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Trade-offs of European agricultural abandonment

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ABSTRACT

Agricultural land abandonment is a policy challenge, especially for areas with unfavorable conditions for agriculture and remote and mountainous areas. Agricultural abandonment is an important land use process in many world regions and one of the dominant land use change processes in Europe. Previous studies have shown that abandonment can have both positive and negative effects on several environmental processes, influenced by location and scale. Preferred policies and management of these areas are debated given concerns for the loss of (traditional) agricultural landscapes and potential impacts on biodiversity and ecosystem services. We present a European-scale impact assessment of the possible effects of agricultural abandonment, based on eight indicators that are on the forefront of the agricultural abandonment debate. Using a multi-scale modelling approach, we expect between 71.277 and 211.814 km^2 of agricultural abandonment in 2040. Impacts on the indicators and trade-offs between the impacts are spatially variable. A typology of typical trade-off bundles at a 1 km^2 resolution resulted in four typical trade-off clusters. All clusters identified are characterized by a loss of agriculture-related values, such as agro-biodiversity and cultural heritage. For two clusters, this was accompanied by positive effects on indicators such as carbon sequestration, nature recreation and mammal habitat suitability. Overall, our results indicate that location and scale are key to assess the trade-offs originating from agricultural abandonment in Europe. Identification of typical trade-offs bundles can help to distinguish potential desirable outcomes of agricultural abandonment and assist in targeting measures to areas that face similar management challenges.

1. Introduction

While competition for farmland is globally on the rise, simultaneously the process of agricultural abandonment has shown an increased trend since the 1950s (Cramer et al., 2008). Agricultural abandonment is an important land use process in many world regions and one of the dominant land use change processes in Europe (Grau and Aide 2008; Prishchepov et al., 2012; Keenleyside and Tucker 2010). The process of agricultural abandonment is a complex and multi-dimensional process (Munroe et al., 2013), which often can be described as a situation were "[the] human control over land (e.g. agriculture, forestry) is given up and the land is left to nature" (FAO, 2006a). While the process of agricultural abandonment seems contrasting to the required increase in agricultural production, it is often closely related to intensified land uses in more suitable areas and results from different physical, environmental, social and economic factors in an increasingly globalized agricultural economy (Rey Benayas et al. 2007; Verburg et al. 2013a,b). Agricultural abandonment in marginal areas can be viewed as an example of land sparing, as agricultural activities are concentrated through intensification elsewhere or displaced to other world regions, driven by economic or other factors, while marginal areas are abandoned (Wentworth 2012).

Measurement and study of abandonment areas is complicated due to different definitions, lack of consistent measurement across the EU and the difficultly of detecting agricultural abandonment by remote sensing data (Keenleyside and Tucker 2010; Verburg and Overmars 2009). While the current extent of abandonment is unknown (Pointereau et al., 2008), European agricultural statistics and land cover maps show a clear decrease of agricultural areas in the past decades, especially for extensive and small-scale agricultural systems (Pinto Correia 1993; Renwick et al., 2013; Fuchs et al.,

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2015), and modeling studies predict significant levels of agricultural abandonment in Europe over the next 20–30 years (Renwick et al., 2013; Verburg and Overmars, 2009).

Recent studies on agricultural abandonment in Europe showed that agricultural abandonment primarily occurs in less productive areas, remote and mountainous regions and areas with soil erosion or unfavorable climatic conditions for agriculture (Rey Benayas et al., 2007; Keenleyside and Tucker, 2010). Secondary drivers of agricultural abandonment include rural depopulation and regional specific factors regarding land ownership and tax regimes (Rey Benayas et al., 2007; Keenleyside and Tucker 2010; MacDonald et al., 2000). While both primary and secondary drivers refer to inadequate agricultural incomes and abandonment of marginal areas, it should be noted that there are different trajectories of agricultural abandonment, including abandonment of non-marginal areas. An example is the abandonment of agricultural land around cities related to urban sprawl, that is often driven by increasing land prices and fragmentation of farms (e.g. Grădinaru et al., 2015; Paül and Tonts 2005).

An important regional event which triggered agricultural abandonment was the collapse of the Soviet Union in the 1980′s, leading to widespread agricultural abandonment in Eastern Europe due to poorly established property rights and problems with land ownership (Kuemmerle et al., 2008; Hartvigsen, 2014). Agricultural policies also play an important role, as abandonment often occurs in areas where the land productivity does not provide an adequate income for farmers. Even with the support of subsidies such as the Less Favored Areas (LFA) support and agri-environmental payments, which are part of the rural development pillar of the Common Agricultural Policy (CAP), agriculture in these areas is often not competitive. Proposed plans to reduce support for agriculture and to decouple support from production within the CAP were therefore highly debated within the EU, as member states feared that this could lead to several risks, including the abandonment of production (Renwick et al., 2013).

Abandonment of agriculture can have positive and negative outcomes, although these consequences differ per location and scale (Rey Benayas et al., 2007; Munroe et al., 2013). Currently, no scientific consensus regarding the most favorable management of abandoned land exists in Europe (Agnoletti 2014; Schnitzler 2014). In literature often the loss of agro-biodiversity and species richness in landscapes with long histories of management is cited (Rey Benayas et al., 2007; Agnoletti 2014). This often relates to species-rich habitats such as low intensity croplands or mosaic areas and meadows (see for example Laiolo et al., 2004; Dauber et al., 2006; Baur et al., 2006). This reduction of land use mosaics and consequently of landscape heterogeneity is also associated with fire risk, especially in the Mediterranean region (Höchtl et al., 2005; Viedma et al., 2006; Moreira et al., 2001). The loss of mosaic landscapes and traditional cultural landscapes has also an important societal consequence, as these areas are associated with historical values, cultural heritage ('sense of place'), aesthetic values and often attract tourism (Navarro and Pereira 2012; Antrop, 2005; Plieninger et al., 2006). The case of erosion is an example of the diverse and location specific impacts of agricultural abandonment, which can have both negative and positive impacts depending on the local circumstances. Local increase of soil erosion (e.g. by break down of conservation structures; Lesschen et al., 2008) and the possible reduction of water stocks at the watershed scale (Andréassian, 2004; Robinson et al., 2003) are mainly reported in dry regions (Rey Benayas et al., 2007).

Positive outcomes associated with agricultural abandonment are related to the effect of revegetation and succession. Often mentioned is the general increase in vegetation density and biomass, although the speed is highly variable between different environments (Rey Benayas et al., 2007). Revegetation generally increases carbon sequestration, by means of woody biomass increase and a net soil organic carbon (SOC) gain on former arable land (Schulp et al., 2008). On former SOC-rich grasslands, the net SOC can be negative or remains equal (Bárcena et al., 2014). Other biophysical benefits from revegetation include increased hydrological regulation and erosion reduction (overview in Rey Benayas et al., 2007; Munroe et al., 2013). Biodiversity is also related to the increase in woody vegetation, but its role is dependent on the local habitat, as abandonment can both increase or decrease local habitat diversity (Hall et al., 2012; Queiroz et al., 2014). In general, species adapted to open spaces will disappear, while species related to shrub, forest and soil fauna are favored (e.g. Kardol et al., 2005; Sirami et al., 2008). In case of species-rich woody vegetation, this will lead to an increase in biodiversity (Rey Benayas et al., 2007), although intermediate stages of natural succession are vulnerable to invasive species (Stoate et al., 2009). Further succession stages with establishment of strong native species could, however, lead to a decrease in invasion level compared to the previous landscape (Chytrý et al., 2012). Within conservation literature, especially in Europe, agricultural abandonment is mentioned as a potential source for the development of large-scale natural areas, sometimes with the possible development of wilderness areas (Navarro and Pereira 2012; Ceauşu et al., 2015; Keenleyside and Tucker 2010; Bowen et al., 2007; Herzog and Schüepp, 2013). The idea that unproductive and abandoned land can serve as new wilderness areas ("rewilding"), i.e. self-sustaining ecosystems close to the "natural state" often supported by (re-)introduction of large herbivores and habitat protection for carnivores and other species (Navarro and Pereira 2012; Brown et al., 2011), is expressed often and is backed by different conservationist groups (e.g the "Rewilding Europe" initiative). While rewilded areas can provide new forms of recreation and tourism (e.g. hunting, bird watching; Kaczensky et al., 2004), the concept of wilderness (Lupp et al., 2011) and rewilding is often criticized by the public, especially by local populations that might be adversely affected. Wilderness is still often associated with being a hostile and dangerous environment and linked to the loss of economic stability within a region (Enserink and Vogel 2006; Bauer et al., 2009; Wilson, 2004).

Different case studies of agricultural abandonment have shown that the process of agricultural abandonment is not a linear process, but that it includes different transitional stages (e.g. Meyfroidt and Lambin 2008). Most importantly, local and temporal differences can lead to different trajectories and long-term outcomes (Munroe et al., 2013; Verburg et al., 2010). These different trajectories combined with the spatial heterogeneity of environmental conditions in many regions lead to the assumption that the different positive and negative outcomes related to environmental consequences of agricultural abandonment differ per location and scale (Ramankutty and Rhemtulla, 2012; Chazdon, 2008). While this is discussed in several studies (MacDonald et al., 2000; Navarro and Pereira 2012; Höchtl et al., 2005), the role of the spatial context related to abandonment trade-offs is often ignored. No larger-scale overview of the possible effects of agricultural abandonment with a spatial component is published to this date.

The objective of this paper is to characterize the spatial diversity in trade-offs of potential agricultural abandonment for the European Union (EU-27) in the next decades at a high spatial resolution. The analysis of the trade-offs is based on the areas identified to be at risk for agricultural abandonment under different scenarios of land use change for the period of 2000–2040. Here, we specifically focus on agricultural areas that are either abandoned of have already undergone further succession towards semi-natural area or forest in 2040. Trade-offs as a result of agricultural abandonment are assessed for eight indicators, selected based on the current scientific discussion on abandonment impacts. A typology of typical trade-off bundles is developed, to give insight on how these impacts

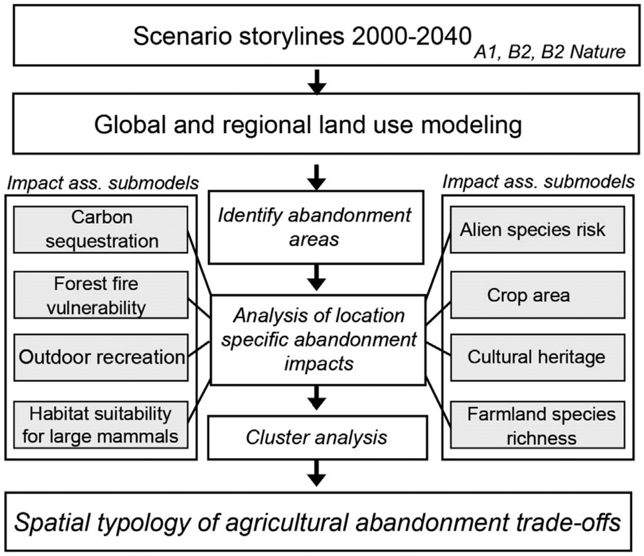

Fig. 1. Outline of the methodology.

interact. Areas of typical trade-off bundles help to identify areas facing similar management challenges and opportunities upon future abandonment.

2. Methodology

This paper focuses on the characterization of areas that face similar trade-offs related to agricultural abandonment in the European Union (EU-27) in the next decades. An overview of the method is presented in Fig. 1. The agricultural abandonment information is derived from an integrated modeling approach that uses two different scenarios (A1 and B2) and a scenario policy option (B2 with an enhanced nature protection focus), chosen to reflect potential economic, demographic and agricultural and conservation policy changes for the European Union (Section 2.1). The scenario-based projection of agricultural abandonment areas is fed into an impact assessment that includes eight different potential effects of agricultural abandonment such as carbon sequestration and emission, changes in fire risk probability, outdoor recreation and the effect on cultural heritage (Section 2.2). We use the results of the impact assessment to derive a spatial typology of areas that face similar tradeoffs between the different impacts and thus share challenges and opportunities regarding agricultural abandonment (Section 2.3).

2.1. Scenarios storylines and global and regional land use modeling

Future areas of agricultural abandonment are determined based on land use simulations for a set of exploratory scenario storylines between the years 2000 and 2040. To account for different possible futures, we compare three different scenarios (A1, B2, B2 Nature policy option), that are chosen to represent contrasting developments in the underlying processes that lead to agricultural abandonment in the European Union. The scenarios closely follow the SRES storylines of the Intergovernmental Panel on Climate Change (IPCC, 2000), but use specific information on projections on socio-economic, political and technological changes in the EU. The scenarios are structured along two axes; "regional vs. global development" and "less intervention vs. more intervention". The B2 storyline (European Localism) is, in this study, chosen as a baseline scenario. This scenario represents a fragmented world with modest economic growth and moderate intervention. As a clear opposite scenario, we use the A1 scenario (Libertarian Europe), which represents a globalized world with strong economic growth and weak intervention. We use a policy option based on scenario B2 (from now on "B2 Nature") to assess the effect of an increased policy focus on nature projection. Besides the general B2 setup, this policy option is based on an expansion of protected zones beyond Natura2000, a robust ecological corridor network and strengthened constraints on land cover conversions and forest management. Detailed scenario storylines are provided in Supplementary Material S1.

To implement these storylines in simulations of future land cover, we use a top-down modeling framework that combines different well-established models covering different spatial scales (from global to sub-national) and including multiple sectors (see also Stürck et al., 2015). The modeling framework starts with a coupled macroeconomic, multi-sector analysis at global scale that, based on the specific scenario conditions, calculate changes in Gross Domestic Product (GDP), population growth, areas for different land uses, agricultural and forest production and consumption patterns (Kallio et al., 2006; Lotze-Campen et al., 2008; Popp et al., 2010; Van Meijl et al., 2006). These outcomes are subsequently used by different regional models to calculate the demands for different agricultural sectors as well as urban demands at the national or subnational level (Britz et al., 2007; Sallnäs 1990; Schelhaas et al., 2007). These demands are used in a land allocation procedure, which disaggregates the simulation outcomes to a 1 km^2 resolution at an annual temporal resolution (Verburg and Overmars, 2009). During this procedure, seventeen land use classes are modeled based on the CLC2000/CORINE land cover database (EEA, 2005), including recently abandoned farmland and recently abandoned arable land. However, certain land conversions are excluded, restricted or based on time restrictions. For instance, land conversions after the start of agricultural abandonment are controlled by the number of years a certain land conversion usually takes (e.g. from abandoned farmland to semi-natural and from semi-natural to forest). A detailed description of the land allocation procedures can be found in Verburg and Overmars (2009). Detailed information on the integrated modeling system can be found in Supplementary Material S2.

Future land abandonment areas are based on all 1 km^2 cells that were abandoned in the period 2000–2040 from the land use simulations of the three scenarios. We considered cells abandoned if they transitioned from an agricultural land use class (arable land, pasture or permanent crops) in 2000 to an abandonment class (recently abandoned arable or pasture land) in 2040 or had continued succession and belonged to semi-natural or forest land use classes in 2040.

2.2. Impact assessment

Eight different variables where chosen as proxies to represent key aspects affected by agricultural abandonment. The variables where chosen based on their mentioning in the discussion on the effects of agricultural abandonment. Most indicators are represented by datasets that were previously published, sometimes adjusted for the purpose of this study. The mammal habitat suitability indicator was developed specifically for the study. All included indicators have their base year in the period between 2000 and 2010 and their change up to 2040 is assessed.

2.2.1. Carbon sequestration and emission

Carbon sequestration is calculated as the annual changes in carbon stock (C km^{-2} $year^{-1}$), which is based on the changes in the combined carbon sink caused by carbon sequestration and emission in soils and by changes in biomass, which are calculated separately. The soil carbon stock change is based on an emission factor (Mg C $year^{-1}$), which is the emission/sequestration per unit area per land use type. The biomass stock increment is calculated based on country specific, age dependent growth factors. Carbon sequestration and emission is calculated per grid cell (1 km^2) in yearly time steps for all three land use scenarios. The method used is an adapted approach of Schulp et al. (2008) and described in more detail in Supplementary Material S3.

2.2.2. Forest fire vulnerability

The indicator for forest fire vulnerability is based on species composition and forest structure as projected by EFISCEN, following the method described by Schelhaas et al. (2010). The indicator is based on the concept that the vulnerability of a forest to fire is mainly dependent on the availability and vertical and horizontal distribution of fuel and the flammability of the material (Fernandes et al., 2000). The specific vulnerability scores are based on tree species as well as threshold ages, as young stands often have conditions that support higher flammability. Forest fire vulnerability is calculated per grid cell (1 km^2) in yearly time steps for all three land use scenarios. See for more information on this indicator Supplementary Material S3.

2.2.3. Outdoor recreation

Outdoor recreation potential is the capacity of a region to provide tourist activities outside the urban areas, with a focus on nature tourism/camping tourism. The method is based on the approach described by Van Berkel and Verburg (2011) and slightly adapted to focus on outdoor recreation only. In the modeling approach, different spatial proxies that describe the attractions for outdoor recreation are used; with the selection of the proxies and the assigned weights based on an expert workshop with participants working in rural development and rural typology domains. Included are proxies on attractive biophysical conditions (e.g. water bodies, forests and landscape variation), areas with low degree of human interventions, areas with policy instruments for nature conservation and "outdoor" tourist attractions. Outdoor recreation is calculated per grid cell (1 km^2) for selected time steps for all three land use scenarios. More information on the modeling procedure and the specific proxies are available in Supplementary material S3.

2.2.4. Habitat suitability of large mammals ("Megafauna")

The habitat suitability of mammals is developed to provide an indicator for the suitability of habitats for the natural recovery of European mammals, specifically in areas of agricultural abandonment. The focus is on mammals species >10 kg ("megafauna"), as these mammals have an important role in natural trophic networks (Ceauşu et al., 2015; Schmitz 2006; Ritchie and Johnson 2009) and as agricultural abandonment is often seen as an opportunity for the comeback of large mammals in Europe (Navarro and Pereira 2012). For the estimation of habitat suitability of large mammals, we assume that the survival of a new or reintroduced population should correspond to at least the Minimum Viable Population (MVP; Foose et al., 1995) and that these populations are viable if the available land area is at least equal to the Minimum Critical Area (MCA):

$$MCA = density * MVPsize$$

The MCA is only considered viable if the land is available in connected areas of appropriate land use types (for comparible methods, see e.g. Jantke and Schneider 2010; Wilson 2004). We have selected species-specific MVP and density information for all megafauna species in Europe and removed the species of which no published or reliable data was available. Based on the MCA, species-specific habitat requirements combined with the modeled land use types per scenario, we could determine the habitat suitability per scenario for seven species. These were summed as final indicator. Species include the carnivores Eurasian lynx (*Lynx lynx),* brown bear (*Ursus arctos*) and European badger (*Meles meles*); the even-toed ungulates European bison (*Bison bonasus*), red deer (*Cervus Elaphus*) and wild boar (*Sus scrofa*); and the rodent Eurasian beaver (*Castor fiber*). Habitat suitability for mammals is calculated per grid cell (1 km^2) for selected time steps for all three land use scenarios. More information on the modeling procedure is available in Supplementary Material S3.

2.2.5. Alien species risk

Alien species risk is based on spatial information on the alien species in Europe, as gathered by the Delivering Alien Invasive Species Inventories for Europe (DAISIE) project (Vilà et al., 2010). Within the DAISIE project, "100 of the worst species" are defined, based on their impact on biodiversity, economy and health (DAISIE, 2010). To develop an alien species risk indicator, each terrestrial species within the "worst species" list was scored on ecological impact and invasive potential based on the scoring system of Molnar et al. (2008). The ecological impact score reflects the impact of the disruption on native species and ecosystems, while invasive potential gives an assessment of the recent spreading speed and the potential for future spread. The scores of ecological impact and invasive potential are combined in an overall threat score per species. Subsequently all species within a cell (8 × 8 km) were combined by assigning the highest threat score in the cell (Mouchet and Lavorel, 2012). The current presence of "worst" species at and around the areas that are modeled as being abandoned in the period until 2040 is assumed to give an indication of alien species risk for these areas.

2.2.6. Crop area

Information on crop area is based on the specific cover percentage of crops at a certain location, provided by the CAPRI modeling system (Leip et al., 2008). Leip et al. (2008) based the crop information on locally weighted bi-nomimal regression models, where ground level observations on crop types (taken from the Land Use/Cover Area Frame Statistical Survey (LUCAS) database; Delincé, 2001) are used, in combination with explanatory variables such as slope, attitude and soil and climatic information (Kempen et al., 2011). To account specifically for the area of arable crops, information on permanent grassland and fallow land are excluded in this study. The loss of crop share within agricultural areas upon abandonment is taken as an indicator in this study.

2.2.7. Farmland species richness

To represent farmland species richness, we use the indicator map presented by Overmars et al. (2014). This indicator is based on downscaling occurrence maps of birds, mammals, reptiles, amphibians and vascular plants (on a 50 km grid) that are dependent on open grassland or arable land to a 1 km^2 grid, using information on environmental pressures for each species. The species- specific pressure information on land cover, fragmentation and pressures related to land use intensity (e.g harvesting, nitrogen input) were linked to maps of these pressures throughout Europe. This allowed species occurrence mapping; if none of the pressure maps hindered occurrence, the species was mapped in the species presence map and all species that occur per cell are summed. As indicator, loss of farmland species richness within agricultural areas upon abandonment is taken as an indicator in this study.

2.2.8. Cultural heritage

To represent the loss of cultural heritage associated with traditional agricultural landscapes, we have used the agricultural landscape typology by van der Zanden et al. (2016) to give weights to traditional agricultural landscapes. Cultural landscapes are acknowledged as a useful concept to link cultural values to ecosystems and are important entities for cultural heritage (Tengberg et al., 2012; Agnoletti, 2014). For instance, the Millennium Ecosystem Assessment (2005) conceptualized heritage as "landscape-related "memories" from past cultural ties, mainly expressed through characteristics within cultural landscapes" (pg. 16, Tengberg et al., 2012). Many traditional cultural landscapes in Europe are vulnerable as they are often no longer economically sustainable or are threatened to lose their economic competitiveness (Vos and Meekes, 1999). These highly diverse landscapes are characterized by a low intensive management regime that is often labor-intensive but uses low nutrient inputs, mechanization and pesticide application. This includes valuable small-scale farming landscapes, such as bocage (enclosed) landscapes and low intensity or seasonal grazing areas (Vos and Meekes 1999; Widgren, 2012). In this study, the loss of cultural heritage within agricultural areas upon abandonment is taken as an indicator. More information on the weights assigned to different landscape categories is available in Supplementary Material S3.

2.3. Data analysis

Individual maps of the environmental variables included in the impact assessment are presented in Fig. 2. To enhance the comparability of the different variables within the impact assessment, the data was normalized by using positional normalization to a −1–1 range. Variables with only negative outcomes where normalized to a −1–0 range.

The first part of the data analysis consisted of an assessment of the relationships between the indicators within the impact assessment, using Principal Component Analysis (PCA). Cluster analysis was used to determine the different spatial areas that have a similar response from the eight different variables included in the impact assessment. Clusters of the variables where identified and analyzed using the K-means clustering method. We determined the optimal amount of clusters by comparison of the within cluster sum of squares (WCSS) and the Davies-Bouldin clustering validity index with an increasing number of clusters based on 25 iterations. The Davies-Bouldin index represents the ratio of the sum of within-cluster scatter to between-cluster separation and, therefore, the objective is to minimize the index during a clustering procedure (Davies and Bouldin, 1979; Maulik and Bandyopadhyay, 2002). All analyses where executed in R (R Development Core Team, 2008), using the "stats" (Chambers and Hastie, 1992), "clusterSim" (Walesiak and Dudek, 2014) and "FactoMineR" packages (Husson et al., 2014).

3. Results

3.1. Modeled abandonment areas

For the European Union, the largest area of agricultural abandonment is expected under the globalization and economy driven scenario A1; 211.814 km^2 in total, which is 10.9% of all agricultural land available in 2000. The B2 Nature policy option results in agricultural abandonment close to the A1 values (169.469 km^2), while the B2 scenario results in less than half that size (71.277 km^2). This is 8.7% and 3.7% of all agricultural land in 2000 respectively. Abandonment of pasture and arable land is almost equal for the A1 and B2 Nature scenario (~48%, 3–5% permanent crops), the B2 scenario has a slight majority of arable land under abandonment (57%).

In Fig. 3, the country-wide differences in expected abandonment areas are visualized (see Supplementary material S4 for percentages per EU-27 country). While the B2 scenario leads in all countries to the lowest abandonment values, the relative amount of abandonment for the other two scenarios are country-specific. The areas being abandoned under scenario A1 are generally marginal and unsustainable areas that are abandoned as a result of intensification of more suitable land. Finland (27.6%) has the highest percentage of agricultural abandonment in 2040 under the A1 scenario, expressed as percentage of all agricultural land in 2000, followed by Estonia (25%) and Austria (19.6%). Abandonment under the B2 Nature policy option is largest in Bulgaria (10.1%), followed by the Czech Republic (9.2%) and Portugal (8.4%). Abandonment under this policy option is influenced by the strong restrictions and need for extra land for nature protection (i.e increase protected areas, improved connectivity and nature development in ecological corridor areas), which results in less area that can be converted to agricultural land and increased land prices. As a consequence, additional demand for agricultural production is allocated to other world regions.

When comparing the different indicators for the European Union, we find statically significant differences between the areas that are predicted to be abandoned compared to the agricultural areas that are not abandoned for all indicators (except Megafauna for the B2 scenario, see Supplementary Material S5). Although a comparison of average values for spatially heterogeneous areas can obscure large differences in values between individual areas, the results give an indication that projected abandonment areas have different values for many indicators. An example are the lower crop area values in the base year, which leads to the assumption that the projected abandoned areas have a lower arable productivity than other agricultural lands, as permanent grassland and fallow land are not taken into account for crop share. Overall, agricultural abandonment leads to a clear change in area characteristics over the period 2000–2040. The expected changes include higher average values for carbon sequestration, fire risk probability and outdoor recreation for abandoned areas, when compared to stable agricultural areas. The habitat suitability for mammals also undergoes a positive change in abandonment areas; while there is a negative trend for stable agricultural areas (see Supplementary Material S5 for a comparison of all variables on a European scale).

3.2. Spatial environmental trade-offs

For the different scenarios we have tested the optimal number of clusters, based on Principal Component Analysis (PCA) and cluster statistics. This analysis showed that the three different scenarios had very comparable clustering patterns. The optimal number of clusters for scenario B2 and B2 Nature was 4 clusters, with scenario A1 having 7 clusters as optimal number, followed by 4. Closer examination showed that the clusters between the B2 and A1 scenarios were very similar. Comparable patterns were also found for the B2 Nature scenario, although there was more explicit variation caused by the Cultural heritage values. As the overall patterns where very similar, we decided to use the clusters based on the reference scenario B2 for the three scenarios (see Supplementary material S6 for the B2 results).

The four clusters that define the environmental trade-off bundles are visualized with their cluster centers in Fig. 4. The values are normalized, using positional normalization to range −1–1, to enhance the comparability of each environmental variable. The results show a clear separation between the first two clusters and the latter clusters: Cluster 1 and Cluster 2 are both defined by increased carbon sequestration and related increased forest fire vulnerability, while this is non- existent for Cluster 3 and 4. However, Cluster 1 has also a large increase in outdoor recreation values, followed by an increase in habitat suitability for mammals ("megafauna"). Contrastingly, Cluster 2 has a larger increase in habitat suitability for mammals, but no increase in outdoor recreation. Clusters 3 and 4 have small or negative values for carbon

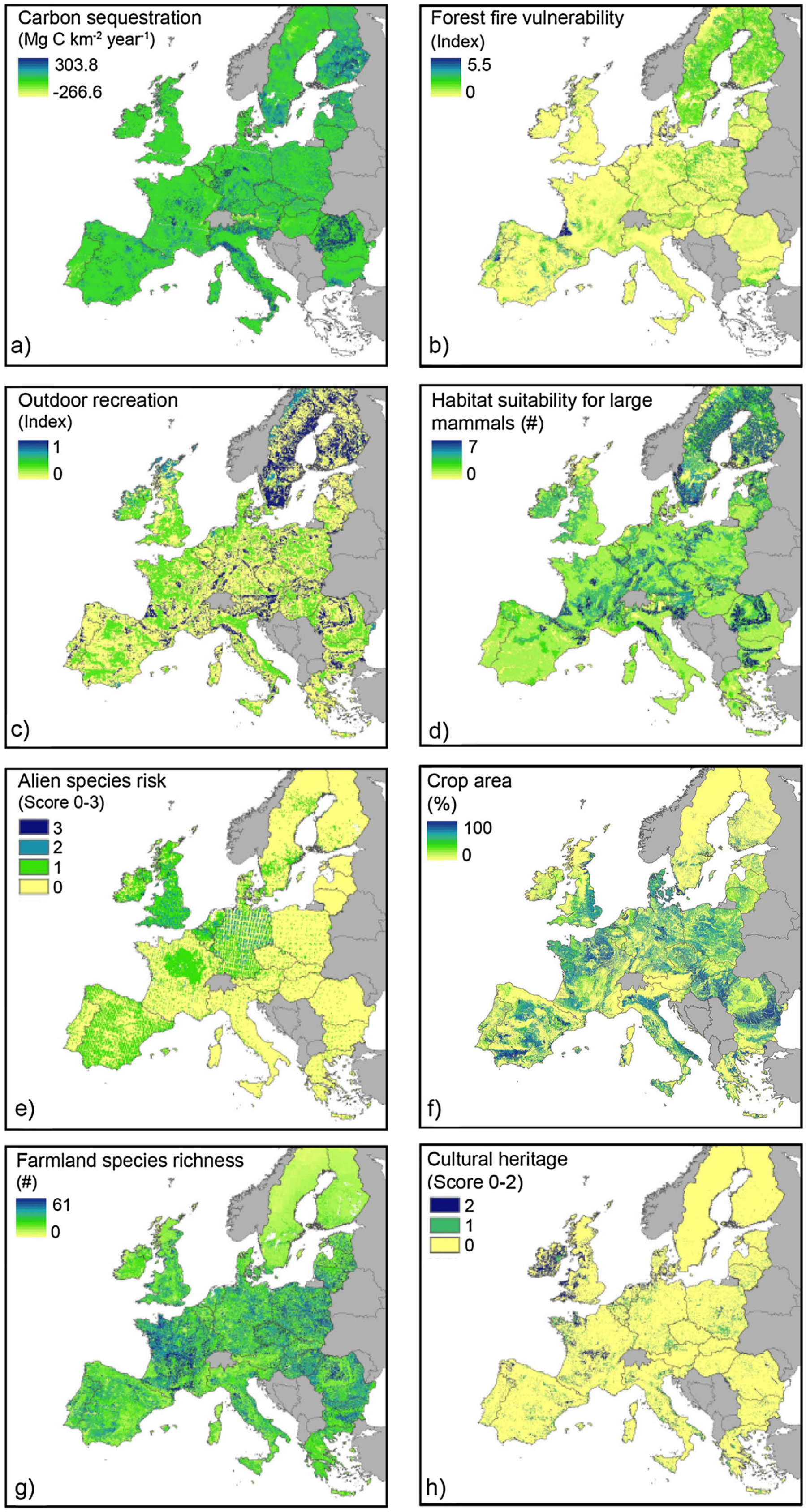

Fig. 2. Individual maps for the state of the indicators included in the impact assessment for the period 2000–2010.

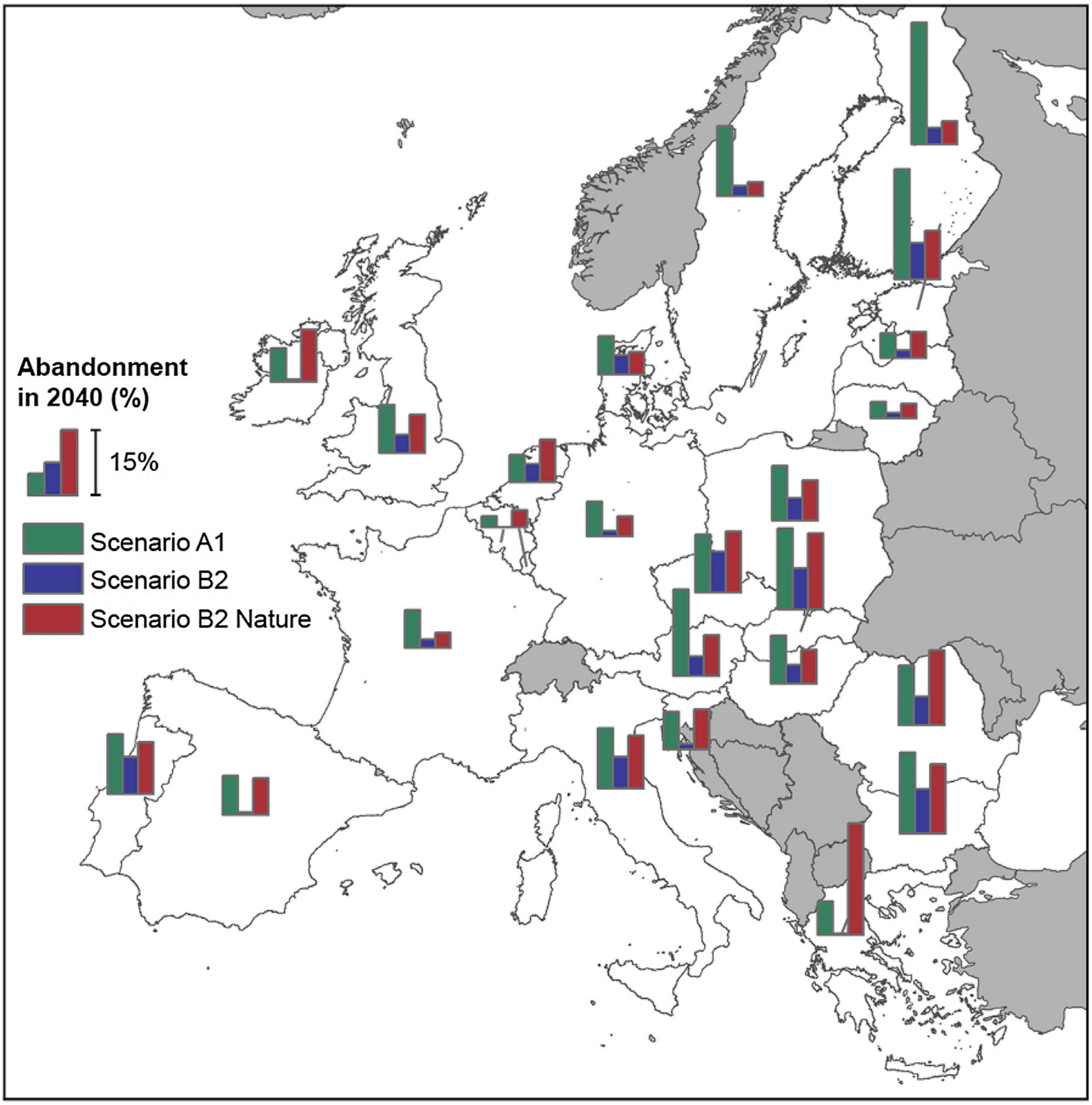

Fig. 3. Agricultural abandonment in 2040 expressed as percentage of all agricultural land in 2000 per scenario storyline: scenario A1 (Libertarian Europe), scenario B2 (European Localism – baseline scenario) and scenario B2 Nature (B2 scenario with nature protection focus). See Supplementary material S4 for percentages per country (EU-27).

sequestration, forest fire risk, outdoor recreation and megafauna. Cluster 3 is characterized by major losses in farmland species richness compared to cluster 4, while also displaying the largest values for alien species risk. While the loss of crop share is large for Cluster 1–3, this is lower (<−0.32) for Cluster 4. Cluster 4 also has the highest values for Cultural Heritage loss (−0.11), followed by Cluster 3.

The spatial patterns of the different clusters that represent the different trade-off profiles are visualized in Fig. 5. The panels on the left (a) show the dominant clusters for the NUTS 3 regions. These results show clearly that Cluster 3 and 4 are overall most prevalent, while Cluster 1 and 2 are locally more dominant. Additionally, the panels at the right (b) show the pairwise occurrence of the clusters: Cluster 1 and 2 occur in the same areas in all three scenarios, similar to Cluster 3 and 4. This confirms that there are two groups of clusters; the "forest dominant groups" (Cluster 1 and 2) which have high values of carbon, forest fire vulnerability and either outdoor recreation and minor megafauna (Cluster 1) or megafauna (Cluster 2) and the "loss of agriculture group" (Cluster 3 and 4); which are defined by the loss of agricultural-related values and increase in alien species risk while there are no increasing other values.

The areas that are dominated by Cluster 1 and Cluster 2 are characterized by favorable conditions for forest succession, as this is the most prevalent land cover in 2040 underlying both clusters (see Supplementary material S7). Areas defined by Cluster 1 and Cluster 2 are variable over the different scenarios, but stable areas occur e.g. for Bulgaria, Finland and Slovakia. Closer examinations of the results shows that these clusters mainly occur in mountainous areas, especially in and around mountain valleys, and in areas where agricultural abandonment causes an extension of already existing forestry areas. Fig. 5(b) clearly shows this for the areas along the Apennines (Italy). The influence of elevation partly explains the difference between Cluster 1 and 2, as a hilly and mountainous landscape has a positive influence on the outdoor recreation index.

The areas characterized by Cluster 3 and Cluster 4 have seminatural areas (i.e. Shrubland) as most prevalent land cover in 2040 underlying both clusters (see Supplementary material S7). This

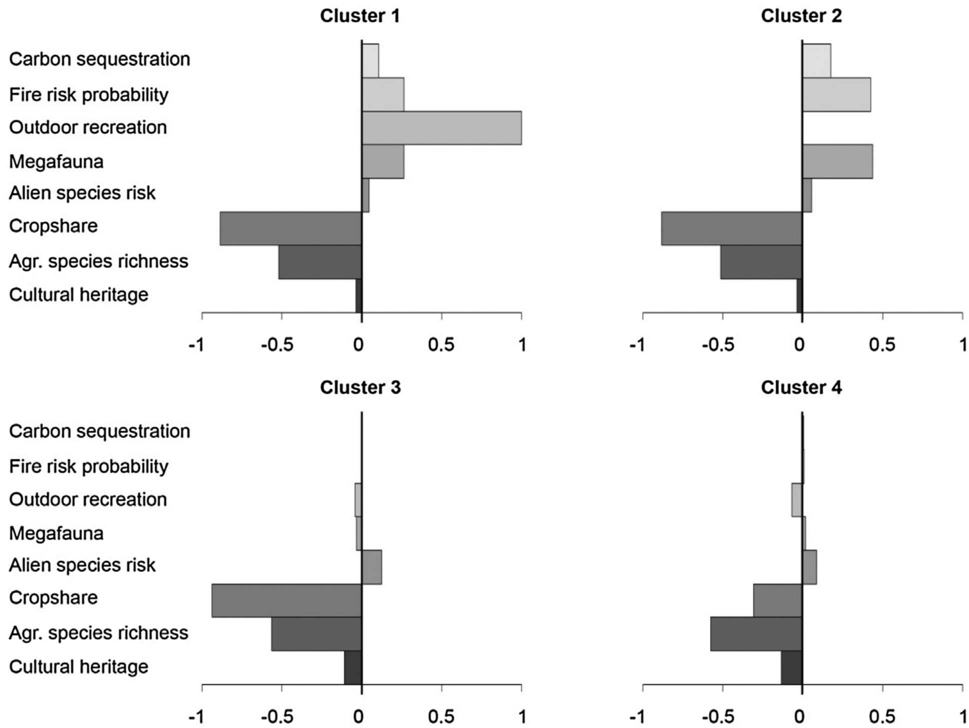

Fig. 4. Average cluster characteristics showing the trade-off bundles resulting from future agricultural abandonment in the European Union (EU-27). The variable values presented are standardised to illustrate the quantification of each variable.

indicates that the local conditions are less suitable for quick forest succession, e.g. by local biophysical conditions, the effects of low-pressure or occasional grazing and population pressure (see Verburg and Overmars, 2009 for more details). The dominance of Cluster 3 and 4 seems relatively stable over the three scenarios, with cluster 4 being most prevalent in areas with well-known cultural landscapes such as Brittany (France). A more detailed look shows also some differences among the scenarios. For instance, in scenario A1 there is an emerging abandonment area in the Midi-Pyrenees that is dominated by Cluster 3, while an emerging abandonment area in central Italy in scenario B2 Nature is clearly dominated by Cluster 4.

4. Discussion

4.1. Agricultural abandonment tradeoffs

The objective of this paper was to characterize the spatial diversity in trade-off bundles of potential agricultural abandonment areas for the European Union (EU-27). Using three different scenarios, we assessed the contrasting options and underlying processes of agricultural abandonment and its future development. By developing a typology of areas characterized by similar trade-offs of abandonment, we identified regions that are facing similar management challenges and opportunities in the coming decades.

Similarly to previous European land use predictions, such as by the Scenar 2020 and EURURALIS projections, the highest levels of abandonment are expected for scenarios that anticipate global competition in agriculture and low CAP support for extensive farming (Keenleyside and Tucker, 2010). Here, agricultural abandonment is the effect of intensification of suitable arable land, with marginal and unsustainable economic areas becoming abandoned. Scenario B2 also shows agricultural abandonment although the abandonment is tempered by CAP measures to a certain degree. For the B2 Nature scenario, abandonment is mainly the result of enhanced nature protection policies that restrict the possibilities for agricultural land and subsequently influences land prices, leading to a reduced demand for pasture and arable land when compared to the B2 scenario. In spite of the different processes, the spatial patterns show an overall similarity with mostly regional differences. The cluster analysis reveals that impacts of agricultural abandonment based on the different indicators are location dependent. The analysis further shows that a majority of abandonment locations is characterized by the potential losses of agricultural production with only limited potential for carbon sequestration due to unfavorable conditions for quick forest succession at many locations of agricultural abandonment.

4.2. Methodological issues

In general, trade-offs and synergies between different spatial land management impacts can occur over time, across different spatial scales and with varying reversibility (Rodriguez et al., 2006). Our results clearly show spatial patterns in the occurrence of different trade-offs, but an analysis based on different units (e.g. higher administrative or ecological units) could therefore result in a different outcome. This is caused by the scale-sensitivity of the input variables and agricultural abandonment impacts (e.g. Spiegelberger et al., 2006; Rey Benayas et al., 2007), as well as the additional information linked to certain analysis units (e.g. culturally influenced administrative boundaries; see Raudsepp-Hearne et al., 2010). Assessment of the interactions between the different impacts was not the focus of this study. Furthermore, the feedbacks between different indicators (e.g. forest fire vulnerability, alien species risk) and the process land use change is not addressed in our modeling approach. It is important, however, to underline that environmental responses, ecosystem services and land use changes are not independent of each other and that there are multiple mechanisms that can lead to certain trade-offs (Rodriguez et al., 2006).

For the trade-off analysis, we have chosen to focus on indicators that were on the forefront of the agricultural abandonment debate.

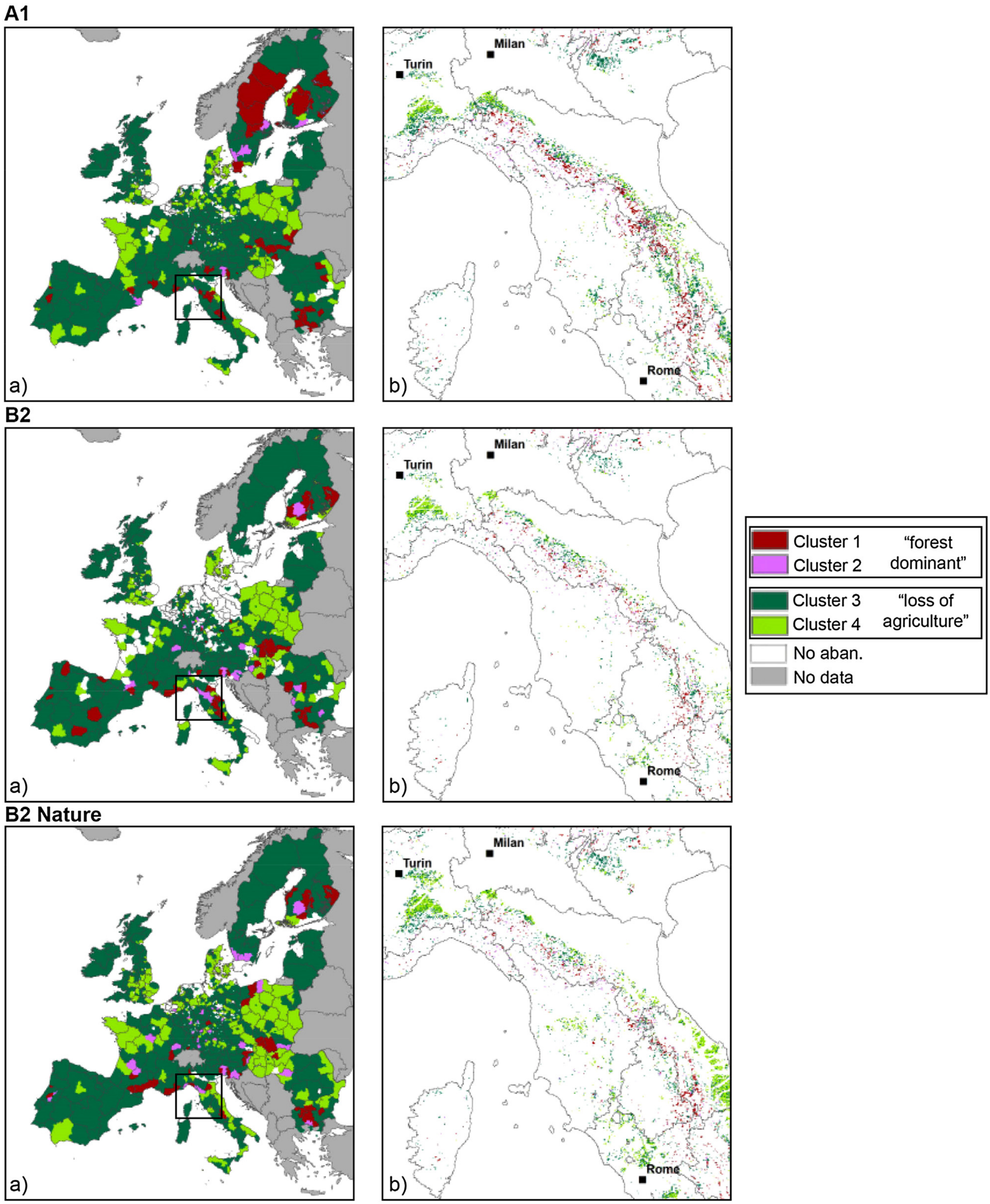

Fig. 5. a): Dominant clusters per NUT3 region for the A1, B2 and B2 Nature scenario. b): zoom in on the cluster patterns on a pixel (1 km^2) level.

However, there are several other indicators that are also influenced by agricultural abandonment and that are worth investigating. These include, among others, erosion and soil stability (Lesschen et al., 2008; MacDonald et al., 2000), cultural values beyond heritage (Agnoletti, 2014; Antrop, 2005) and freshwater quantity and quality (Rey Benayas et al., 2007; Cerqueira et al., 2015).

A main factor affecting the quality of the analysis is the quality and quantity of the data used. For the land use predictions, previous studies have indicated that robust spatial patterns can be obtained despite the inherent uncertainty and have further investigated the error and uncertainty for these linked modeling systems (Verburg et al., 2013b; Dunford et al., 2014). The accuracy of the models within the impact assessment is varied, depending on the available models and data. To account for a sufficient data quality, we have chosen to use indicators that have been previously published if available, while noting that all available proxies and indicators are strongly simplified from the underlying ecological and socio-economic processes given the large extent of analysis. While most of the models used within the impact assessment are independent, the indicators for cultural heritage and farmland species richness both include a similar underlying mechanism (i.e. nitrogen input), which is based on a comparable input dataset in both models. Therefore, autocorrelations might occur between these indicators. As we have combined different data types with different degrees of spatial explicitness and different levels of precision, the resulting outcome has errors which cannot easily be quantified, an issue acknowledged in comparable proxy-based studies (Eigenbrod et al., 2010). Specific limitations exist for the cultural heritage indicator, as cultural values such as cultural heritage are difficult to incorporate in large-scale spatial assessments (Daniel et al., 2012). While we argued that traditional agricultural landscapes represent an important class of cultural landscapes that includes different cultural elements, cultural heritage is a broader concept that also could be presented by specific remnants or cultural landscapes outside of agriculture (Tengberg et al., 2012; Daniel et al., 2012).

4.3. Implications

Coping with agricultural abandonment and rural depopulation is an important European policy challenge (Pinto-Correia and Breman 2008; FAO, 2006a,b). The discussion on the appropriate policy response to agricultural abandonment is clearly linked to the global discussion on the optimal spatial organization of land uses that could maximize carbon sequestration, biological conservation and food production in multifunctional landscapes (e.g. Wilson 2007; Phalan et al., 2011) and the recent focus on outlining the components that would inform decisions about optimal land uses (Rudel and Meyfroidt, 2014; Seppelt et al., 2013). Several authors have stated that rural depopulation and agricultural abandonment may provide opportunities to reconfigure land use and implement sparing strategies, aimed at a spatial separation of intensive agriculture and natural areas in many areas, at lower social costs (Grau et al., 2013; Navarro and Pereira, 2015). In our study we show that, at least for some regions, such a strategy may have negative impacts.

Different factors have influenced the agricultural landscapes in Europe and subsequent policy challenges, with a large role of the Common Agricultural Policy (CAP). The current orientation of the CAP has changed from a production focus to an increased focus on environmental concerns and land stewardship incentives (Lowe et al., 2002; Burton and Schwarz, 2013). Consequently, areas that are sensitive to agricultural abandonment are covered by a combination of different policies. Besides rural subsidies (single farm payments) and land management incentives (agri-environmental schemes), specific policies focus on local needs. For instance, 92% of EU mountain regions are designated as Less Favoured Area, of which 43% is a Natura 2000 protect area and 51% is defined as High Nature Values Farmland (EEA, 2010). Despite the CAP support towards agriculture and rural development, including measures to manage and support extensive and high-value farmland, rural depopulation is currently not adequately halted and the decrease of GDP and employment based on agriculture is predicted to increase even further (Navarro and Pereira 2015; Nowicki et al., 2007).

A better targeting and improved integration of current EU policies and management strategies regarding agricultural landscapes is therefore vital and has been identified as a current shortcoming (Baylis et al., 2008; Burton and Schwarz 2013; EEA, 2010). Targeting, which means appropriate objective setting and instrument provision, has been limited to a focus on geophysical conditions and environmental threats to sensitive areas (Piorr et al., 2009). Poor targeting and a lack of payment differentiation are important factors related to the ineffectiveness of current rural development projects and agri-environmental schemes (Marsden and Sonnino, 2008; Young et al., 2005; Moxey and White, 2014).

Analysis of the trade-offs between different conservation and management objectives can be a useful step towards the strategic achievement of multiple objectives (Karp et al., 2015). The identified areas of comparable abandonment impact can help in connecting areas that are facing similar management challenges and provide a first guideline to target policies and determination of the 'optimal use'. It may help to target which areas benefit most from biological conservation efforts, passive or mild levels of intervention associated with rewilding, or the stimulation of traditional farming systems and rural development (Grau et al., 2013; Nijsen et al., 2012; Lomba et al., 2014). In the presented trade-off analysis all indicators of impacts are given an equal weight. Depending on values, norms and interests of the local population and policy targets, a weighting of the considered impacts could be applied for delineation of areas with relevant management challenges.

Frameworks for land management at a landscape scale could help achieve more cost effective management to deliver different targets (Henle et al., 2008). For instance, current agri-environmental schemes do not encourage landscape level coordination while it is suggested that this is economically more efficient than a farm level approach (Prager and Freese, 2009; Wünscher et al., 2008; Van Zanten et al., 2013). Part of a targeting approach could include wilderness regulation/rewilding as land management option, including zonation with different levels of protection and intervention (Navarro and Pereira 2015). In this regard, rewilding can be seen as a particular case of restoration that can contribute to achieve specific carbon sequestration and biodiversity goals, especially regarding large mammals and old-forest specialists (Navarro and Pereira 2015; European Commission 2013), and potentially increase the ecological coherence and connectivity of protected areas in the EU. Both directions of the targeting approach, either a focus on rural development or rewilding, are not regionally incompatible, as passive management and rewilding of abandonment can be spatially and functionally compatible on a larger regional scale (Lomba et al., 2014; Merckx and Pereira, 2014).

Overall, our results indicate that location is key in assessing the impacts of agricultural abandonment for the European Union. The results confirm that agricultural abandonment can have both negative and positive consequences, for instance, while abandonment of certain areas has carbon sequestration and habitats for large mammals as a positive consequence, this is in other places accompanied with large losses in, among others, cultural heritage landscapes and crop share. We therefore argue that the discussion on agricultural abandonment should focus more on this spatial diversity and target at context-dependent, nuanced policy and management strategies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2017.01.003.

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