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Mapping and modelling past and future land use change in Europe's cultural landscapes

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ABSTRACT

Cultural landscapes are valued for their landscape character and cultural heritage. Yet, these often low-intensity, multifunctional landscapes are at risk of disappearance. Understanding how cultural landscapes might change under alternative futures is important for identifying where to target actions towards persistence of cultural landscapes. This study therefore aims to identify past and future land use changes in the European Union's (EU's) cultural landscapes. To do so, we overlay past and projected plausible future land change trajectories with the spatial distribution of cultural landscapes in the EU. Our results highlight a clear co-occurrence of specific land change trajectories and cultural landscape types. Past and future urbanization and agricultural abandonment are the land use change processes most strongly affecting small-scale, low-intensity agricultural landscapes that are valued by society. De-intensification is overrepresented in landscapes with a low management intensity. Past intensification was overrepresented in small-scale landscapes with a high value to society, while future intensification might concentrate on landscapes with a low intensity. Typical cultural landscapes show a strong variation of changes under different scenario conditions in terms of future landscape change. Scenario analysis revealed that some of the threats to cultural landscapes are related to agricultural policies, nature policies and other spatial restrictions. At the same time, these policies may also alleviate these threats when properly designed and targeted by accounting for the impacts they may have on cultural landscapes. Considering cultural landscapes more directly in decisions to be made for the post-2020 Common Agricultural Policy period is needed, and could be achieved by a focus on landscape quality beyond the current focus on specific greening measures.

1. Introduction

For centuries, humans have shaped landscapes by utilising ecosystem services for the sustenance of societies. Both conversion of land cover and changing management intensity influence the functioning of ecosystems (Brandt et al., 2017), their biodiversity (Donald et al., 2002), and the services they provide to society (Palacios-Agundez et al., 2015). In many places around the world, current landscapes are thus substantially different from landscapes without human influence. Cultural landscapes, i.e. landscapes that have evolved from this long history of interactions between people and the landscape (Agnoletti, 2014; Plieninger et al., 2014), are cherished and valued for their unique landscape character and cultural heritage, and for providing sense of place and inspiration (Brown and Raymond, 2007; Szücs et al., 2015).

In Europe, cultural landscapes are of particular importance. The long history of human influence and the large environmental, political, and socio-economic heterogeneity has resulted in the variety of typical landscapes that Europe is known for (Jepsen et al., 2015; Vos and Meekes, 1999). These landscapes are mostly characterized by low-intensity, multifunctional land use. Yet, the global competitiveness of agriculture is believed to trigger polarization of land use, with intensification on productive and accessible areas and de-intensification and abandonment in less productive and more remote areas (Van Vliet et al., 2015). Such land changes pose threats to cultural landscapes by e.g. removing characteristic landscape elements upon scale enlargement or their deterioration by lack of management (Kizos and Koulouri, 2006). Urbanization and extraction of non-renewable resources changes landscapes completely, while also expansion of protected

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nature areas can lead to a loss of characteristic landscape structures (Plieninger et al., 2016). Global societies' demand for food, biomass, and nature protection therefore conflicts with the benefits Europeans enjoy from cultural rural landscapes (Almeida et al., 2016).

Understanding how cultural landscapes may change under alternative futures is important for identifying where to target actions towards persistence of cultural landscapes (Fischer et al., 2012). Although the European Landscape Convention (ELC) calls for identifying cultural landscapes and taking note of their changes (Council of Europe, 2000), no landscape policies at European Union (EU) level exist and policies impacting the landscape are segregated in different sectoral policies. Additionally, the information required for the aim of the ELC is largely lacking. At a European scale, there is insight in long-term (McGrath et al., 2015) and short term (Levers et al., 2015) historical changes in land use. In addition, future projections of land use and land cover exist for Europe. These are however not yet used to understand changes in the cultural heritage value of European landscapes. Linking past and future land changes with patterns of cultural landscapes enables assessing how cultural landscapes may evolve in the future, understanding possible path dependency, and identifying potential future threats to cultural landscapes caused by land change.

This study aims to identify the impacts of past and future land use and land cover changes on the EU's cultural landscapes. To do so, we used existing data on past (Levers et al., 2016) and existing simulations of predefined future archetypical land change trajectories (Stürck et al., 2015) (spatially explicit characterization of a temporal trajectory of land changes; (Zomlot et al., 2017)) to assess how land use and land cover change between 1990 and 2040 affect different types of cultural landscapes. We ask the following research questions:

1 Where and how does the occurrence of past and projected future land change overlap with cultural landscapes?
2 Where are hotspots of spatial concordance between archetypical land change trajectories and cultural landscapes, and do these hotspots persist over time?

2. Data and methods

2.1. Overview

We compared existing spatially-explicit data of past land change trajectories and simulations of future land change trajectories with the spatial distribution of cultural landscapes in the EU (Fig. 1). We first harmonized historic land change maps and future land change projections into a common classification (Section 2.2). Next, we calculated the spatial co-occurrence between land change and cultural landscapes and compared hotspots of past and future land change with the distribution of cultural landscapes (Section 2.3). Finally, we identified the spatial overlap between past and future change trajectories to analyse the continuity of land change trajectories (Section 2.3).

2.2. Input data and harmonization

2.2.1. Spatial distribution of cultural landscapes

Cultural landscapes can be understood as landscapes primarily shaped by human use (Plieninger and Bieling, 2012), or landscapes that "have a distinct and recognizable structure which reflects clear relations between the composing elements and having significance for natural, cultural, or aesthetical values" (Antrop, 1997). Despite the myriad definitions available (Jones, 2003), cultural landscapes are frequently described by three dimensions: (a) management intensity; (b) landscape structure; and (c) value and meaning of the landscape to society (Plieninger and Bieling, 2012). We here use a cultural landscape map by Tieskens et al. (2017) who mapped the spatial distribution of cultural landscape types in the EU based on these dimensions. Management intensity was mapped based on the economic farm size and nitrogen input (in arable land and grassland) or harvest intensity (in forests and permanent crops). Landscape structure was mapped based on field size and the density of green linear elements (agricultural areas) or age (forests). Value and meaning was mapped based on the density of Panoramio pictures and the density of Protected Designations of Origin (PDOs) for both agricultural and forested areas (Tieskens et al., 2017). Each of the three dimensions was converted to a single, continuous indicator map, scaled from 0 (low) to 100 (high). A landscape typology was then derived by classifying whether each dimension was above or below the median indicator value, and by identifying co-occurrence of two or three dimensions (Fig. S2; Supplementary material).

2.2.2. Past land changes

To assess past land changes across Europe, we used an existing 3-km resolution map of Archetypical Change Trajectories (ACTs) for the time period 1990 to 2006 (Levers et al., 2015). This map builds upon changes of 12 indicators representing the extent and intensity of broad land use categories that were clustered using Self-Organizing Maps. Land use extent was represented by the spatial extent of cropland, grazing land, forested areas, and built-up areas, as derived from CORINE land cover and corrected with CAPRI statistics (Plutzar et al., 2015). Land use intensity was represented by nitrogen fertilizer application (Temme and Verburg, 2011), livestock units (Neumann et al., 2009), crop yields, grassland yields (Plutzar et al., 2015), and wood production (Verkerk et al., 2015). The resulting ACTs (Fig. S2; Supplementary material) reflect area changes, intensity changes, or land change processes that combined area and intensity changes.

2.2.3. Future land changes

We used existing maps of future land change trajectories (Stürck et al., 2015) from a scenario study on future changes in Europe's rural areas, performed within the VOLANTE FP7 project (www.volante-project.eu). The scenarios are organized along axes of contrasting global (indicated as 1) and regional (2) development, and low (A) versus high (B) levels of governmental intervention (Verkerk et al., 2017). This setup results in four scenarios that explore potential future developments in the EU's rural areas under combined socio-economic and policy conditions: Libertarian Europe (A1), Eurosceptic Europe (A2), Social Democracy (B1), and European Localism (B2). Land use changes were simulated with a series of macro-economic (REMIND, MagPIE, CAPRI), sectoral (EFI-GTM, EFISCEN), and land use allocation (Dyna-CLUE) models. First, population growth, trade patterns, food and bioenergy demands were used to simulate regional land demands. Second, land demands were disaggregated into 1 km^2 land use maps. Here, Dyna-CLUE simulates competition between land use/cover types, based on empirical relations between current land use/cover patterns and underlying biophysical and socio-economic variables, such as soil suitability, elevation, climate conditions, and accessibility. These are combined with spatial restrictions or incentives that are scenario dependent, and decision rules that define to what extent specific land conversions are likely (Verburg and Overmars, 2009). Region- and product specific yields and fertilizer use resulting from CAPRI simulations were downscaled into intensity maps. Forest intensity was mapped through wood removals that were downscaled based on tree species maps and harvest likelihood maps (Verkerk et al., 2015).

Land changes were summarized into fourteen future land change trajectories (FCTs) that represent well-known and significant land change trends in Europe. FCTs are defined based on decreasing or increasing human impact on the landscape, and the scale of the impact, ranging from local to regional scale (Stürck et al., 2015) (Example in Fig. 2, all four maps included as Supplementary material).

2.2.4. Harmonization of land change trajectories

Although the ACT and FCT maps broadly describe similar land change trajectories and both are based on CORINE land cover

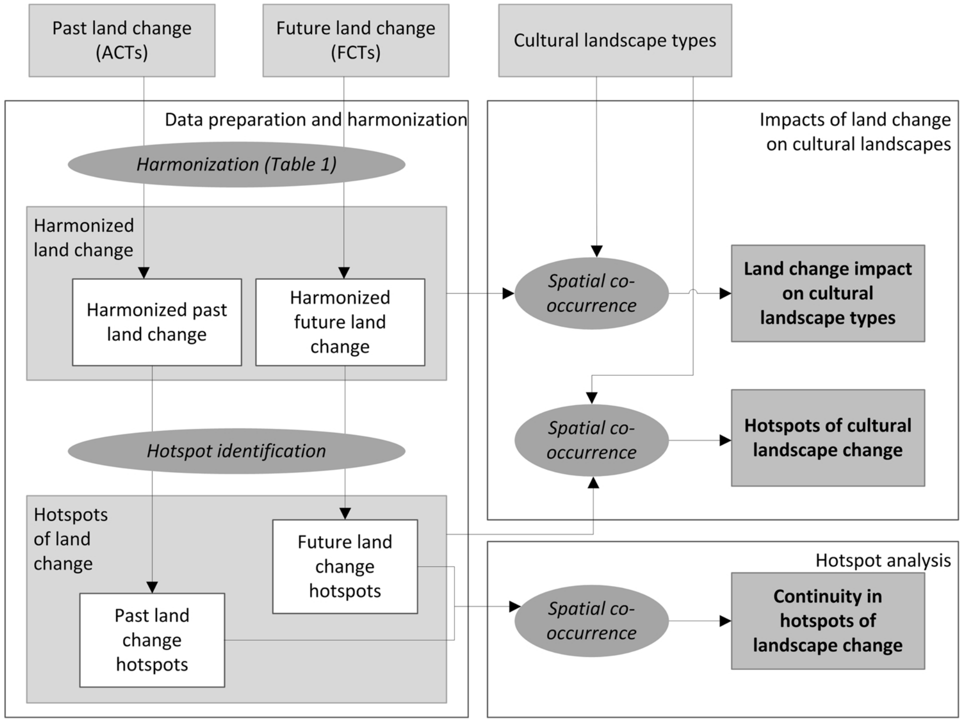

Fig. 1. Overview of the approach for analysing co-occurrence of land change trajectories and cultural landscapes. ACT = Archetypical change trajectory; FCT = Future change trajectory.

(European Environmental Agency, 2015), they differ in the exact definitions, resolution, and spatial coverage. The ACT map compares observations of past land cover and a wide range of land use intensity indicators derived from statistical data, where nitrogen application is a common intensity indicator between the ACT and FCT maps. FCTs focus on hotspots of land change, while ACTs also cover smaller, dispersed areas. The cultural landscape typology only considers agricultural and forest areas, resulting in areas with No-Data values, mostly covering current inland water and urban areas.

To compare the different maps, we resampled the ACT map to 1-km resolution, matching the resolution of the FCT map and the cultural landscape map. We then reclassified ACT and FCT maps into consistent harmonized change trajectories (HCTs): Urbanization, Agricultural intensification, Agricultural de-intensification, Agricultural abandonment, Agricultural expansion, Forestry intensification, and Stability (elaboration in Table 1). When analysing land use changes between the broad classes agriculture and forest, we interpret forest expansion as agricultural contraction and forest loss as agricultural expansion.

2.3. Impacts of land change on cultural landscapes

To quantify the amount of cultural landscape change, we compared the observed spatial co-occurrence of cultural landscape types with HCTs to the expected spatial co-occurrence. This gives an indication on the over- or underrepresentation of an HCT within a cultural landscape type. As some HCTs cannot occur on some land areas or cultural landscape types, assessing overall area changes would provide a skewed picture whereas assessing over- or underrepresentation indicates to what extent HCTs cluster in specific landscapes. We defined the expected co-occurrence between a cultural landscape type and an HCT following Eq. (1). We calculated over- or underrepresentation of an HCT within a cultural landscape type by dividing the observed overlay by the expected overlay. Values larger than one indicate overrepresentation and values smaller than one indicate underrepresentation.

$$\text{Expected Overlay}_{CLa,\ HCTz} = (\text{Area}_{CLa} \text{ x } \text{Area}_{HCTz}) \ / \ \text{Total area considered} \quad (1)$$

Location and extent of the simulated future land change trajectories can differ among the scenarios, resulting in different impacts on cultural landscapes. We analysed to what extent impacts of future land change on cultural landscapes were scenario dependent. First, we mapped where each future HCT is expected to occur in all four scenarios, or in 1–3 of the scenarios. Next, we calculated the amount of spatial co-occurrence with cultural landscapes. We did this separately for scenario-independent land change (occurring in all scenarios) and scenario-dependent land change (occurring in 1–3 scenarios).

To analyse spatial patterns of cultural landscape change, we mapped hotspots of each HCT in cultural landscapes. We calculated the occurrence density of the HCT in a 15 km radius, to ensure consistency with Stürck et al. (2015). Next, we selected the top 25% quantiles as hotspots. We visually compared the spatial co-occurrence of the HCTs with the cultural landscape types to assess where across the European territory specific HCTs are simulated to affect different cultural landscapes. We distinguished between FCTs occurring in all scenarios and FCTs occurring in 1 up to 3 scenarios.

Finally, we analysed how the location of land change hotspots differs between the past and the future. This was done by mapping the spatial co-occurrence of hotspots of past land change and hotspots of future land change.

3. Results

3.1. Past land changes

Between 1990 and 2006, approximately 40% of the EU's land area was characterised by stable land systems. De-intensification occurred at approximately 30% of the land area, intensification covered approximately 20% of the EU's surface. On agricultural areas, changes in intensity dominated, while changes of land cover were dominant for forests.

Urbanization, agricultural expansion, and forest intensification are significantly concentrated on specific cultural landscape types (Table 2;

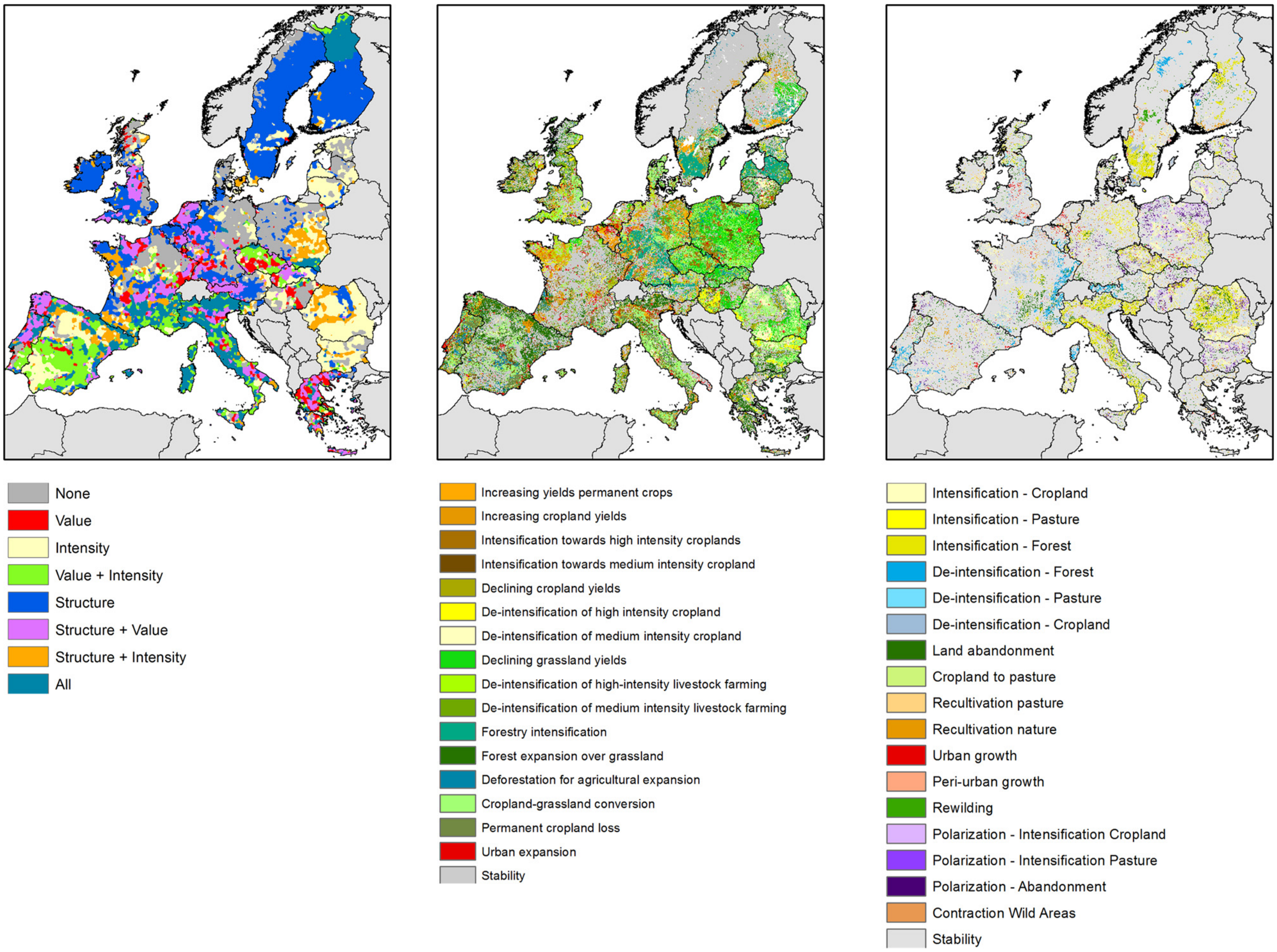

Fig. 2. Input maps. Left: Cultural landscape types (Based on Tieskens et al. (2017)). Centre: Past land change trajectories (Based on Levers et al. (2015)). Right: Example of future land change trajectories for a scenario assuming globalization and a low level of governmental intervention. Based on Stürck et al. (2015). Full-size versions of the input maps, including future land change trajectories for all scenarios, can be found in the supplementary material. GIS data of the cultural landscape map and future change trajectories maps are downloadable from www.environmentalgeography.nl. GIS data of the past change trajectories map is available on request.

Table 1
Description of archetypical change trajectories (ACTs) over 1990–2006, future change trajectories (FCTs) over 2000–2040, and harmonization into comparable harmonized change trajectories (HCTs).

Harmonized change trajectory		ACTs included	FCTs included[a]
1.	Urbanization	ACT16 Urban expansion	FCT11 Urbanization FCT12 Peri-urbanization
2.	Agricultural intensification	ACT01 increasing yields in permanent crops ACT02 increasing cropland yields ACT03 Intensification towards high-intensity cropland ACT04 intensification towards medium intensity cropland	FCT01 intensification cropland FCT02 Intensification pasture FCT09 Recultivation pasture
3.	Agricultural de-intensification	ACT05 Declining cropland yields ACT06 De-intensification of high-intensity cropland ACT07 De-intensification of medium intensity cropland ACT08 declining grassland yields ACT09 de-intensification of high-intensity livestock farming ACT10 de-intensification of medium intensity livestock farming ACT14 cropland to grassland conversion	FCT05 de-intensification pasture FCT06 de-intensification cropland FCT08 cropland to grassland conversion
4.	Agricultural abandonment	ACT12 Forest expansion over grassland ACT15 Permanent cropland loss	FCT07 Abandonment
5.	Agricultural expansion	ACT13 Deforestation for agricultural expansion	FCT10 Recultivation nature
6.	Forestry intensification	ACT11 Forestry intensification	FCT03 Forestry intensification
8.	Stability	ACT17 Stability	FCT20 Stability

[a] FCTs 14–16 (Polarization; occurrence of intensification and abandonment in each other's vicinity) are highlighted separately. Data on forestry de-intensification (FCT04) was only available from future simulations and therefore not harmonized into an HCT.

Table 2
Over / underrepresentation of harmonized change trajectories (HCTs) occurring over 1990–2006 in cultural landscape types. Values < 1 indicate that a HCT is underrepresented on a cultural landscape type; values < 1 indicate overrepresentation.

Cultural landscape type as defined by cultural landscape dimensions	Harmonized Change Trajectory							Occurrence of cultural landscape type (% of total forest / agricultural area)
	Urbanization	Agricultural intensification	Agricultural de-intensification	Agricultural abandonment	Agricultural expansion	Forestry intensification	Stability	
	Forest							
None	0.63					1.12	0.97	***19%***
Value/Meaning	4.94					1.25	0.84	***6%***
Intensity	1.42					0.36	1.17	***6%***
Intensity and Value/ Meaning	2.96					0.08	1.21	***8%***
Persistence	0.13					1.24	0.95	***37%***
Persistence and Value/ Meaning	1.51					2.31	0.63	***8%***
Persistence and Intensity	0.33					0.48	1.16	***5%***
Value/Meaning, Intensity, and Persistence	0.65					0.16	1.24	***10%***
Occurrence of HCT (% of total forest area)	***2%***					***21%***	***77%***	
	Agriculture							
None	0.39	1.14	1.01	0.97	0.29		1.03	***20%***
Value/Meaning	1.28	1.30	0.77	1.07	1.67		1.08	***6%***
Intensity	0.42	0.66	1.30	0.97	0.40		0.84	***24%***
Intensity and Value/ Meaning	0.89	0.84	0.89	1.47	3.07		0.78	***10%***
Structure	1.30	1.34	0.86	0.59	0.67		1.35	***14%***
Structure and Value/ Meaning	2.44	1.21	0.84	0.81	1.51		1.13	***8%***
Structure and Intensity	0.96	1.07	1.04	0.89	0.62		1.02	***10%***
Value/Meaning, Intensity, and Structure	2.22	0.75	0.75	1.56	2.07		0.85	***8%***
Occurrence of HCT (% of total agricultural area)	***2%***	***11%***	***37%***	***21%***	***1%***		***27%***	

Supplementary material Table S2). In agricultural areas, urbanization is overrepresented in landscapes with a small-scale structure and high value/meaning to society. This is most obvious in the Netherlands, Belgium, and Portugal (Fig. 3). Urbanization is also overrepresented in landscapes where all three cultural landscape dimensions occur. Particularly in southern France and Italy, these cultural landscapes are strongly affected by urbanization. Urbanization particularly occurs in those forested areas that either have a high value/meaning to society or that are extensively managed. Agricultural expansion is overrepresented in landscapes with low-intensity management and a high value/meaning, as well as in landscapes where all three cultural landscape dimensions occur. Especially Spain and Portugal stand out (Fig. 3). Landscapes with low-intensity management and landscapes with low scores on all cultural landscape dimensions are hardly affected by agricultural expansion. Forest intensification is concentrated in central Europe, where it mostly affects forests that have been persistent over the past century and have a high value/meaning (Fig. 3).

3.2. Future land changes

3.2.1. Quantity of future land change

Overall, between 22% (scenario B2) and 27% (scenario B1) of EU's agricultural area is expected to change until 2040. The most widespread changes expected in agricultural land are cropland intensification (affecting 10–15% of EU's agricultural land), and polarization (4-8%). In forests, we project between 23% (A2) and 30% (B2) of the area to change. The most widespread change expected is intensification, affecting 17-25% of EU's forest. De-intensification is expected in 3-4% of the EU's forest area (Table 3).

In different scenarios, very different impacts on agricultural areas with low-intensity management are projected (Table 3). Contrarily, small-scale agricultural landscapes and/or landscapes characterized by their value/meaning differ less in the amount of change among the different scenarios (Fig. S4; Supplementary material). In extensively managed forests with a high value/meaning, simulated land changes are strongly different between the scenarios. This also applies for forests that score high on all cultural landscape dimensions (Fig. 4). Extensively managed forests (both non-persistent and persistent over time) show the opposite: We expect large areas to be affected by land changes that occur at the same location in all scenarios. Most importantly, these forests are expected to intensify.

3.2.2. Impacts of future land change on cultural landscapes

Future urbanization, agricultural expansion and contraction, and forest intensification could have a significantly different impact on different cultural landscape types (Table 3; Supplementary material Table S3–S6). Projected urbanization in agricultural land is overrepresented in small-scale landscapes and/or landscapes with a high value/meaning, and in landscapes that unite all cultural landscapes dimensions (Table 3). In forests, future urbanization clusters in extensively managed forest and/or forests with a high value/meaning.

Abandonment is projected to be overrepresented in landscapes with low-intensity management, particularly in those areas with low-intensity management that also have a high value/meaning (Table 3). This is apparent in Portugal and south-eastern Europe (Fig. 3). Agricultural landscapes that score high on more than one cultural landscape dimensions are expected to face more abandonment, and the widespread differences of amounts of abandonment among the scenarios

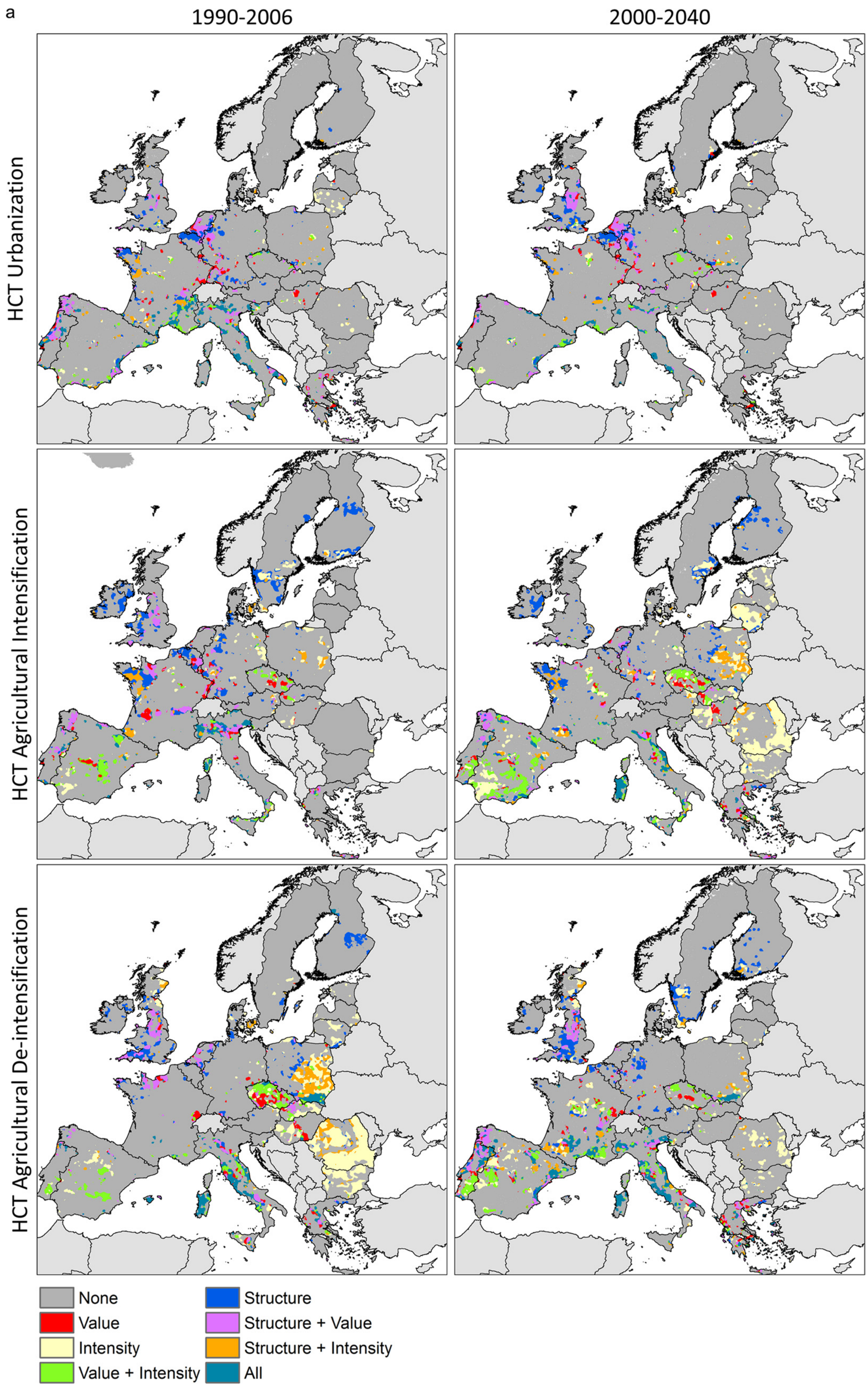

Fig. 3. (a) Overlap between HCTs and cultural landscape types. Left panels display ACTs; right panels display FCTs. Light grey countries are not considered. (b) (Continued): Overlap between HCTs and cultural landscape types. Left panels display ACTs; right panels display FCTs. Light grey countries are not considered.

suggest a large uncertainty in the impact of future abandonment (Fig. 4).

In agricultural land, we expect the lowest level of stability in low-intensity areas, and land change scenarios exhibit the largest future uncertainty in low-intensity areas (Fig. 4). Most importantly, wide-spread intensity changes are expected. Intensification could affect around 20% of low-intensity agricultural lands, while de-intensification could occur on 5% of the area. In forests, the historically persistent

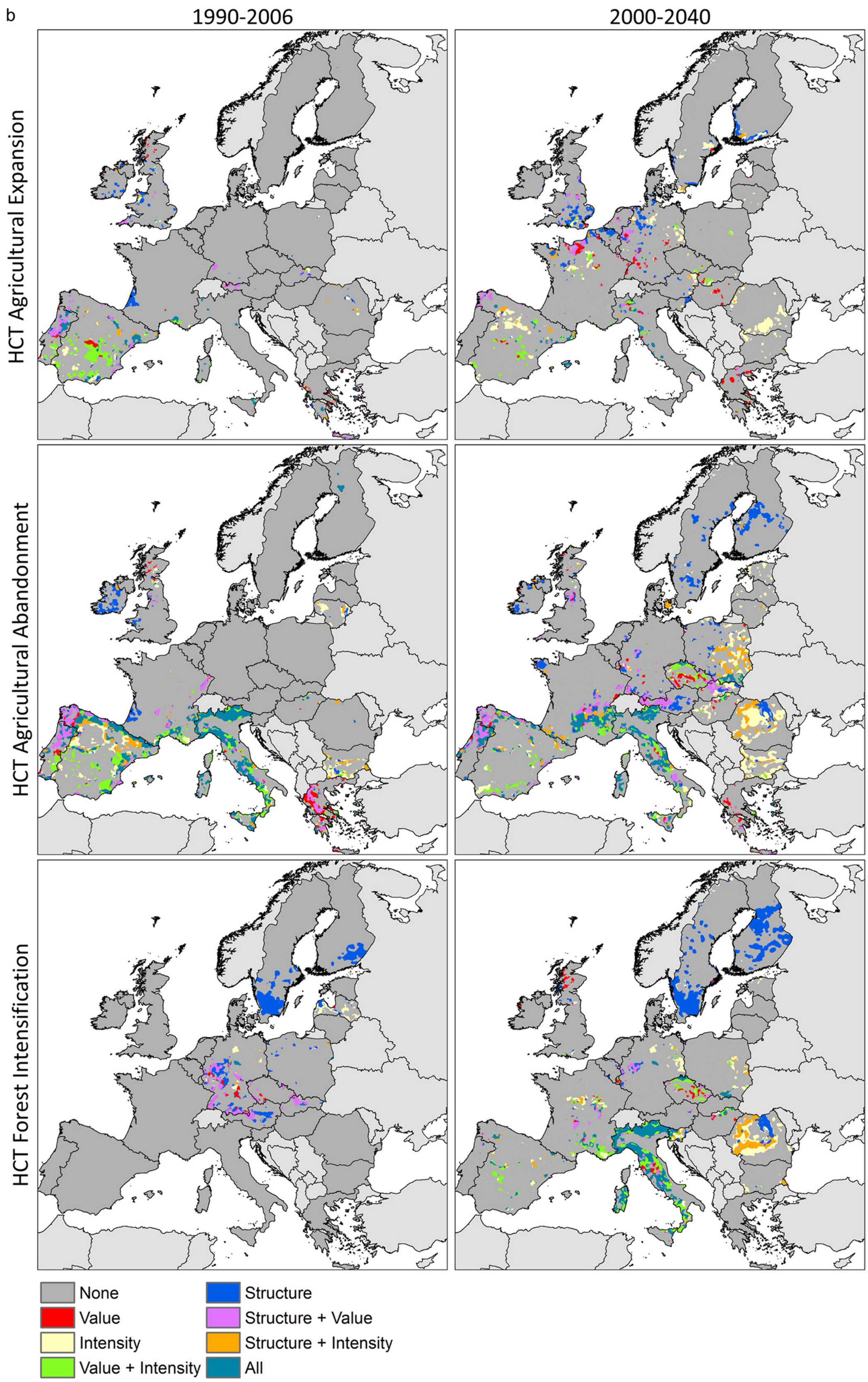

Fig. 3. (*continued*)

Table 3
Over / underrepresentation of harmonized change trajectories (HCTs) occurring over 2000–2040 in cultural landscape types. Values < 1 indicate that a HCT is underrepresented on a cultural landscape type; values < 1 indicate over-representation. Dark grey shaded cells are overrepresented compared in all scenarios, light grey shaded cells in 1–3 scenarios.

Cultural landscape type as defined by cultural landscape dimensions	Urbanization	Agricultural intensification	Agricultural de-intensification	Agricultural abandonment	Agricultural expansion	Forestry intensification	Forestry de-intensification	Stability	*Occurrence of cultural landscape type (% of total forest / agricultural area)*
	Harmonized Change Trajectory								
Forest									
None	0.60					0.70	0.88	1.10	*19%*
Value/Meaning	4.15					0.81	1.81	1.01	*8%*
Intensity	1.57					1.63	0.29	0.84	*8%*
Intensity and Value/Meaning	2.37					1.18	1.12	0.92	*10%*
Persistence	0.14					0.82	0.65	1.07	*30%*
Persistence and Value/Meaning	1.14					0.76	2.06	1.03	*8%*
Persistence and Intensity	0.28					2.03	0.29	0.74	*6%*
Value/Meaning, Intensity, and Persistence	0.28					1.10	1.53	0.94	*11%*
Occurrence of HCT (% of total forest area)	*0%*					*22%*	*3%*	*74%*	
Agriculture									
None	0.52	1.10	0.69	0.47	1.35			1.03	*20%*
Value/Meaning	1.43	0.54	0.77	0.94	2.41			1.05	*7%*
Intensity	0.39	1.71	1.10	1.21	1.22			0.90	*23%*
Intensity and Value/Meaning	1.04	0.86	1.22	1.84	1.87			0.96	*9%*
Structure	1.30	0.71	0.80	0.42	0.49			1.07	*15%*
Structure and Value/Meaning	2.35	0.42	0.90	0.84	0.21			1.07	*9%*
Structure and Intensity	0.88	0.95	1.31	1.29	0.23			0.99	*10%*
Value/Meaning, Intensity, and Structure	1.61	0.51	1.55	1.73	0.12			1.00	*8%*
Occurrence of HCT (% of total agricultural area)	*1%*	*10%*	*6%*	*3%*	*1%*			*79%*	

forests that are extensively managed would face the most widespread change. Particularly in Romania, these forests are expected to face widespread intensification.

3.3. Continuity of land change trajectories

In many parts of the EU, location and extent of urbanization are highly continuous over time. For example, continuous urbanization over the 1990–2040 period occurs in the Netherlands, Flanders, the Ruhr area, the Mediterranean coastal areas, and England. Elsewhere in the Mediterranean, past urbanization trends are expected to be discontinued in the future (Fig. 5). New urbanization hotspots are expected to occur in the United Kingdom and in the vicinity of major eastern European cities. As a result, impacts of urbanization on landscapes that unite all features of cultural landscapes are expected to decrease (Fig. 3).

There is a clear distinction between observed recent intensification in the northern, central, and western zone of Europe and simulated future intensification in the east. This makes impacts of intensification shift away from small-scale landscapes to landscapes with low-intensity management. Ongoing agricultural intensification is mainly expected in Eastern Germany, Poland, and the Czech Republic and a few areas in eastern and southern Europe (Fig. 5). De-intensification follows opposite patterns (Fig. 5). Continuity of agricultural expansion is very limited, while some continuous abandonment is likely in the Alps and in southern Europe. Expansion is expected to shift from southern to northern Europe, while abandonment is expected to shift from southern to eastern Europe.

4. Discussion

4.1. Continuity and trend breaks in cultural landscape change

Among the different past and future land change trajectories, urbanization and agricultural abandonment strongly affect European landscapes that adhere to the most common understanding of cultural landscapes (extensive, characteristic structure, and with a high value/meaning). The results of our analysis suggest that cultural landscapes are particularly sensitive to differences between the scenarios. Differences between the scenarios in terms of affected area and type of land use change are larger in cultural landscapes as compared to other landscapes. This indicates a high uncertainty and dependence on future societal developments and policies for the development of these strongly appreciated cultural landscapes.

General trends of urbanization are influenced by demographic trends and economic growth. As population trends and economic growth are assumed to be fairly continuous over the 1990–2040 time period, urbanization is also expected to be strongly continuous over time (Maes et al., 2014). In all scenarios, accessibility from existing urban centres is an important factor explaining locations of urban spread, which explains why urbanization affects small-scale agricultural landscapes and landscapes with a high value/meaning. Small-scale landscapes with a high density of hedgerows are common in easily accessible areas (Baudry et al., 2000) and landscapes with a high value/meaning are partly defined using Panoramio photo densities, which are strongly influenced by accessibility. Exactly these landscapes are at risk of conversion. Studies on recent changes in landscape structure in Slovakia and the United Kingdom show similar trends (Pazúr and Bolliger, 2017; Petit et al., 2003). At the same time, expansion of urban

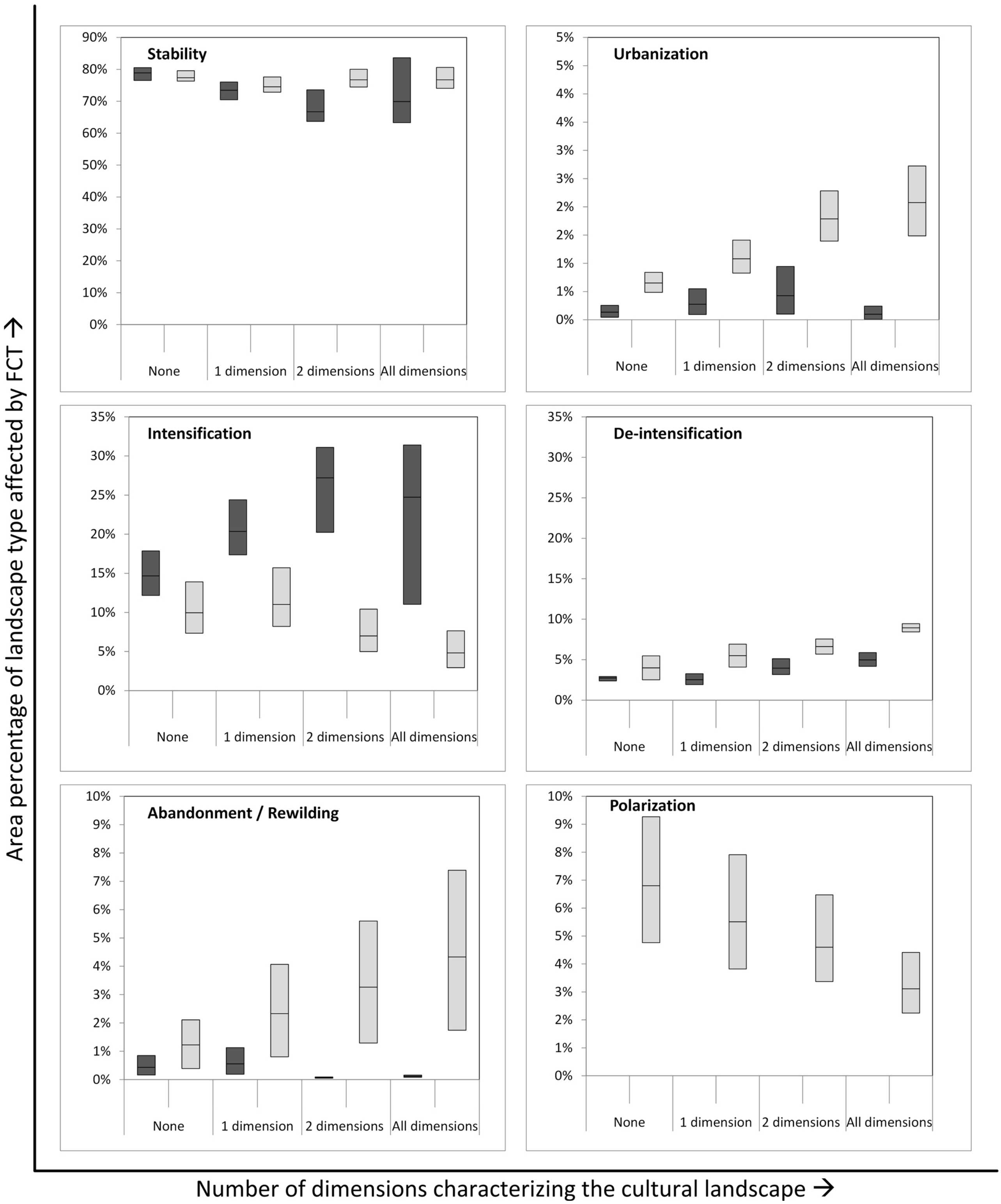

Fig. 4. Future land change trajectories in forest (dark grey) and agriculture (light grey) cultural landscape types. The line indicates the average over the four scenarios; the bars indicate the range among the four scenarios.

areas might go together with a changing urban-rural gradient, resulting in changing landscape appreciation patterns (Arnaiz-Schmitz et al., 2018).

Differences in urbanization among the scenarios are mainly due to uncertainties in future demand for urban land. Additionally, the scenarios that explore the consequences of a higher level of regulation (B1, B2) include stricter and better enforced nature protection policies that designate larger areas as Natura2000 and stimulate active nature development (Verburg et al., 2013). Stricter nature protection means that demand for built areas has to be met by converting agricultural land. Because landscapes where all cultural landscape dimensions occur tend to be on locations more attractive for urbanization, these landscapes would be most affected by such stricter nature protection. Protecting forests from urbanization thus renders a risk of displacement (Lambin

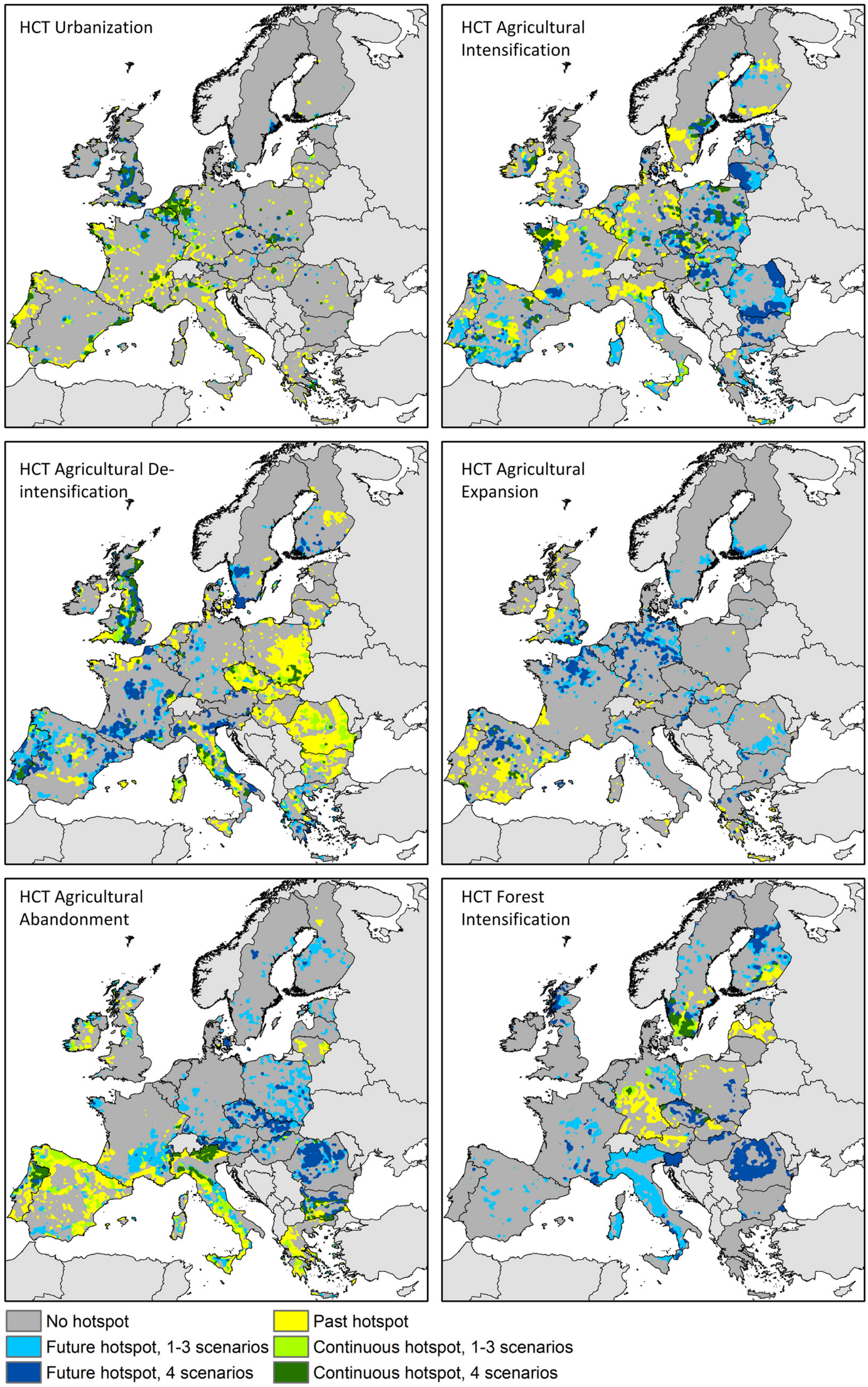

Fig. 5. Continuity of harmonized change trajectories (HCTs) in cultural landscapes.

and Meyfroidt, 2011) onto cultural landscapes.

Agricultural abandonment and de-intensification are driven by farmer characteristics, institutional drivers including subsidies and spatial planning, and economic drivers (Van Vliet et al., 2015). Areas with biophysical constraints to agricultural production are more prone to de-intensification and abandonment (Hart et al., 2012; Hatna and

Bakker, 2011). In the alpine parts of Italy, extensive, small-scale landscapes with a high value/meaning to society are strongly affected by these drivers over the 1990–2040 period. This marginal landscape faced an exodus throughout the second half of the 20th century, related to a weak economy (Giupponi et al., 2006). The already marginal situation is expected to exacerbate in the scenarios that evaluate the effects of increased global competition (A1, B1). Also in scenarios that assume more regional support through limiting trade liberalization and maintaining the Common Agricultural Policy (CAP) funding (A2, B2), the region loses competition from regions with fewer constraints. Only in a scenario that targets more specifically at maintaining rural areas with high biodiversity that are attractive to rural tourism, abandonment in these landscapes can be reduced (Verburg et al., 2013). Similar risks of loss of traditional agricultural landscapes in remote mountain areas are projected by Pazúr and Bolliger (2017) in Slovakia.

England provides an example of continuous de-intensification (Fig. 5) as a result of continuity of the drivers of abandonment from the historic period into the future scenarios. Landscapes in eastern England have been used intensively since the 19th century (Jepsen et al., 2015) and have been dressed with hedgerows, increasing their value to society. Recently, the aging farming population is acting as a trigger for de-intensification. The high suitability for farming (Giannakis and Bruggeman, 2015) counteracts the decreasing intensity due to ageing farming populations. This might result in a polarization of farming, with increasing numbers of lifestyle farmers with a low management intensity, combined with scale enlargement (Zasada, 2011). Eastern Europe demonstrates the impact of strengthening and diverging drivers of abandonment over the 1990–2040 period, resulting in de-intensification followed by polarization. Many parts of eastern Europe face biophysical constraints (Fischer et al., 2002), that are assumed to remain constant over the 1990–2040 time period. Eastern Europe faced less intensification in the second half of the 20th century than western Europe and since the collapse of the Eastern Bloc in 1989, polarization of land use started (Jepsen et al., 2015). Future scenarios are characterized by divergence of the institutional and economic drivers. Consistent with other European scale land use projections (Maes et al., 2014), scenarios with increased global competition (A1, B1) decrease support for extensive farming and agri-environmental management (Verburg et al., 2013), which can trigger abandonment (Van Vliet et al., 2015). Contrarily, more regionally focused scenarios (A2, B2) might be beneficial for extensively farmed areas by providing continuous CAP support in both Pillar I and Pillar II. In Romania, the low economic performance (Giannakis and Bruggeman, 2015) provides too many constraints to benefit from this support, resulting in abandonment in all scenarios. Agriculture in Poland is more large-scale and more profitable and might be sufficiently competitive to be suitable for intensification (Fig. 5).

Cultural landscapes undergoing intensification tend to be on more accessible, less marginal locations (Bender et al., 2005). Visual comparison of the cultural landscape types affected by intensification with a map of capacity for development of intensive agriculture (Van Berkel and Verburg, 2011) indicates that most landscapes with high scores for all three dimensions defining cultural landscapes have low to intermediate capacities for intensification.

4.2. Methodological considerations

Our work combines existing recent land change data, land change projections and a designation of cultural landscapes. The underlying studies were conducted independently and were not previously integrated. We show that integration of these different types of data and projections has added value in determining the dynamics and threats to cultural landscapes. All input maps were validated where possible, or a sensitivity analysis has been performed. Results of these analyses (for a full description of sensitivity analyses see (Levers et al., 2015; Prestele et al., 2016; Tieskens et al., 2017)) demonstrate the robustness of the input maps, but also point at several limitations that might propagate in the current work. Archetypical Change Trajectories emphasise the dominant, broad-scale trends of land system change. These overshadow other, more local change processes that may also affect cultural landscapes (Levers et al., 2015). Comparison of ACTs with the cultural landscape map is challenging, because the definition of some of the ACTs excludes the presence of a specific cultural landscape type and vice versa. For example, the ACTs could inform recent cultural landscape loss in more detail. However, it cannot be identified if areas that have been intensified between 1990 and 2006 were characterized by their low intensity before 1990. From comparing the ACTs with the cultural landscape map, one can derive a general idea of where and how cultural landscapes might have been changed or lost. Other cultural landscapes that have been intensified over the past are now characterized by their structure or cultural value. Beyond a general overview, definitive conclusions are hampered by a lack of spatially explicit historical data on agricultural or forest management intensity. Also, changes in structure and value/meaning are difficult to back-cast at larger scales given limitations in available data.

The future scenarios underlying the FCTs are a means to address the uncertainty in future socio-economic and policy developments affecting land use in Europe. As such, the approach captures some of the uncertainty in future land use change. However, a comparison of differently structured land use models, including a CLUE-based model, showed that spatial patterns of change are not robust among different models (Prestele et al., 2016). In Europe, particularly simulations of the amount and location of pasture change are highly variable. The model results applied here provide a close-to-average result compared to other models. Amount and location of the simulated forest change is large compared to other models (Prestele et al., 2016), which might have resulted in overestimation of the impact of afforestation of cultural landscapes. Other land use modelling scenarios tend to have a coarse spatial resolution, making comparison of land change patterns difficult. An exception is the 1 km-resolution Business-as-Usual (BaU) land change simulation from the LUISA modelling framework (Lavalle, 2014). Comparison of projected amounts of future land use change used in the current study against the LUISA BaU show that land use change quantities are in the same order of magnitude. Our four scenarios thus provide a range of estimates around the BaU that together give insight in the uncertainty of future developments. Visual comparison of simulated land changes used in this study with the LUISA simulations indicates that our simulations tend to project urbanization to be concentrated in northwestern Europe, while LUISA simulations suggest more dispersed urbanization. Consequently, our results might underestimate impacts of future land use change on cultural landscapes in eastern Europe, while impacts in northwestern Europe might be overestimated compared with other, equally uncertain, simulations of future land use change. Full validation of land use change models is hampered by a lack of sufficiently consistent time series of data to allow a full validation (Prestele et al., 2016).

Another methodological consideration is the thematic resolution. The land change trajectories are broad and ignore more subtle changes in land use such as infrastructure construction, field enlargement, or change in crop types (van Zanten et al., 2016). While some of such changes are studied at smaller scales (Garré et al., 2009; Rogge et al., 2007; Soini et al., 2011; Vouligny et al., 2009) they are not included in the European scale assessments underlying the current study, due to lack of data and complexity in representing these many different processes. Nevertheless, these processes may seriously affect the character and value of cultural landscapes. Finally, although the ACT and FCT maps as well as the cultural landscape map build on common data for the year 2000, the comparison gives rise to uncertainties due to some differences in underlying data. In particular, using only nitrogen application as an indicator for future intensification might underestimate where other intensification measures affect cultural landscapes.

5. Implications and conclusions

Our study identified how land change in the EU results in losses or changes of cultural landscapes. Europe's cultural landscapes are particularly threatened by abandonment and urbanization, and cultural landscape changes are strongly different between future scenarios. This variety of threats to cultural landscapes and large dependence on uncertainties in societal demands and policy may complicate the design of measures targeted at maintaining and strengthening cultural landscapes. At the same time, the variation of cultural landscape change under different socio-economic and policy scenarios demonstrates that potential threats to cultural landscapes are partly related to the interaction between projected socio-economic conditions and scenario specific differences in implementation of CAP policies, nature policies and other spatial restrictions. This study shows rebounds of nature protection into cultural landscapes, but also indicates that a scenario where trade liberalization is limited and support for rural areas is provided through continuation of CAP funding can help sustaining cultural landscapes by limiting abandonment. Therefore, in designing policies and protected areas, the larger consequences of such policies on cultural landscapes should be accounted for.

The land change trajectories assessed in this study also have indirect impacts on functioning of the cultural landscape. Changes in intensity can have varying impacts on landscape functioning, depending on location and on the manifestation of intensity changes. Abandonment might occur at the cost of erosion regulation (Gabarrón-Galeote et al., 2015), and landscape character and visual appreciation (Kienast et al., 2012; Paracchini et al., 2014). Abandonment can additionally decrease the accessibility of the landscape. Combined with the loss of landscape character and visual appreciation, this might limit the actual availability of land for recreation (Schulp et al., 2016). Abandonment could alternatively provide space for rewilding, which might create landscapes attractive for tourists (Brown et al., 2011). The spatial and scenario dependence of these threats to cultural landscapes as found in our study make it complicated to address these changes in landscape functioning, as possible measures need to be spatially and context dependent. On the other hand, the linkage between specific types of cultural landscapes and land change trajectories suggests that for different types of cultural landscape different approaches can be designed to preserve their values and functionality (Hartel et al., 2014). Supporting cultural landscapes in the post-2020 CAP could be broadened by a focus on landscape quality beyond the current focus on specific greening measures. Our study has shown the urgency of such policies for sustaining cultural landscapes while at the same time indicating that measures need to be implemented accounting for the large differences in threats and contextual conditions across Europe.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2018.04.030.

References

Agnoletti, M., 2014. Rural landscape, nature conservation and culture: some notes on research trends and management approaches from a (southern) European perspective. Landsc. Urban Plan. 126, 66–73. http://dx.doi.org/10.1016/j.landurbplan.2014.02.012.

Almeida, M., Loupa-Ramos, I., Menezes, H., Carvalho-Ribeiro, S., Guiomar, N., Pinto-Correia, T., 2016. Urban population looking for rural landscapes: different appreciation patterns identified in Southern Europe. Land Use Policy 53, 44–55. http://dx.doi.org/10.1016/j.landusepol.2015.09.025.

Antrop, M., 1997. The concept of traditional landscapes as a base for landscape evaluation and planning. The example of Flanders Region. Landsc. Urban Plan. 38, 105–117.

Arnaiz-Schmitz, C., Schmitz, M.F., Herrero-Jauregui, C., Gutierrez-Angonese, J., Pineda, F.D., Montes, C., 2018. Identifying socio-ecological networks in rural-urban gradients: diagnosis of a changing cultural landscape. Sci. Total Environ. 612, 625–635. http://dx.doi.org/10.1016/j.scitotenv.2017.08.215.

Baudry, J., Bunce, R.G.H., Burel, F., 2000. Hedgerows: an international perspective on their origin, function and management. J. Environ. Manage. 60, 7–22.

Bender, O., Boehmer, H.J., Jens, D., Schumacher, K.P., 2005. Using GIS to analyse long-term cultural landscape change in Southern Germany. Landsc. Urban Plan. 70, 111–125. http://dx.doi.org/10.1016/j.landurbplan.2003.10.008.

Brandt, K., Glemnitz, M., Schröder, B., 2017. The impact of crop parameters and surrounding habitats on different pollinator group abundance on agricultural fields. Agric. Ecosyst. Environ. 243, 55–66. http://dx.doi.org/10.1016/j.agee.2017.03.009.

Brown, C., McMorran, R., Price, M.F., 2011. Rewilding – a New paradigm for nature conservation in Scotland? Scott. Geogr. J. 127, 288–314. http://dx.doi.org/10.1080/14702541.2012.666261.

Brown, G., Raymond, C., 2007. The relationship between place attachment and landscape values: toward mapping place attachment. Appl. Geogr. 27, 89–111. http://dx.doi.org/10.1016/j.apgeog.2006.11.002.

Council of Europe, 2000. European Landscape Convention. Council of Europe, Florence, Italy.

Donald, P.F., Pisano, G., Rayment, M.D., Pain, D.J., 2002. The Common agricultural policy, EU enlargement and the conservation of Europe's farmland birds. Agric. Ecosyst. Environ. 89, 167–182. http://dx.doi.org/10.1016/S0167-8809(01)00244-4.

European Environmental Agency, 2015. CORINE Land Cover 2012. European Environmental Agency, Copenhagen, Denmark.

Fischer, G., van Veldhuizen, H.T., Shah, M.M., Nachtergaele, F.O., 2002. Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results. IIASA, Laxenburg, Austria p. 157.

Fischer, J., Hartel, T., Kuemmerle, T., 2012. Conservation policy in traditional farming landscapes. Conserv. Lett. 5, 167–175. http://dx.doi.org/10.1111/j.1755-263X.2012.00227.x.

Gabarrón-Galeote, M.A., Trigalet, S., van Wesemael, B., 2015. Effect of land abandonment on soil organic carbon fractions along a Mediterranean precipitation gradient. Geoderma 249–250, 69–78. http://dx.doi.org/10.1016/j.geoderma.2015.03.007.

Garré, S., Meeus, S., Gulinck, H., 2009. The dual role of roads in the visual landscape: a case-study in the area around Mechelen (Belgium). Landsc. Urban Plan. 92, 125–135. http://dx.doi.org/10.1016/j.landurbplan.2009.04.001.

Giannakis, E., Bruggeman, A., 2015. The highly variable economic performance of European agriculture. Land Use Policy 45, 26–35. http://dx.doi.org/10.1016/j.landusepol.2014.12.009.

Giupponi, C., Ramanzin, M., Sturaro, E., Fuser, S., 2006. Climate and land use changes, biodiversity and agri-environmental measures in the Belluno province, Italy. Environ. Sci. Policy 9, 163–173. http://dx.doi.org/10.1016/j.envsci.2005.11.007.

Hart, K., Allen, K., Lindner, M., Keenleyside, C., Burgess, P.J., Eggers, J., Buckwell, A., 2012. Land as an Environmental Resource. Institute for European Environmental Policy, London.

Hartel, T., Fischer, J., Câmpeanu, C., Milcu, A.I., Hanspach, J., Fazey, I., 2014. The importance of ecosystem services for rural inhabitants in a changing cultural landscape in Romania. Ecol. Soc. 19, 42. http://dx.doi.org/10.5751/es-06333-190242.

Hatna, E., Bakker, M.M., 2011. Abandonment and expansion of arable land in Europe. Ecosystems 14, 1–12. http://dx.doi.org/10.1007/s10021-011-9441-y.

Jepsen, M.R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P.H., Haberl, H., Vesterager, J.P., Andrič, M., Antrop, M., Austrheim, G., Björn, I., Bondeau, A., Bürgi, M., Bryson, J., Caspar, G., Cassar, L.F., Conrad, E., Chromý, P., Daugirdas, V., Van Eetvelde, V., Elena-Rosselló, R., Gimmi, U., Izakovicova, Z., Jančák, V., Jansson, U., Kladnik, D., Kozak, J., Konkoly-Gyuró, E., Krausmann, F., Mander, Ü., McDonagh, J., Pärn, J., Niedertscheider, M., Nikodemus, O., Ostapowicz, K., Pérez-Soba, M., Pinto-Correia, T., Ribokas, G., Rounsevell, M., Schistou, D., Schmit, C., Terkenli, T.S., Tretvik, A.M., Trzepacz, P., Vadineanu, A., Walz, A., Zhllima, E., Reenberg, A., 2015. Transitions in European land management regimes between 1800 and 2010. Land Use Policy 49, 53–64. http://dx.doi.org/10.1016/j.landusepol.2015.07.003.

Jones, M., 2003. The concept of cultural landscape: discourse and narratives. In: Palang, H., Fry, G. (Eds.), Landscape Interfaces: Cultural Heritage in Changing Landscapes. Springer, Dordrecht, pp. 21–52.

Kienast, F., Degenhardt, B., Weilenmann, B., Wäger, Y., Buchecker, M., 2012. GIS-assisted mapping of landscape suitability for nearby recreation. Landsc. Urban Plan. 105, 385–399. http://dx.doi.org/10.1016/j.landurbplan.2012.01.015.

Kizos, T., Koulouri, M., 2006. Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. Environ. Sci. Policy 9, 330–342. http://dx.doi.org/10.1016/j.envsci.2006.02.002.

Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proc. Natl. Acad. Sci. 108, 3465–3472. http://dx.doi.org/10.1073/pnas.1100480108.

Lavalle, C., 2014. OUTPUT - Land use/cover Maps (LUISA Platform REF2014). Joint Research Centre (JRC) of the European Commission (Ed.).

Levers, C., Butsic, V., Verburg, P.H., Müller, D., Kuemmerle, T., 2016. Drivers of changes in agricultural intensity in Europe. Land Use Policy 58, 380–393. http://dx.doi.org/10.1016/j.landusepol.2016.08.013.

Levers, C., Müller, D., Erb, K., Haberl, H., Jepsen, M.R., Metzger, M.J., Meyfroidt, P.,

Plieninger, T., Plutzar, C., Stürck, J., Verburg, P.H., Verkerk, P.J., Kuemmerle, T., 2015. Archetypical patterns and trajectories of land systems in Europe. Region. Environ. Change 18, 715–732. http://dx.doi.org/10.1007/s10113-015-0907-x.
Maes, J., Barbosa, A., Baranzelli, C., Zulian, G., Batista e Silva, F., Vandecasteele, I., Hiederer, R., Liquete, C., Paracchini, M.L., Mubareka, S., Jacobs-Crisioni, C., Castillo, C.P., Lavalle, C., 2014. More green infrastructure is required to maintain ecosystem services under current trends in land use change in Europe. Landsc. Ecol. 30, 517–534. http://dx.doi.org/10.1007/s10980-014-0083-2.
McGrath, M.J., Luyssaert, S., Meyfroidt, P., Kaplan, J.O., Bürgi, M., Chen, Y., Erb, K., Gimmi, U., McInerney, D., Naudts, K., Otto, J., Pasztor, F., Ryder, J., Schelhaas, M.J., Valade, A., 2015. Reconstructing European forest management from 1600 to 2010. Biogeosciences 12, 4291–4316. http://dx.doi.org/10.5194/bg-12-4291-2015.
Neumann, K., Elbersen, B.S., Verburg, P.H., Staritsky, I., Perez-Soba, M., de Vries, W., Rienks, W.A., 2009. Modelling the spatial distribution of livestock in Europe. Landsc. Ecol. 24, 1207–1222. http://dx.doi.org/10.1007/s10980-009-9357-5.
Palacios-Agundez, I., Onaindia, M., Barraqueta, P., Madariaga, I., 2015. Provisioning ecosystem services supply and demand: the role of landscape management to reinforce supply and promote synergies with other ecosystem services. Land Use Policy 47, 145–155. http://dx.doi.org/10.1016/j.landusepol.2015.03.012.
Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., Termansen, M., Zandersen, M., Perez-Soba, M., Scholefield, P.A., Bidoglio, G., 2014. Mapping cultural ecosystem services: a framework to assess the potential for outdoor recreation across the EU. Ecol. Indic. 45, 371–385. http://dx.doi.org/10.1016/j.ecolind.2014.04.018.
Pazúr, R., Bolliger, J., 2017. Land changes in Slovakia: past processes and future directions. Appl. Geogr. 85, 163–175. http://dx.doi.org/10.1016/j.apgeog.2017.05.009.
Petit, S., Stuart, R., Gillespie, M., Barr, C., 2003. Field boundaries in Great Britain: stock and change between 1984, 1990 and 1998. J. Environ. Manage. 67, 229–238.
Plieninger, T., Bieling, C., 2012. Resilience and the Cultural Landscape : Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press, Cambridge xvi, 348 pages : illustrations, maps ; 26 cm pp.
Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Bürgi, M., Kizos, T., Kuemmerle, T., Primdahl, J., Verburg, P.H., 2016. The driving forces of landscape change in Europe: a systematic review of the evidence. Land Use Policy 57, 204–214. http://dx.doi.org/10.1016/j.landusepol.2016.04.040.
Plieninger, T., van der Horst, D., Schleyer, C., Bieling, C., 2014. Sustaining ecosystem services in cultural landscapes. Ecol. Soc. 19 (59). http://dx.doi.org/10.5751/ES-06159-190259.
Plutzar, C., Kroisleitner, C., Haberl, H., Fetzel, T., Bulgheroni, C., Beringer, T., Hostert, P., Kastner, T., Kuemmerle, T., Lauk, C., Levers, C., Lindner, M., Moser, D., Müller, D., Niedertscheider, M., Paracchini, M.L., Schaphoff, S., Verburg, P.H., Verkerk, P.J., Erb, K.-H., 2015. Changes in the spatial patterns of human appropriation of net primary production (HANPP) in Europe 1990–2006. Region. Environ. Change 16, 1225–1238. http://dx.doi.org/10.1007/s10113-015-0820-3.
Prestele, R., Alexander, P., Rounsevell, M.D., Arneth, A., Calvin, K., Doelman, J., Eitelberg, D.A., Engstrom, K., Fujimori, S., Hasegawa, T., Havlik, P., Humpenoder, F., Jain, A.K., Krisztin, T., Kyle, P., Meiyappan, P., Popp, A., Sands, R.D., Schaldach, R., Schungel, J., Stehfest, E., Tabeau, A., Van Meijl, H., Van Vliet, J., Verburg, P.H., 2016. Hotspots of uncertainty in land use and land cover change projections: a global-scale model comparison. Glob. Change Biol. 22, 3967–3983. http://dx.doi.org/10.1111/gcb.13337.
Rogge, E., Nevens, F., Gulinck, H., 2007. Perception of rural landscapes in Flanders: looking beyond aesthetics. Landsc. Urban Plan. 82, 159–174. http://dx.doi.org/10.1016/j.landurbplan.2007.02.006.
Schulp, C.J.E., Van Teeffelen, A.J.A., Tucker, G., Verburg, P.H., 2016. A quantitative assessment of policy options for no net loss of biodiversity and ecosystem services in the European Union. Land Use Policy 57, 151–163. http://dx.doi.org/10.1016/j.landusepol.2016.05.018.
Soini, K., Pouta, E., Salmiovirta, M., Uusitalo, M., Kivinen, T., 2011. Local residents' perceptions of energy landscape: the case of transmission lines. Land Use Policy 28, 294–305. http://dx.doi.org/10.1016/j.landusepol.2010.06.009.
Stürck, J., Levers, C., van der Zanden, E.H., Schulp, C.J.E., Verkerk, P., Kuemmerle, T., Helming, J., Lotze-Campen, H., Tabeau, A., Popp, A., Schrammeijer, E., Verburg, P., 2015. Simulating and delineating future land change trajectories across Europe. Region. Environ. Change 18, 733–749. http://dx.doi.org/10.1007/s10113-015-0876-0.
Szücs, L., Anders, U., Bürger-Arndt, R., 2015. Assessment and illustration of cultural ecosystem services at the local scale – a retrospective trend analysis. Ecol. Indic. 50, 120–134. http://dx.doi.org/10.1016/j.ecolind.2014.09.015.
Temme, A.J.A.M., Verburg, P.H., 2011. Mapping and modelling of changes in agricultural intensity in Europe. Agric. Ecosyst. Environ. 140, 46–56. http://dx.doi.org/10.1016/j.agee.2010.11.010.
Tieskens, K.F., Schulp, C.J.E., Levers, C., Lieskovský, J., Kuemmerle, T., Plieninger, T., Verburg, P.H., 2017. Characterization of European cultural landscapes: accounting for structure, land use intensity and value of rural landscapes. Land Use Policy 62C, 29–39. http://dx.doi.org/10.1016/j.landusepol.2016.12.001.
Van Berkel, D.B., Verburg, P.H., 2011. Sensitising rural policy: assessing spatial variation in rural development options for Europe. Land Use Policy 28, 447–459. http://dx.doi.org/10.1016/j.landusepol.2010.09.002.
Van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015. Manifestations and underlying drivers of agricultural land use change in Europe. Landsc. Urban Plan. 133, 24–36. http://dx.doi.org/10.1016/j.landurbplan.2014.09.001.
van Zanten, B.T., Zasada, I., Koetse, M.J., Ungaro, F., Häfner, K., Verburg, P.H., 2016. A comparative approach to assess the contribution of landscape features to aesthetic and recreational values in agricultural landscapes. Ecosyst. Serv. 17, 87–98. http://dx.doi.org/10.1016/j.ecoser.2015.11.011.
Verburg, P.H., Lotze-Campen, H., Popp, A., Lindner, M., Verkerk, P.J., Kakkonen, E., Schrammeijer, E., Helming, J., Tabeau, A., Schulp, C.J.E., van der Zanden, E.H., Lavalle, C., Batista e Silva, F., Eitelberg, D., 2013. VOLANTE Deliverable 11.1: Report Documenting the Assessment Results for the Scenarios Stored in the Database. VOLANTE, Amsterdam p. 124.
Verburg, P.H., Overmars, K.P., 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landsc. Ecol. 24, 1167–1181. http://dx.doi.org/10.1007/s10980-009-9355-7.
Verkerk, P.J., Levers, C., Kuemmerle, T., Lindner, M., Valbuena, R., Verburg, P.H., Zudin, S., 2015. Mapping wood production in European forests. For. Ecol. Manage. 357, 228–238. http://dx.doi.org/10.1016/j.foreco.2015.08.007.
Verkerk, P.J., Lindner, M., Perez-Soba, M., Paterson, J., Helming, J., Verburg, P.H., Kuemmerle, T., Lotze-Campen, H., Moiseyev, A., Müller, D., Popp, A., Schulp, C.J.E., Sturck, J., Tabeau, A., Wolfslehner, B., van der Zanden, E.H., 2017. Identifying pathways to visions of future land use in Europe. Region. Environ. Change 18, 817–830. http://dx.doi.org/10.1007/s10113-016-1055-7.
Vos, W., Meekes, H., 1999. Trends in European cultural landscape development: perspectives for a sustainable future. Landsc. Urban Plan. 46, 3–14.
Vouligny, É., Domon, G., Ruiz, J., 2009. An assessment of ordinary landscapes by an expert and by its residents: landscape values in areas of intensive agricultural use. Land Use Policy 26, 890–900. http://dx.doi.org/10.1016/j.landusepol.2008.10.016.
Zasada, I., 2011. Multifunctional peri-urban agriculture—a review of societal demands and the provision of goods and services by farming. Land Use Policy 28, 639–648. http://dx.doi.org/10.1016/j.landusepol.2011.01.008.
Zomlot, Z., Verbeiren, B., Huysmans, M., Batelaan, O., 2017. Trajectory analysis of land use and land cover maps to improve spatial–temporal patterns, and impact assessment on groundwater recharge. J. Hydrol. 554, 558–569. http://dx.doi.org/10.1016/j.jhydrol.2017.09.032.