Ecosystem responses to land abandonment in Western Mediterranean Mountains

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A R T I C L E   I N F O

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Erosion
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A B S T R A C T

Agricultural expansion in the Mediterranean resulted in plant and soil degradation due to the intensive use, climate conditions, and rugged terrain. After abandonment, the recovery of vegetation contributed to improvement in soil quality from a hydrological, pedological and geomorphological point of view. This paper shows three examples of ecosystem evolution in abandoned fields in Valencia, Murcia and Andalucia and the application of different methodological approaches that resulted in similar findings. In Valencia, the main responses were the recovery of vegetation after land abandonment and an increase in organic matter and infiltration capacity of soils. In Murcia, with the exception of some terraced areas on marls, where erosion processes following abandonment were important, land abandonment resulted in vegetation recovery, improved soil properties, and reduced surface wash and soil losses. In Andalucia, research along climatological gradients showed the relationship between vegetation patterns and soil moisture and the control that climate exerts on hydrological and erosive behaviour. The experimental research conducted in three different regions in Western Mediterranean demonstrated that abandonment can result in recovery of the geo-ecosystem as vegetation and soil quality improvements were shown. The marls areas in Murcia were the exception with low soil quality and low vegetation cover, and as a consequence showed evidence of high erosion rates after abandonment.

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1. Introduction

Land abandonment is the result of worldwide land use change and is altering the fate of landscapes (García-Ruiz and Lana-Renault, 2011; Cerdà et al., 2014; Arnáez et al., 2015). Land abandonment has been increasingly studied over the last few decades, as shown by the numerous literature reviews carried out, especially in recent years. However, most of them focus on Europe (MacDonald et al., 2000; García-Ruiz and Lana-Renault, 2011; Hatna and Bakker, 2011; Lasanta et al., 2015a), mainly in the Mediterranean and mountainous regions (Sheffer, 2012; Plieninger et al., 2014). The abandonment of land not only results in changes to the soil system, but also in the hydrological cycle and fauna and flora resources (de Araújo et al., 2015; Keesstra et al., 2016a).

This land abandonment has been the result of socioeconomic changes, but the impact will also be environmental as the goods, services, and resources the abandoned land offers to humankind will change. The impact of the abandonment is diverse (MacDonald et al., 2000) and the main changes are determined by pedological, lithological or climatic factors (Romero-Díaz et al., 2007; Navarro and Pereira, 2012; Lasanta et al., 2016). Traditionally, abandonment has occurred in marginal or degraded lands (MacDonald et al., 2000; García-Ruiz and Lana-Renault, 2011), but recently some areas with fertile soils are also being abandoned (Hatna and Bakker, 2011) due to the low income of the farmers (Cerdà et al., 2012). Anthropogenic factors are also relevant on the process such as Vicente-Serrano et al. (2005) demonstrated.

The Mediterranean mountains were affected by land degradation due to agricultural development that resulted in degradation of the shallow soils, including increased erosion. García-Ruiz (2010) demonstrated that during the 19th century agriculture changed the fate of many marginal areas, where soils were too shallow for good agricultural production, and soon the land was abandoned. After abandonment vegetation recovery was the key factor that determined which areas

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experienced high erosion rates and additional soil degradation and which ones recovered with improvements in soil quality. Areas that developed dense vegetative cover after abandonment acted as sinks of sediments and water in semiarid ecosystems (Cerdà, 1997a; Cammeraat and Imeson, 1999; Bochet, 2015). Forest fires also played a key role in the fate of abandoned land due to changes in the soil, vegetation, and water resources as a consequence of recurrent forest fires (Keessstra et al., 2014; Pereira et al., 2015; van Eck et al., 2016; Keessstra et al., 2016b).

There is a need for scientific research that advances our understanding of the main environmental features that lead to abandonment, such as the work of Alonso-Sarria et al. (2016) in Southeast Spain. We need better comprehension of the impact of abandonment on water resources (López-Vicente et al., 2016), soil properties (Novara et al., 2015; Brevik et al., 2016; Nadal-Romero et al., 2016) and its impact on the chemical composition of the atmosphere due to changes in the carbon cycle induced by the abandonment (Gabarrón-Galeote, 2016a; 2016b; Nadal-Romero et al., 2016; Novara et al., 2016). Although land abandonment mainly occurred in developed countries during the last century and this is where most of the research has been conducted (Shelef et al., 2015), it is now also a process found in developing countries such as some regions of Ethiopia (Mekonnen et al., 2015; Tesfahunegn et al., 2016), China (Kou et al., 2016; Tengberg et al., 2016; Yu et al., 2016), South Africa (Russell and Ward, 2016) and South America (Ochoa-Cueva et al., 2015; Trabaquini et al., 2015). To this point scientific research has mainly focused on the impact of abandonment from the pedological (Giménez-Morera et al., 2010; Brevik, 2013; Bruun et al., 2015; Colazo and Buschiazzo, 2015), hydrological (Keessstra, 2007; Keessstra et al., 2009; Nadal-Romero et al., 2011; Serrano-Muela et al., 2015; Sanjuán et al., 2016), biological (Russell and Ward, 2016; van Hall et al., 2016), geomorphological (Nadal-Romero et al., 2015), and landscape (Lasanta et al., 2015a, 2015b) points of view. There is also an economic issue behind abandonment due to the lack of income for farmers, and there is an interest in the use of abandoned agriculture fields to increase soil carbon sequestration (Alexander et al., 2015) as once the land is abandoned there may be an increase in soil organic matter as new vegetation grows and covers the soil with a consequent sequestration of carbon (Cerdà et al., 2014; Hombegowda et al., 2016). Changes in agricultural use and management are not only found in the mountains of developed and developing countries, they are also found in urban terrain as there has been an expansion in urban agriculture (Beniston et al., 2015; Brevik et al., 2015) than can result in abandonment within the urban environment.

The objective of this paper is to assess, review and synthesize the impact of agricultural abandonment in Western Mediterranean Mountains, with three different approaches and three study sites to understand how the landscape, soils, vegetation, and water resources behave and are altered after land abandonment.

2. Material and methods

2.1. Study areas

The study areas were selected in the Valencia, Murcia, and Andalucia Regions (Fig. 1) to show the impact of land abandonment in Western Mediterranean mountainous regions. The Valencia study site is located in the municipality of Vallada, within the Canyoles river watershed, in the La Costera district of the Valencia region (East Spain). The parent materials are Cretaceous limestone and Tertiary deposits that develop Typic Xerothent soils. Low levels of soil organic matter (SOM) (<2%) were found when the soils were cultivated, the pH was high (8), and the soil texture was loamy. The climate is typically Mediterranean with 3–5 months of summer drought (June–September). Mean annual rainfall at the study site is 585 mm, which falls primarily in autumn, winter and spring. Mean annual temperature is 13.7 °C. The vegetation cover move from an herbaceous cover (Brachypodium retusum) after the abandonment to a dense Quercus ilex forest after some decades of abandonment. In Murcia three research sites were selected: Fuensanta, Murta, and Corvera, with metamorphic (phyllite and schist, MET), limestone (LIM) and marl (MAR) parent materials, respectively. At each site we recognized recent (<20 years) and old (>20 years) abandoned fields. Mean annual rainfall is 286 mm in MET and 335 mm in LIM and MAR, and the mean annual temperature is 16 °C in LIM and MAR. SOM content was low (<2%) except in the recently abandoned MET area, which had 3.5% organic matter content. Soil texture was loamy in MET, loamy to sandy loam in LIM and loamy to silty

Fig. 1. Location of the study areas. VA = Vallada; COR = Corvera; MU = La Murta; FU = Fuensanta; BE = Berja; COL = Colmenar; AL = Almogía.
loam in MAR. The vegetation cover in MAR was dominated by *Lygeum spartum* (0.94) and *Artemisia campestris, Brachypodium retusum* and *Salsola genistoides* for the old abandoned fields (>20 years) and by *Helichrysum stoechas, Thymelaea hirsuta* and *Anthyllis cytisoides* in the recently abandoned. In LIM by *Thymelaea hirsuta, Anthyllis cytisoides* and *Teucrium capitatum* for the old abandoned fields (>20 years) and *Helichrysum stoechas, Thymelaea hirsuta* and *Anthyllis cytisoides* for the recently abandoned ones. In MET *Rosmarinus officinalis, Pinus halepensis* and *Helychrisum stoechas* were found in the old abandoned fields and *Helichrysum stoechas, Artemisia barreleri* and *Teucrium capitatum* in the recently abandoned (<20 years).

In Andalucia, the field sites were selected according to the pluviometric gradient approach in which topography, geology and land use must be similar in order to compare them. All of the sites were characterized by a similar slope gradient and aspect, lithology, plant cover and land use but with different climatic conditions: Colmenar (CO) was subhumid (668 mm of mean annual rainfall), Almogía (AL) dry-Mediterranean (513 mm), and Berja (BE) semi-arid (335 mm) with 15.2, 16.4 and 18 °C for the mean annual temperature. All were cultivated and abandoned at least 50 years before the survey. The vegetation recovered to shrub lands after abandonment with the following species: *Cistus monspeliensis, Phlomis purpurea, Retama sphaerocarpa, Daphne gnidium, Lavandula stoechas, Chamaerops humilis, Helichrysum stoechas, Ulex baeticus in Colmenar (CO); Quercus suber, Cistus monspeliensis, Cistus aibidus, Phlomis purpurea, Lavandula stoechas, Helichrysum stoechas, Genista umbellata, Chamaerops humilis, in Almogía (AL) and Cistus clusii, Lavandula stoechas, Thymus vulgaris, Genista umbellata, Thymelaea hirsuta, Lavandula dentata, in Berja (BE).

Our strategy was to approach the impact of land abandonment with three study sites that are focused on the impact of the age of abandonment (Valencia), parent material control (Murcia), and climatic conditions (Malaga) to have an overview of the problem in the Western Mediterranean basin.

### 2.2. Measurements

The methods applied at each study area were different in order to show different approaches and strategies to study abandoned landscapes (Table 1). Different approaches and different study areas with particular topics (age of abandonment, climate and parent material) give a better overview of the impact of land abandonment.

#### 2.2.1. Valencia

We selected terraces that were abandoned 100, 60, 30, 20, 10, 5, 2 and 0 (plough) years before the measurements, all of them with olive crops, which are representative of traditional rainfed areas of the Mediterranean. Within each of the eight research sites a 1 ha plot was selected and 10 sampling points (8 sites × 10 measurements = 80) were randomly used to measure the infiltration rates by cylinder infiltrometer (*Cerdà*, 1996) and to determine the soil organic matter content in each research plot. The infiltration rate was measured in the field at 0, 1, 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 min and later fitted to the Horton Equation (*see more information in Cerdà*, 1996) to determine the steady-state infiltration rate. Soil organic matter was measured with the *Walkley and Black* (1934) method.

#### Table 1

Main measurements carried out at each study site. *ring infiltrometer; **Mindisk

<table>
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<tr>
<th>Valencia</th>
<th>Murcia</th>
<th>Andalucia</th>
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<td>Soil properties</td>
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<td>Infiltration rates**</td>
<td>Soil moisture</td>
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<td>Erosion features</td>
<td>Vegetation cover</td>
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<td>Floristic composition</td>
<td>Erosion features</td>
<td>Floristic composition</td>
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#### 2.2.2. Murcia

Sampling and monitoring was performed for 27 samples, 9 at each of the three study sites: i) texture, aggregate stability, bulk density, SOM, pH, electrical conductivity, total calcium carbonate, total organic carbon, total nitrogen, cation exchange capacity, and Na, K, Mg, Mn, Fe, Zn and Cu. The infiltration rates were measured with minidisk infiltrometers; ii) soil erosion features were obtained qualitatively through 30 m transects, with an interval of 1 m, identifying: weak sheet erosion (WSE), strong sheet erosion (SSE) and rill and gully erosion (RandG); iii) vegetation was sampled in 100 m² circular plots that were randomly distributed. The cover of different strata (tree canopy, nanophanerophytes, small shrubs, chamaephytes, tussock grasses, other perennial grasses, forbs and annuals, mosses and lichens, plant litter and rocks, plus bare soil) was measured in four orthogonal 10 m transects. A more detailed description of field procedures as well as of indicator selection and statistical analyses can be found in Robledano-Aymerich et al. (2014).

#### 2.2.3. Andalucia

Measurements taken were: i) vegetation pattern, ii) soil moisture, and iii) soil proprieties. To measure vegetation patterns, three experimental plots were established on each hillslope with dimensions of 5 × 5 m each, in which the vegetation pattern was mapped and analyzed every 6 months (from Nov-2002 to Nov-2004). Soil moisture (SM) was measured in the top 15 cm every two weeks for two years (Oct-2002 to Nov-2004) with the use of TDR-Tektronik 1502C probes. The differences in the measured vegetation cover and SM variables were tested by means of analysis of variance (ANOVA). The differences in the measured vegetation cover and SM variables were quantified based on the ANOVA.

### 3. Results

#### 3.1. Valencia research site. Age of abandonment

The main sampling strategy in Valencia was the age of abandonment. All the sites were selected in the Vallada municipality to avoid changes in climatic conditions and parent materials.

#### 3.1.1. Vegetation cover changes after land abandonment

The field abandoned 100 years ago had developed a *Quercus ilex* woodland and a thick layer of litter; vegetation covered 100% of the soil surface. In contrast, the active agricultural fields were almost bare

#### Table 2

Vegetation cover (%) on each of the ten subplots selected in the 8 plots that were abandoned 0, 2, 5, 10, 20, 30, 60, and 100 years ago.

<table>
<thead>
<tr>
<th>Age of abandonment and vegetation cover (%)</th>
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due to ploughing, few weeds were present, and the soil surface cover averaged 2.1% (0–5% range). After abandonment, the vegetation recovery began and some herbs such as Brachypodium retusum were found under the shade of the olive trees. After 5 years, the colonization of dwarf shrubs (Thymus vulgaris) resulted in a surface cover of 46%, and in the 10-year old abandoned plots a cover of Ulex parviﬂorus. Additional studies reported a cover of 65%. After 20 years of abandonment vegetation covered 70% of the soil surface and included the previously mentioned species along with new ones such as Pistacia lentiscus and Quercus coccifera. Pinus halepensis was also found. Pistacia lentiscus and Quercus coccifera were more present after 30 years with a cover of 79%. After 60 years of abandonment we found Quercus ilex and Pinus halepensis covering 23% of the plot, and when the previously mentioned species were included total ground cover was 94.8% (Table 2).

3.1.2. Soil organic matter

During agricultural use the SOM levels were controlled by agricultural management that included intense ploughing that reduced the organic matter and prevented weed growth. Moreover, pruned branches from the olive trees were burnt rather than being returned to the soil. These conditions produced soils that were poor in organic matter. In our current agriculture plot (0 years), olive production resulted in a soil with 1.6% SOM on average (1.1–1.6%). Abandonment favored an increase in SOM with time. After two years of abandonment the average SOM content was 1.5%, with 1.7, 2.2, and 2.6% 5, 10 and 20 years after abandonment, respectively. After 30 years of abandonment the soil reached 3.2% organic matter with 4.5 and 7.0% after 60 and 100 years, respectively (Table 3).

3.1.3. Steady-state infiltration rate

The steady-state infiltration measured under ponding conditions (ring infiltrometer) showed that the infiltration rates were medium-high (228.58 mm h⁻¹) in the current agriculture field. This was because ploughing favors infiltration due to the low soil bulk density in the plough layer. After abandonment there was a sudden decrease in infiltration rates (91.17 mm h⁻¹) that was recovered 20 years later (241.42 mm h⁻¹). The highest steady infiltration rate was found 100 years after abandonment at 477.06 mm h⁻¹. Thirty and sixty years after the abandonment the infiltration rates were slightly lower than after 100 years (318.58 and 393.93 mm h⁻¹, respectively) but were higher than in any of the younger plots (Table 4).

3.2. Murcia research site. Parent material

The main strategy for the sampling in Murcia was based on parent material diversity, which can help us understand the fate of land abandonment and the role that lithology plays.

### Table 3

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### Table 4

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3.2.1. Soil properties and erosion

Soil bulk density increased in marls (MAR), while in limestones (LIM) and metamorphic (MET) rocks it was reduced with increased time of abandonment. The grain size showed little change in relation to the change in land use, being remarkable for the high presence of gravel in MET that contributed to the superficial protection of the soils, but also informed us that there was erosion of the finer particles. Aggregate stability was low with <50% stable aggregates, but in the three study sites, there was an improvement in aggregate stability with increased time of abandonment. The values of SOM were very low in MAR (0.87%) and further decreased with time of abandonment (0.71%). In LIM, SOM content was still low (1.46%), but slightly increased with time of abandonment (1.63%). In MET, SOM increased from 1.66% in the recent sites to 3.5% in the ancient sites. The cation exchange capacity decreased with time of abandonment in MAR, but increased in LIM and especially in MET, which is related to the increase in SOM and, then, the aggregate stability (Khaledian et al., 2016). All macronutrients increased with time since abandonment in MET and LIM, but decreased in MAR (with the exception of Mn). In general, micronutrients also increased with time since abandonment. There was a definite quality improvement in soils originated from MET and LIM parent materials, and a worsening in MAR derived soils as a consequence of agricultural abandonment (Table 5).

In all parent materials, sheet erosion (WSE) was initially the dominant type of erosion evidence, but it diminished after abandonment. Strong sheet erosion (SSE) increased following abandonment. In MET, evidence of sheet erosion was remarkable, but not those of concentrated erosion, nor of rill or gully (RandG) erosion. In LIM, collapses were found on the terraces. MAR notably stood out for the increase in concentrated rill erosion, which was due to subsurface erosion processes (piping), very common and with strong development (Romero-Díaz et al., 2012) (Fig. 2). The infiltration capacity of the studied soils exhibited great variability depending on the lithological characteristics and the age of abandonment. In general, the rates of infiltration in cultivated areas were greater than those measured in abandoned fields.

3.2.2. Vegetation

The study revealed that the lithological characteristics of the areas brought about important differences in their floristic composition. Total cumulative richness (RTO) increased from MAR (18 species) to MET (37), with intermediate values (28) in LIM (Table 5). The structural complexity was also maximum in MET. There were notable differences among parent materials in the richness of endozoochorous species: in MAR and LIM only one species was found, while in MET up to 9 were recorded. The representation of this life form with regard to the natural areas surrounding the old fields was 100% of the available species pool in MAR and MET, and
only 60% in LIM. Chamaephyte richness (RCH) was also significantly different among parent materials (Fig. 3), being higher in MET areas compared with any other. Conversely, the richness of small, non-endozoochorous shrubs (RLS) displayed an inverse pattern, being higher in MAR than in the other two types. Perennial grasses were favored in MET and MAR substrates. These species could play an important role (especially in marly areas) in the protection of soil against erosion. In MAR, the cover of perennial grasses seemed to also play a key role in soil protection although with a patchy and heterogeneous spatial pattern. Climbers (e.g. Asparagus acutifolius, Rubia peregrina), absent from MAR, were present more often in MET than in LIM. Differences among substrates did not hold when the variable tested was the mean frequency of occurrence (a measure of relative abundance) instead of species richness, with the exception of perennial grasses. Only marl substrates exerted a positive effect on that variable, which also increased with age, reflecting its colonization capacity.

There were no significant differences between abandonment ages for any floristic variable, although in the case of RLS and RCH the interaction Lithology × Age showed significant results (ANOVA, p < 0.01 and p < 0.05, respectively). This indicated successional changes in the richness of these life forms, of different nature depending on substrate type. These changes mainly affected limestone areas, where chamaephyte richness increased with age, while small shrubs’ richness decreased, illustrating the pioneering and relatively transient character of the latter plant type.

The three study sites in Murcia can be ordered in a gradient of plant cover, with the (ancient) MAR area dominated by perennial, lignified gramineae (Brachypodium, Lygeum) and bare soil (steep physiognomy), with a frequent but sparse presence of endozoochorous species (Asparagus hortensis). Perennial grass cover can be attributed some nurse effect for that chamaephyte, whose mean density (＞300 adult plants/ha) was an order of magnitude higher than in LIM. In an intermediate position in the cover gradient were ancient and recent LIM areas, and on the extreme positive end MET ones, where trees and nanophanerophytes were already found in recently abandoned stages, although they were still dominated by small and pioneering shrubs. In the older MET areas pine trees and large shrubs created a quasi-forest stage whose agricultural origin was often only recognized by the persistence of dead almond trees (Fig. 3). To provide an overall view of the successional syndromes identified, Table 6 summarizes the main biophysical features and indicators that characterized the areas studied in the Murcia region.

3.3. Andalucía research site. Pluviometric gradient

In the Andalucía research areas, and along a pluviometric gradient, land abandonment had effects on soil moisture content and vegetation patterns.

3.3.1. Variability of soil moisture

There was a clear relationship between the soil moisture (SM) content and rainfall in the three study areas: Colmenar (CO), Almogía (AL), and Berja (BE). Even in the rainiest months (October–November) SM values rarely exceed 0.10 cm² cm⁻². This is due to the great influence exerted by the warm summer (more than 4 months long) in the field sites, with a strong reduction in the content of SM after the final spring rains, which leads to soils frequently reaching the wilting point. All these inter-annual SM changes were significant according to the F-test for p < 0.05 (Table 7). Such differences were seen both between hilltops and within them. Hence, at the wetter sites (CO and AL) there was a great disparity of values along the hilltops, while BE was more uniform. The relationship of SM with the slope had clear statistical support in Pearson’s correlation coefficient: CO, r = 0.56; AL, r = 0.53; BE, r = −0.56; p < 0.05. The spatial variability of SM decreased as mean annual rainfall decreased. Fig. 4 shows the temporal variation of the iij test at the three-field sites, and indicates the highly complex and dynamic hydrological functioning. At AL the results of the test were at times very high indicating a strong SM variability on days when a large area of the hillslope presented a very low average. So greater SM variability on the hilltops with greatest rainfall constituted a spatially and temporally limiting factor on vegetation growth. (See Tables 8 and 9.)

3.3.2. Changes in vegetation pattern

At all three field sites there was a vegetation pattern similar to a patchy-mosaic and differences within hilltops could be found. While at the wettest sites the variation coefficient (VC) decreased, the opposite occurred at the driest site. Statistically, VC changed along the hillside at the field sites with less rain (AL and BE), while at CO vegetation cover diminished downslope although statistically these spatial changes were not found to be significant (Tables 6 and 7). Besides, the type of plant cover also had an important role. At the wettest sites, vegetation required a high water content to survive, reducing their VC in the dry season, as is the case of Cistus monspeliensis. While, in the driest month, xerophytic

### Table 5

Comparisons of different indicators of plant structure and biodiversity recorded in Murcia research sites, among classes of lithology (MAR, LIM and MET) and abandonment age (Ancient–Recent). Absolute richness values per sampling period (Sum = summer 2011; Aut = autumn 2011) and statistical comparisons (ANOVA) among all samples are shown. Statistical significance: *" = p < 0.05; **" = p < 0.01; ***" = p < 0.001. Significant post-hoc paired comparisons between square brackets.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lithology</th>
<th>Age</th>
<th>Site</th>
<th>Lithology</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAR</td>
<td>LIM</td>
<td>MET</td>
<td>MAR</td>
<td>LIM</td>
</tr>
<tr>
<td></td>
<td>Ancient</td>
<td>Recent</td>
<td>Ancient</td>
<td>Recent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>Aut</td>
<td>Sum</td>
<td>Aut</td>
<td>Sum</td>
</tr>
<tr>
<td>RNF</td>
<td>0 0</td>
<td>1 1</td>
<td>0 0</td>
<td>6 5</td>
<td>3 5</td>
</tr>
<tr>
<td>RLS</td>
<td>5 5</td>
<td>2 2</td>
<td>4 3</td>
<td>2 2</td>
<td>1 0</td>
</tr>
<tr>
<td>RCH</td>
<td>5 7</td>
<td>13 15</td>
<td>9 7</td>
<td>19 19</td>
<td>17 17</td>
</tr>
<tr>
<td>REZ</td>
<td>2 2</td>
<td>2 2</td>
<td>1 1</td>
<td>9 7</td>
<td>6 7</td>
</tr>
<tr>
<td>RTO</td>
<td>18 28</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% EZ sp</td>
<td>100</td>
<td>16.67</td>
<td>66.67</td>
<td>85.71</td>
<td>100</td>
</tr>
<tr>
<td>Pinus halepensis</td>
<td>–</td>
<td>P</td>
<td>–</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

**RNF =** Richness of nanophaneropytes; **RLS =** id of small shrubs; **RCH =** id of chamaephytes; **REZ =** id of endozoochorous species; **RTO =** Cumulative richness of all woody species, including perennial grasses, climbers and trees; **% EZ sp. =** Percent of endozoochorous species present in oldfields with respect to surrounding natural areas. Presence of Pinus halepensis: **S** = sampled; **P** = present (marginally), not included in samples.
vegetation, which is best adapted to the dry periods, displayed less significant changes between wet and dry seasons. The ratio veg/non-veg patches decreased at the end of the dry season, significantly increasing the area of bare soil. At the three field sites, the ratio decreased in the areas with lower VC, which are those that had a lower capacity for water retention. At the end of the wet season the same process occurred, that is, the areas with a high VC were the ones that showed higher values of soil moisture.

4. Discussion

4.1. Abandonment and vegetation recovery

Land abandonment in the Western Mediterranean basin occurs under different crops, parent materials, and climatic conditions. Research conducted in Spain showed that there was a recovery pattern of vegetation over time that moved from herbs as the dominant species the first 5 years, to dwarf shrubs (10 years), to shrubs (maquia) that were the most widespread vegetation until 50 years after abandonment, and finally a mixture of Aleppo pine and oak developed a forest after 100 years, such as was found at the Valencia study site. This was also found by researchers in the Pyrenees (Molinillo et al., 1997). This is a process of natural recovery that is very efficient and is found in the Mediterranean type ecosystems after any disturbance such as deforestation or forest fires. Forest fire is a good example of the resilience of vegetation (Cerdà and Doerr, 2005; Tessier et al., 2015), and recovery of the vegetation also indicates initiation of the successful recovery of the biological, chemical and physical properties of soils (Hedo et al., 2015). This same process of soil recovery is also seen when organic farming is applied after millennia of ploughing and decades of pesticides and herbicides application (Costantini et al., 2015; van Leeuwen et al., 2015; Vaudour et al., 2015). The recovering vegetation interacts with the soil, leading to recovery and development of soil properties. This can be found in any climate and region of the world (Brevik, 2013; Feng et al., 2015; Hu et al., 2015; Jacob et al., 2016; Ola et al., 2015; Roa-Fuentes et al., 2015; Yu and Jia, 2015).

The study sites in Murcia showed that the recovery of vegetation is dependent on the type of parent material. After abandonment, the colonization by nanophanerophytes with fleshy fruits seemed more limited in limestone areas than in metamorphic ones, although their structural contribution was very small in any of these substrates, probably due to the water limiting semi-arid climate and to the historical degradation of these formations (Ibáñez et al., 2015). In marly areas, the total absence of this life form seemed a consequence of the degradation of the vegetation at the landscape scale. Only a chamaphyte with this type of fruits was found (A. horridus), but with some relevance given the partially frugivore character of many typical wintering birds of these areas. In limestone areas these endozoochorous shrubs can be scarce even in the ancient oldfields, suggesting the existence of barriers to their establishment. Conversely, metamorphic fields represented favorable sites for their colonization. Only marly substrates exerted a positive effect on the relative frequency of perennial gramineae. There, tussock or mat-forming species like Stipa tenacissima, Lygeum spartum or Brachypodium retusum took advantage with their clonal vegetative growth (Haase et al., 1995; Gasque and García-Fayos, 2004). These grasses likely performed relevant structural and functional roles in marly fields, conditioning their plant and animal biodiversity and exerting some control over physical processes, which confers on them a key role in restoration strategies. An overview of the successional syndromes identified in Murcia study sites is provided in Table 6, on the basis of the main biophysical features and indicators recorded there.

The research in Andalucia contributes to our understanding of the importance of the patchy distribution of vegetation in the recovery of abandoned lands and that this recovery is partly a result of the control that climate exerts. As Ruiz-Sinoga et al. (2011) have shown, this patchy distribution contributes to greater biodiversity. Even a woodland Quercus suber sprouts first in wet sites, meanwhile in the dry ones the recovery of plants is slow. In Murcia, the combination of marls with a dry climate resulted in the intensification of soil erosion following abandonment and resulted in degradation of the soils.

Parent material plays a key role in the vegetation after abandonment. Marly areas, even after more than 20 years of abandonment, had a lower richness of woody plants and a poorer structural development, which was related to the deterioration of edaphic properties and the erodibility of the substrate, with a soil cover of < 50%. In these
areas, facilitative interactions related to greater physical stress were favored and most of the vegetation cover consisted of tussock-forming graminineae and other perennial grasses (covering up to 30% of the soil). In limestone and metamorphic (phyllite and schist) areas, the percent of bare soil was still high as compared to typical semiarid areas, but was reduced to 34–35% on average with the plant cover being dominated by small shrubs and chamaephytes. They also showed comparatively high cover values of protective elements like leaf litter and rocks. Cover of annuals and forbs was always higher in the recently abandoned fields.

4.2. Soil properties changes after land abandonment

Vegetation changes after abandonment were determined by elapsed time (Valencia), climate (Andalucia), and parent material (Murcia). The vegetation changes contributed to changes in soil parameters such as SOM, bulk density, nutrient cycling, and improvements in infiltration rates (Figs. 5 and 6). There was a clear relationship between SOM and vegetation cover, which was controlled by the time of abandonment. The importance of SOM recovery is paramount, it is absolutely essential to restore an ecosystem altered for millennia by agricultural management (Behera and Shukla, 2015; de Oliveira et al., 2015). This is because SOM is important in determining soil properties such as available nutrients, structure, and water holding capacity (Gelaw et al., 2015; Adugna and Abegaz, 2016). Ploughing was found to be the management that resulted in the lowest SOM levels due to the lack of vegetation and carbon emissions as a consequence of repeated ploughing (Lozano-García and Parras-Alcántara, 2014; Carr et al., 2015; de Moraes et al., 2015; Parras-Alcántara et al., 2016). The recovery of SOM as seen at the Valencia study site has also been documented in mine soils by Brevik (2013) and Chaudhuri et al. (2015), as natural revegetation or reclamation resulted in an increase in the vegetation cover and SOM content. Jaiarree et al. (2014) found that restoration strategies that used amendments such as compost were very positive for soil quality. We found the same behaviour in the abandoned fields of Eastern Spain, but with no amendments. It was the natural development of vegetative cover that stimulated pedogenesis, and showed that abandonment can be seen as a possible strategy to recover soil properties, functions, and services (Brevik, 2013; Debasish-Saha et al., 2014). The effect of the redistribution of SOM by soil erosion is a key topic that needs additional research (Li et al., 2014).

The interaction of vegetation with soil properties is affected by climate, parent material, and time. The research in Murcia showed that in metamorphic and limestone soils the recovery of soil properties was successful, meanwhile, in the marls derived soils it was not. SOM
content is the key factor in soil recovery as it controls aggregate stability and vegetation recovery such as we found at the Murcia research sites, where the marls proved to be more prone to degradation than the other parent materials. The low vegetation recovery in marls resulted in the development of soil erosional features that were a symptom of land degradation.

4.3. Soil hydrology and erosion after abandonment

The recovery of vegetation and SOM resulted in the improvement of soil hydrological properties as shown by the increased infiltration rates. Fig. 6 shows the constant increase in infiltration rates after the second year of abandonment. It should be noted that the active agricultural soil had higher infiltration rates than the soils abandoned for 2, 5 and 10 years, although after the second year of abandonment there was a clear increase in the steady-state infiltration rate with increased time of abandonment. It is well known that management determines the infiltration rates in agricultural soils (Wang et al., 2015; Shi et al., 2015; Hazbavi and Sadeghi, 2016) and that as we found at the Valencia study site, there was a clear influence of vegetation on soil properties due to the improvement of soil quality by litter and root additions (de Boever et al., 2014) and an impact on runoff generation and hydraulics (Zhao et al., 2015). This positive impact of vegetation can be seen in agricultural soils, but also in restored mine soils and landfills (Cassinari et al., 2014). In forest soils, the impact of vegetation type and biomass is also definitive to understanding the infiltration capacity of soils. Cerdà (1997b) found that in the maquia, plants are the key factor to understand spatial distribution of infiltration, and that aspect determines contrasting responses between south and north-facing slopes (Cerdà, 1996) likely due to differences in SOM contents (Lozano-García et al., 2016). An issue that should be highlighted here is the impact of rock fragments on soil hydrology. After abandonment and due to the erosion of the fine material and the organization of the grain size in the profile (no ploughing anymore) there was an increase in rock fragments at the soil surface. Rock fragments contribute to increased infiltration rates and reduced surface wash and soil erosion (Cerdà, 2001), which is a clear factor in the recovery of soils affected by land abandonment. This research showed that land abandonment

Table 6
Summary of the biophysical features and indicators that characterize the three areas studied. ‘+’ indicates increase, and ‘−’, decrease after abandonment (with respect to equivalent cultivated soils). WSE = weak sheet erosion, SSE = strong sheet erosion and Rand G = rill and gully erosion.

<table>
<thead>
<tr>
<th>Marls</th>
<th>Lithology</th>
<th>Metamorphic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>Lowest species richness dominance of small shrubs (non-endozoochorous)</td>
<td>Intermediate species richness (increasing in ancient abandonment)</td>
</tr>
<tr>
<td>Structure</td>
<td>Steppic physiognomy &gt;50% bare soil (AA)</td>
<td>Bare soil &lt;40% (AA) dominance of small shrubs</td>
</tr>
<tr>
<td>Flora Function</td>
<td>High occurrence of positive interactions (facilitation)</td>
<td>Higher occurrence of negative interactions (inhibition/competition)</td>
</tr>
<tr>
<td>Conservation value</td>
<td>High for frequency of Red Data Book species Genista cinerea (LRFS)</td>
<td>Lowest</td>
</tr>
<tr>
<td>Bulk density</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Texture</td>
<td>+ Silt</td>
<td>− Silt</td>
</tr>
<tr>
<td>Stability of aggregates</td>
<td>+ Sand</td>
<td>− Sand</td>
</tr>
<tr>
<td>Organic matter</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Catonionic exchange capacity</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Macro-nutrients</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Micro-nutrients</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Infiltration capacity</td>
<td>Very low</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Erosion Grade</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Evidences</td>
<td>− WSE</td>
<td>− SSE</td>
</tr>
<tr>
<td>+ SSE</td>
<td>+ SSE</td>
<td>− SSE</td>
</tr>
<tr>
<td>+ Rand G, piping</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Robledano-Aymerich et al. (2014).

Table 7
Summary of the statistical test values of soil moisture at the field sites in southern Spain. Units of soil moisture in cm³ cm⁻³.

<table>
<thead>
<tr>
<th></th>
<th>Colmenar</th>
<th>Almorégua</th>
<th>Berja</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Mean</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>DJ</td>
<td>Std</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>Max</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Std</td>
<td>Value</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>Max</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Std</td>
<td>Value</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>Max</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Std</td>
<td>Value</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>Max</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>Mean</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Std</td>
<td>Value</td>
<td>0.001</td>
</tr>
</tbody>
</table>

resulted in recovery of the natural vegetation cover, improvement in soil quality (SOM is a clear factor), and increased infiltration rates. The recovery of SOM is very much dependent on biomass. We can say that vegetation is the engine of the change as it reduced soil erosion and increased infiltration rates.

Again, in the research conducted at the marls site at Murcia, abandonment resulted in a reduction in the infiltration rates and a greater capacity to generate runoff which, together with the difficulty for plant colonization due to the low organic matter content, resulted in greater erosion potential. Ancient abandonment in all three lithologies lead to greater infiltration rates, which indicates the influence of the advanced state of plant colonization. The research conducted under different climatic conditions in Andalucía showed that the climate exerts a control on the vegetation, soil properties and soil moisture content, but all the study sites showed recovery following abandonment. Fig. 7 shows the relationship between the expected and measured plant cover under different soil moisture contents, and this showed that after 50 years of abandonment, the geosystem has evolved subject to climatic, soil and topographic factors, but in nearly all cases the abandonment resulted in higher soil quality.

4.4. A general overview: ecosystem responses to land abandonment

The analysis and comparisons of different study areas of abandoned agricultural fields in different geoeological environments of the south and east of Spain showed how each of these ecosystems evolved. A notable increase in plant cover was observed in relation to abandonment age. The plant cover increased gradually from 18% in fields of two years of abandonment, to full cover (100%) in fields abandoned for a century, through a sequence of cover values of 46% (five years), 65% (ten years) and ca. 80% (thirty years) in Valencia. In Murcia, where the abandoned plots studied were aged over and below 20 years, changes in plant cover with age were also shown. However, the greater coincidence between these two areas lies in the type of plant succession that occurs in relation to the age since abandonment. In the first years after abandonment, perennial grasses (Brachypodium retusum) established, later a low-stature scrubland mixed with tussock-forming grasses (Thymus vulgaris, Rasmarinus officinalis, Stipa tenacissima) developed, followed by taller, mostly animal-dispersed shrubs (Rhamnus sp., Pistacia lentiscus, Juniperus oxycedrus, Quercus coccifera), which finally gave way to a woodland of Pinus halepensis or Quercus ilex (depending on the location). In Andalucía the vegetation recovery was always efficient, but highly dependent on climate.

Vegetation recovery always brings about an improvement of edaphic characteristics, as has been demonstrated in the three study areas with the increase in soil infiltration capacity and water retention as a consequence of the SOM. One of the main indicators to determine soil quality is SOM content, which was analyzed in all three-study sites. It has been shown that, in the most arid areas of less coherent lithologies such as marls, SOM content is scarce, the recovery low and soil erosion high, but in all the other lithologies and climatic conditions SOM recovery was very successful.

With respect to the hydrological characteristics of the soils, also analyzed in the three regions studied, they improved with increased years after abandonment when the soils were deep, the climate regime was moister, or the lithology was more favorable for infiltration. It was also demonstrated that the spatial and temporal variability of soil moisture, analyzed specifically in Andalucía, has repercussions for the pattern of vegetation development in the abandoned fields.

From the lithological point of view, abandonment was studied in Valencia in limestones, in Andalucía in phyllites and schists, and in Murcia in both of these lithologies, along with marls. It was shown that

<table>
<thead>
<tr>
<th>Field site</th>
<th>Soil moisture</th>
<th>Vegetal cover</th>
<th>Ratio</th>
<th>Vegetation/Non vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colmenar</td>
<td>0.94</td>
<td>1.61</td>
<td>2.03</td>
<td></td>
</tr>
<tr>
<td>Almogía</td>
<td>1.30</td>
<td>2.71</td>
<td>3.91</td>
<td></td>
</tr>
<tr>
<td>Berja</td>
<td>0.61</td>
<td>4.14</td>
<td>4.06</td>
<td></td>
</tr>
</tbody>
</table>

T: temporal variability of the variable during the sampling period.
S: spatial variability of the variable along the hillslope.

![Fig. 4. Temporal variability of the relative differencing index at the field sites in southern Spain.](image-url)

Table 9

<table>
<thead>
<tr>
<th>Field site</th>
<th>Hillock section</th>
<th>Ratio/SM</th>
<th>VC/SM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Top</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>Almogía</td>
<td>Total</td>
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<td>0.71</td>
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<td>Medium</td>
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<td>Berja</td>
<td>Total</td>
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lithology exerts a significant influence on the revegetation patterns and the erosion processes that can develop after abandonment. From the standpoint of soil protection and erosion, in marly lithologies abandonment had negative effects. Soil characteristics worsened and erosion increased, especially concentrated and subsurface erosion, with extensive development of piping processes, especially in terraced areas. This occurred despite the fact that, at present, these areas have developed a vegetative cover, but a low-growing and fragmented one, providing little protection to the soil. In some areas where the gullying and piping progress occur a badland landscape develops (Martínez-Murillo et al., 2013). By contrast, in limestone lithologies and especially in phyllite and schist substrates, erosion and soil degradation were less strong, concentrated erosion did not exist, and soil properties improved (especially in metamorphic areas) due to a significant increase in natural vegetation cover after a long period without agricultural use.

The cases analyzed here confirmed that the evolution of abandoned fields is very complex and depends on many factors (soil, lithology, topography, climate, and post-abandonment management), but when there is a positive recovery of vegetation, soil quality and hydrological properties also improve. This occurred at all sites in this study except at the semiarid marly site. Comparisons between the different areas studied showed how in semi-arid areas, the plant colonization process is slower than in other climatic environments and dependent on lithologic substrate. Therefore, the type of management that can and should be done in these fields is very different. In metamorphic (phyllite and schist, as was the case in Andalusia and Murcia) and limestone areas (Valencia and Murcia), passive restoration (natural reforestation) could be allowed, but marly areas (Murcia) require active intervention (selective reforestation) to correct erosion and edaphic deterioration. Without it, marly areas may see their resilience compromised, but are also likely to lose their ecological uniqueness if such intervention modifies the steppe physiognomy that often characterizes them. Management, especially in these areas, must be a trade-off between physical protection measures and biodiversity conservation. Consequently, as a general rule, recovery must have a different character, with more assistance in marly areas, while recovery can simply be supervised but more autonomous in limestone, phyllite, and schist areas. This management will result in a better service of the soils to the society (Galati et al., 2016) due to the sequestration of carbon as a consequence of the increase in the soil organic matter (Laudicina et al., 2015).

5. Conclusions

The research conducted in Western Mediterranean Mountains showed that vegetation recovery after abandonment was very successful under different parent materials and climate conditions except on marls under semiarid conditions. The vegetation recovery determined the increase in SOM, which in turn resulted in a general improvement of soil properties with an increase in the infiltration rates and soil moisture levels, and a reduction in the soil losses. We suggest passively supervising the autonomous evolution of limestone, phyllite, and schist areas after abandonment, but not to intervene. Meanwhile, marls under semiarid conditions will need an active intervention to avoid high erosion rates and improve soil properties, mainly the SOM content.

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