PP approach) and temporally, leading to more valid results. We also compared results from PAs with two control areas using two models of increased validity. However, some LULC changes are difficult to interpret from an environmental sustainability point of view, as trade-offs among species and habitats are expected (Gregor et al., 2016; Hewitt et al., 2016; van der Zanden et al., 2017).

The CORINE Land Cover project can be considered the largest operational application of remote sensing at European level for the detection of LULC changes (EEA, 1993; Bossard et al., 2000). Due to its spatial-temporal dimension, it is appropriate to apply a BACI approach. Thus, our work could be replicated in other studies using the same procedure. However, CLC data may result in some inaccuracies mostly (Rodríguez and Martínez-Vega, 2018a). This is the closest and most distant PA categories to main cities in Spain, re-

5. Conclusions

Spanish NRs, NPs, SCGs and SPAs experienced more environmentally sustainable LULC changes and processes of change than their surrounding areas in the 1987–2006 period. However, their effectiveness, assessed as persistence of LULCs and balance between positive and negative LULC change processes, differs, being the greatest in NRs and the smallest, in NPs, which suggests paramount importance of regulation stringency and limited influence of management on LULC changes (Rodríguez-Rodríguez and Martínez-Vega, 2018a). Agro-forestry areas and transitional woodland-shrub experienced the greatest increases inside PAs, whereas artificial surfaces, permanently irrigated land and burned areas dominated in the proximal and distant controls, indicating worrisome unsustainable LULC processes in those areas (Martínez-Fernández et al., 2015) such as new irrigated areas, land development, forest regression or burned areas that are not unique to the four PA networks studied here (Rodríguez-Rodríguez and Martínez-Vega, 2017). However, not all control areas were equally unsustainable. An environmental sustainability gradient emerged: SCIs > SPAs > NPs > NRs. Also, proximal controls were more sustainable than distant ones. Greater effort should be made to increase environmental sustainability in Spanish PAs, mainly in NPs, as well as in their surrounding areas. Methodologically, interpreting the environmental sustainability of some LULC changes and processes is challenging due to trade-offs (Gregor et al., 2016). Also, environmental regulations affecting control areas should be considered when assessing PA effectiveness, as not doing so affects result validity (Andam et al., 2008; Rodríguez-Rodríguez and Martínez-Vega, 2018a).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jag.2018.08.006.

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