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Future uncertainty in scenarios of ecosystem services provision: Linking differences among narratives and outcomes

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ABSTRACT

Future provision of ecosystem services (ES) has been increasingly analysed through the scenario approach to address uncertainties and to communicate them to stakeholders and decision-makers. Multiple uncertainty-related aspects of the scenario approach have been discussed in the literature, e.g. how uncertainty is accounted for in ES modelling processes. However, this contribution aims to address another uncertainty-related aspect of scenario analysis, exploring the relationship between the diversity of qualitative scenario narratives on the one hand and the diversity of their respective quantitative outcomes on the other. We build on a local-scale case study and present a semi-quantitative approach to compare scenario narratives and outcomes, based on participatory scenario planning and ES modelling. Our results show that different scenario narratives may lead to similar levels of modelled ES provision, and vice versa, that similar narratives may result in contrasting scenario outcomes. We use these findings to derive uncertainty-related insights, and discuss how these can help formulate landscape management decisions, resulting in desirable ES outcomes across a range of plausible futures. Finally, we discuss the need to apply both spatial and aspatial approaches to compare the convergence of scenario outcomes, and the implications for potential interpretation of the results by stakeholders and decision-makers.

1. Introduction

Ecosystem services (ES), as a vital precondition of human well-being, have gradually become a major concern for decision makers worldwide and at all scales of governance (Daily et al., 2009; Díaz et al., 2015; EC, 2011). Modelling the provision of ES and its potential future development has gained momentum across professional communities and contexts (Bagstad et al., 2013; Lorencová et al., 2013; Maes et al., 2013; Peh et al., 2013). In particular, a special attention has been given to the provision of ES bundles (Martín-López et al., 2012; Queiroz et al., 2015; Raudsepp-Hearne et al., 2010) and to assessing multiple aspects of trade-offs and synergies among ES (Daw et al., 2015; Maes et al., 2012; Nelson et al., 2009; Ruijs et al., 2013).

Future provision of ES has been increasingly explored through the scenario approach (IPBES, 2016; Kok et al., 2017; Oteros-Rozas et al., 2015). The scenario approach has been designed to capture the complex dynamics of social-ecological systems (SES), as well as to understand key natural and societal driving forces and their potential future effects, including the impact on ES provision (Bennett et al., 2003; Carpenter et al., 2006; MA, 2005a; Peterson et al., 2003). The scenario approach in ES assessments generally aims to build diverse, plausible descriptions of potential future development (qualitative "narratives"), and to quantify the levels of ES provision resulting from each narrative ("outcomes") (Harrison et al., 2013; Reed et al., 2013; Rounsevell and Metzger, 2010). Scenario analysis has been recognised as a tool to address future uncertainties, which stem from the dynamic and changing nature of SES, by outlining multiple plausible ways of future development (MA, 2005b). Furthermore, scenario analysis helps communicate different aspects of uncertainty to decision makers and take proactive steps to enhance society's ability to navigate future change (IPBES, 2016). Multiple uncertainty-related aspects of the scenario approach have been discussed in the recent literature, e.g. how uncertainty is accounted for in ES modelling (Hamel and Bryant, 2017; Hou et al., 2013; Schulp et al., 2014) or how different types of uncertainty emerge throughout the interplay between policy-making processes and related science-based decision support (Walker et al., 2003).

Formally, in terms of the nature of uncertainty, most of these studies generally deal with epistemic (also known as 'scientific') uncertainty, i.e. the uncertainty due to imperfect knowledge or data on the system being described (IPBES, 2016; Refsgaard et al., 2007). A certain level of epistemic uncertainty is unavoidable but can be reduced by additional research or empirical efforts, e.g. by improving data analysis or by

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deepening our understanding of the modelled system (IPBES, 2016; Refsgaard et al., 2007).

However, the scenario approach has the potential to addresses yet another type of uncertainty, the variability uncertainty, stemming from the random behaviour, inherent variability or unpredictability of complex natural, social and economic systems (also known as 'ontological' or – in a narrower sense – 'stochastic' uncertainty). Although variability uncertainty is inherently irreducible, it can be accommodated through the construction of a set of plausible future scenarios rather than a single one, and through analysing the differences among them (IPBES, 2016; Walker et al., 2003). Accordingly, the purpose of scenarios is not to reduce variability uncertainty, but rather to convey this source of uncertainty and its implications to policy and decision making (Enserink et al., 2013).

This contribution addresses the variability-uncertainty related aspects of the scenario approach by exploring the relationship between the range of qualitative scenario narratives on the one hand and the diversity of their respective quantitative outcomes on the other. Specifically, we focus on what insights regarding an uncertain future state of a system we can derive from the cases in which diverse scenario narratives lead to similar modelled ES provision outcomes, and vice versa. For this purpose, we present a feasible semi-quantitative approach to compare among scenario narratives and outcomes, based on participatory scenario planning and ES modelling, and illustrate it on a local-scale case study. Consequently, we discuss the relevance of the uncertainty related considerations derived from our findings for landscape management and decision-making processes.

2. Methods

Building on an illustrative case study, we first analysed the social-ecological dynamics of the selected SES and developed an array of local-scale, participatory scenario narratives. Second, the narratives were translated to spatially explicit land use and land cover (LULC) scenarios, which were subsequently used as the basis to model potential future ES provision (further denoted as scenario outcomes). Finally, a semi-quantitative approach was applied to compare the differences among scenario narratives on the one hand and among their respective ES outcomes on the other, using multiple quantification and visualization approaches (Fig. 1).

2.1. Case study area

The case study was carried out in Třeboň Basin UNESCO Biosphere Reserve (BR) in the Czech Republic (Fig. 2), as a part of a research project focusing on the development of Long-Term Socio-Ecologic Research in the study area (Harmáčková and Vačkář, 2015). The study area (700 km^2) is most distinctly characterized by coniferous forests, wetlands, wet meadows and artificial water reservoirs (fish ponds). The region has had a historical tradition of fish-farming since the 15th century and has been highly valued due to its natural and cultural assets. Třeboň Basin has been recognized as a UNESCO Biosphere Reserve, a Long-Term Ecological Research site, wetlands of international importance under the Ramsar Convention on Wetlands as well as a Protected Landscape Area (Jeník and Přibyl, 1978; Pokorný et al., 2000).

Although Třeboň Basin is a declared Protected Landscape Area, several exploitive activities are permitted within its boundaries as a legal consequence of previous protection regimes. At the same time, it draws the interest of multiple businesses due to the economic potential of local natural resources. Therefore, Třeboň Basin has faced pressures in the form of intensively fertilised fish-farming (IUCN, 1996; Pechar et al., 2002; Vinciková et al., 2015), sand and gravel mining along protected water and wetland ecosystems, and biogas energy production (which serves as an energy supply for Třeboň spas). Beside fish-farming and agriculture, Třeboň Basin is an important destination for tourism and recreation, which presents another source of pressure on this vulnerable area. In sum, local landscape management is challenged by a trade-off between sustaining current levels of landscape protection and promoting economic growth, potentially counterbalanced by decreasing provision of ES.

2.2. Step 1: Scenario planning

As the first step, we developed an array of participatory scenario narratives, capturing local social-ecological dynamics, key driving forces and their potential future impact on local landscape and ecosystems in the medium-term future (to 2050) (Rounsevell and Metzger, 2010; Spangenberg et al., 2012). We used the approach of participatory scenario planning, collaborating with a wide range of local stakeholders (Hanspach et al., 2014; Peterson et al., 2003; Reed et al., 2013).

In the initial stage of the study, we identified local stakeholders either substantially influencing the land use regime in Třeboň Basin, or having expertise in the driving forces forming the local landscape. The key stakeholders involved in the study represented industrial, agricultural and tourism sectors, nature protection, as well as scientific and educational institutes conducting research in the study area (Table S1). The representatives of local fishing industry and forestry were unwilling to participate in the scenario building process; thus, plausible trends in these sectors were elicited from researchers involved in local hydrological, ecological and landscape research.

In total, 14 key stakeholders participated in the study through a series of semi-structured interviews and individual discussions to identify driving forces most influential in the local SES and key benefits provided by the local landscape (Box S1) (Celio et al., 2015; EEA, 2012; Fagerholm et al., 2013; Reed, 2008; Termorshuizen and Opdam, 2009). Furthermore, the stakeholders were asked to describe how they assume the landscape will develop in the medium-term future (2050) and what their preferences are regarding landscape development according to their professional perspective. Although expectations of a certain type of a future development and preferences regarding future development represent two distinct perspectives, we believe both are important for envisioning different futures. Therefore, we addressed them explicitly in the interviews, and the themes and trends identified under both of these perspectives were treated equally as building blocks for the subsequently formed narratives.

In the material from the interviews, key topics and trends in social-ecological dynamics, landscape development and landscape management were identified and grouped into several coherent scenario narratives (Hunt et al., 2012; Kok et al., 2011), namely the Market narrative, the Exploitation narrative, the Business-as-Usual (BaU) narrative, the Conservation narrative and the Biofuels narrative (see the Results section).

2.3. Step 2: LULC scenarios

In the second step, we translated the participatory narratives into spatially explicit LULC scenarios and used these as the basis to model potential future ES provision. In order to capture both the locally specific landscape dynamics and larger-scale drivers of landscape change, we combined the participatory narratives compiled based on stakeholder input (Box S1) with European-scale LULC datasets (CORINE Land Cover; EEA, 2007) and dynamic LULC change scenarios (the 6th Framework Programme ALARM project scenarios; Dendoncker et al., 2006; Rounsevell et al., 2006; Settele et al., 2005; Spangenberg et al., 2012), using spatial modelling tools in ArcGIS (ESRI, 2013). The ALARM scenarios were used as at the time of the analysis, they represented the only downscaled set of LULC scenarios for Europe with a fine spatial resolution; CORINE Land Cover was selected as its resolution and LULC categorization corresponded to those of the ALARM scenarios.

The modelling framework is outlined in Fig. 1 and described in

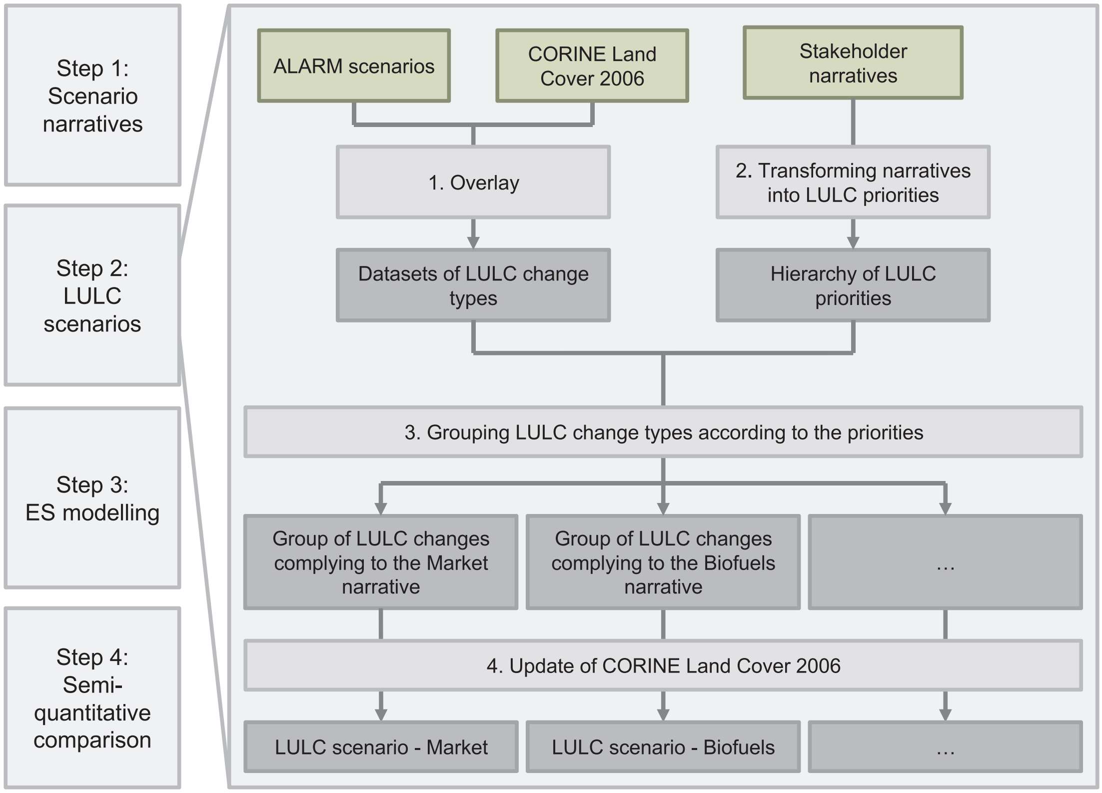

Fig. 1. Workflow diagram and the modelling framework for developing participatory LULC change scenarios.

detail in Harmáčková and Vačkář (2015) and Harmáčková (2016). As a brief overview, the approach included the following steps:

1. Overlaying CORINE Land Cover 2006 with downscaled ALARM 2050 LULC scenarios at 100 × 100 m resolution and identifying all changed grid cells, their initial LULC and final LULC category. Dividing changed grid cells into separate datasets based on distinct LULC change type (e.g. forests to grasslands, grasslands to built-up, etc.).
2. Transforming each participatory scenario narrative into a hierarchy of LULC priorities (Table S2). Each narrative was characterised by several key LULC change types, i.e. which LULC types will stay unchanged, which ones will expand and replace others, and vice versa (e.g. a part of intensive arable land is assumed to be abandoned and replaced by forest in the Market narrative). Such assumptions were transformed to LULC priority levels, ordered in hierarchies, describing which types of LULC are more likely to be replaced by other LULC types under particular narratives, and vice

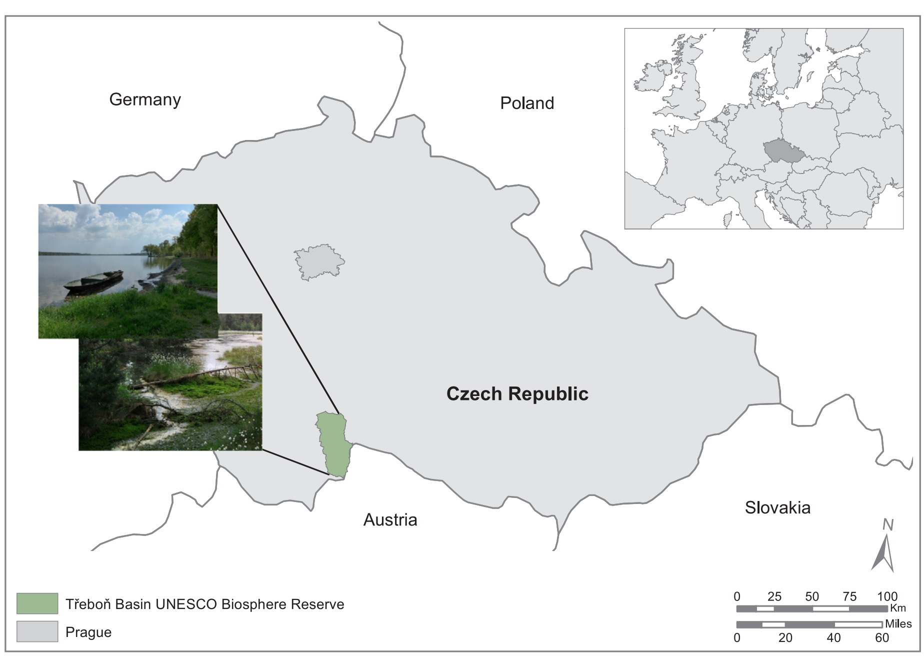

Fig. 2. Localisation of the case study area, Třeboň Basin UNESCO Biosphere Reserve.

versa, which types of LULC will be prioritized and will likely remain in their original extent or even expand.
3. Comparing the LULC change types identified in step 1 with the LULC priority hierarchies from step 2 and, accordingly, aggregating respective spatial LULC change datasets into distinct groups for each scenario. In addition, supplementing each group by locally specific LULC changes proposed by the stakeholders (e.g. ecological restoration of selected fish-ponds, etc.).
4. Stepwise updating CORINE Land Cover 2006 with resulting groups of LULC change datasets, gaining an array of participatory LULC scenarios to 2050 corresponding to stakeholder narratives.

2.4. Step 3: Ecosystem services modelling

The resulting LULC scenarios were used as an input into a biophysical modelling of selected ES. We aimed to assess a balanced sample of provisioning, regulating and cultural services (MA, 2005b), identified as key in the case study area during the participative scenario planning process. Specifically, we assessed crop and timber production, climate regulation, water quality regulation in terms of nitrogen and sediment retention, recreation potential and landscape aesthetics. For the purposes of this study, we defined the provision of ES as the capacity of a landscape to generate goods and benefits contributing to human well-being, in accord with Kareiva et al. (2011) and Villamagna et al. (2013).

All selected ES were modelled using a combination of spatially explicit LULC-based models and modelling approaches at the spatial resolution of 100 m × 100 m (1 ha). Model parametrizations and data sources are summarized in Tables S3–S9 and described in detail in Harmáčková and Vačkář (2015) and Harmáčková (2016).

Provisioning services were assessed using a simple proxy analysis of the extent of arable land and forested areas (Queiroz et al., 2015; Raudsepp-Hearne et al., 2010). The assessment of all regulating services was conducted using the InVEST suite of biophysical models (Goldstein et al., 2012; Kareiva et al., 2011; Nelson et al., 2009), versions 3.0.1 (water quality regulation services) and 3.1.3 (climate regulation) (Table S3–S5). The assessment of cultural ES was approached from a GIS perspective, in order to keep the coherence with the assessment of provisioning and regulating ES. Recreation potential index (RPI) was modelled using the ESTIMAP approach (Paracchini et al., 2014, 2011, Zulian et al., 2014, 2013) and landscape aesthetics index (LAI) was assessed following an approach by Otero Pastor et al. (2007) and Martín Ramos and Otero Pastor (2012) (Table S6–S9, Fig. S1). Both of these approaches are based on landscape attributes and patterns (such as LULC composition and configuration, scenic landscape features, ecologically valuable phenomena) and their favourability by people in terms of recreation potential and aesthetic quality (Dramstad et al., 2006; Swanwick, 2009).

2.5. Step 4: Semi-quantitative comparison of scenario narratives and outcomes

In the final step, we applied a semi-quantitative approach to assess the extent of differences among qualitative scenario narratives on the one hand and the differences among quantitative scenario outcomes on the other.

Since the scenario narratives in this study were qualitative and multi-faceted, a qualitative approach was applied to compare the differences among them by locating them along several gradients of characteristics (Hunt et al., 2012). Locating the narratives was based on their major focus and key themes (e.g. attitude towards nature protection in the Conservation narrative), and the axes defining the narrative space applied in this analysis included the impact of large-scale or local-scale driving forces and the consideration of environmental issues.

Quantitative scenario outcomes were first compared in aggregated terms and, subsequently, analysed in terms of spatial similarity in the resulting maps of ES provision. For the aggregated comparison of ES outcomes, we calculated relative change between the ES provision in the baseline landscape (2006) and each scenario to 2050 (Goldstein et al., 2012; Nelson et al., 2009):

$$\Delta ES = \left(\frac{ES_\tau}{ES_t} - 1\right) * 100 \tag{1}$$

where ΔES is the relative change in the provision of a given ES, ES_t is the provision of the service in respective units in time t = 2006 and ES_τ in time τ = 2050. Relative change in ES provision was used to illustrate trade-offs among different types of ES under various scenarios (i.e. situations when the provision of one ES is reduced as a consequence of increased use of another ES) and synergies among ES (Rodriguez et al., 2006).

To gain additional insights from a spatial perspective, we calculated a Map Comparison Statistic (MCS) (Schulp et al., 2014). Although MCS again represents an aggregated index, it takes into account spatial similarities and differences between pairs of spatial datasets. The MCS was calculated for ES bundle maps resulting from different scenario narratives (understanding an ES bundle as the overall level of the provision of the seven services considered; Schulp et al., 2014). ES bundle maps were prepared by:

1. Spatial aggregation of each ES map into sub-watersheds (N = 73) by calculating the mean value. Sub-watersheds represented the resolution of the least detailed ES maps in our results (the sub-watershed level is the most detailed aggregation level for which the water-related services modelled by InVEST can be reasonably interpreted according to Sharp et al., 2015).
2. Normalising the aggregated maps to gain a unified range of values [0,1], according to

$$x_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{2}$$

with minimum x_{min} and maximum x_{max} taken across all sub-watersheds and scenarios for each single ES.

3. Summing up the normalised maps into one ES bundle map per scenario, each bundle including all seven analysed services.

The MCS for each pair of scenarios was then calculated as

$$MCS = \frac{\sum_{n=1}^{N} (|a_n - b_n| / \max(a_n, b_n))}{N} * 100 \tag{3}$$

where MCS is the Map Comparison Statistic, a_n and b_n are the normalised values of an ES bundle in sub-watershed n, and N is the total number of sub-watersheds in the study area. Possible values of MCS range between 0 (two identical maps), 50 (random maps) and 100 (opposing maps).

As described above, LULC maps served as an intermediate step of translating scenario narratives to scenario outcomes in this analysis. Thus, we wanted to identify whether the source of the differences among scenario outcomes was the LULC assignment or the modelling of ES, conditional on LULC. For this purpose, alongside the spatial comparison of the ES outcomes through MCS, we also compared the agreement between the underlying LULC maps applying the Kappa statistic (Cohen, 1960; Jenness and Wynne, 2005).

Kappa quantifies the percentage of agreement between two categorical maps, corrected for the similarity which can be expected by chance. We apply this statistic as it represents a measure widely used for map comparison in the spatial modelling community; however, it is important to note that its use has been also contested by some authors (Pontius and Millones, 2011). Kappa is calculated based on a contingency table of map classification categories also denoted as confusion or error matrix (Remmel, 2009; Remmel and Csillag, 2006) (Fig. S2). Possible values of Kappa range between 0% (no agreement between maps) and 100% (strong agreement).

Kappa was calculated as follows (according to Congalton and Green, 2009; p. 60 and 106):

$$\hat{K} = \frac{n\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i\bullet} n_{\bullet i}}{n^2 - \sum_{i=1}^{k} n_{i\bullet} n_{\bullet i}} * 100 \quad (4)$$

where n refers to the number of sampling locations (in our case equivalent to $N = 686{,}240{,}000$ raster grid cells in each of the compared LULC maps) and i refers to a classification category ($i \in \langle 1;k \rangle$; here corresponding to $k = 17$ LULC types). Furthermore, n_{ii} denotes the number of raster cells classified in an identical category in both compared maps, $n_{i\bullet}$ the number of samples classified into category i in the first map and $n_{\bullet i}$ the number of samples classified into category i in the second map compared. For a visual representation of the confusion matrix and the notation used in Eq. (4), see Fig. S2.

For easier comparison, the resulting values x of MCS were normalised to x_{norm} according to Eq. (2), for $x_{min} = 0$ and $x_{max} = 100$. The resulting values y of Kappa were normalised to $1 - y_{norm}$ (due to the opposite interpretation of MCS and Kappa), with y_{norm} again calculated according to Eq. (2), for $y_{min} = 0$ and $y_{max} = 100$.

3. Results

3.1. Scenario narratives

Stakeholders' insights in the social-ecological dynamics of the case-study system and their opinions regarding potential future development focused mainly on the influence of local driving forces. Their visions generally clustered in two contradicting directions, focusing on stronger levels of nature protection on the one hand, and at higher economic revenues derived from local natural assets on the other. Thus, the insights were compiled into two storylines, denoted as Conservation and Exploitation, along the gradient of their environmental focus. Furthermore, a Business as Usual (BaU) storyline was identified as a status quo option. All of these storylines were consistent with the European-level ALARM BAMBU scenario, since they assume stable, business-as-usual development at the larger scale, while diverging in the locally-specific dynamics.

To provide a counterbalance to the locally-driven scenario storylines, we introduced two other storylines, reflecting potential differences in the development of larger-scale driving forces, such as climate change, European Union policies, national and European economic development and demographic projections. These storylines were based on the ALARM GRAS and SEDG scenarios and denoted as Market and Biofuels, respectively. To keep the coherence, locally-specific aspects were supplemented to these narratives by participating stakeholders.

The detailed characteristics of the resulting narratives were as follows:

1. **Market**: This narrative embraces large-scale driving forces, namely further market liberalization and globalization. It assumes increasing deregulation of trade, with economic growth presenting a key target. In the local conditions, this translates mainly to further growth of local businesses, primarily in the tourism sector and services, as a result of higher inflow of international visitors; however, not necessarily leading to larger exploitation of local natural resources. Increasing globalisation of trade in agricultural products leads to further abandonment of arable land and pastures, replaced mostly by forests. Under this scenario, environmental policies focus mainly on retroactive actions. This scenario is consistent with ALARM GRAS 2050 scenario storyline.
2. **Exploitation**: The Exploitation narrative assumes weakening nature protection in the study area and landscape intensification, supported by locally active economic subjects. Under this scenario, exploitative landscape changes are pronounced (e.g. extensive increase in mining areas, a transformation of pastures into arable land), due to increasing demand for mineral resources and biomass for biogas production in Třeboň. This scenario is consistent with ALARM BAMBU 2050 scenario storyline.
3. **Business as Usual (BaU)**. This narrative assumes minor landscape changes, reflecting existing trends and predominantly preserving the landscape in its current state. Landscape changes occurring under this storyline are e.g. moderate growth of urban areas, limited abandonment of agricultural land and increase in forested areas, with the exception of changes affecting strictly protected areas, such as peat bogs and wetlands. This scenario is consistent with ALARM BAMBU 2050 scenario storyline.
4. **Conservation**. This narrative assumes highly protected landscape assets, rejects further intensification of human activities, and only allows for transformations to less intensive LULC types (e.g. from arable lands to pastures, from shrub-land to forests). Mining ceases due to strict nature conservation and former mining sites are subject to ecological restoration. Intensive agriculture in areas close to nature reserves is abandoned. This scenario is consistent with ALARM BAMBU 2050 scenario storyline.
5. **Biofuels**. The Biofuels narrative is shaped by European-scale policies promoting sustainable development targets, such as halting biodiversity loss, building a competitive green economy and nurturing a healthy environment, gender equity and international cooperation. An important characteristic of this storyline is a substantial increase in the production and use of biofuels, growth of local biogas energy production and the related spa sector. This scenario is consistent with ALARM SEDG 2050 scenario storyline.

The extent to which individual scenario narratives differed from each other is qualitatively summarized in Fig. 3. The Biofuels scenario represents the most extreme narrative in terms of the assumed intensity of driving forces, namely implementation of EU sustainability policies. A contrasting vision is represented by the Exploitation scenario, assuming low importance assigned to environmental issues and a predominant influence of local drivers (such as local pursuits of economic revenues). The BaU and Market scenarios are similar in terms of assuming competitive economic conditions and rather reactive attitudes to environmental issues. The Conservation scenario represents a continuation and intensification of current, locally-driven nature-protection endeavours.

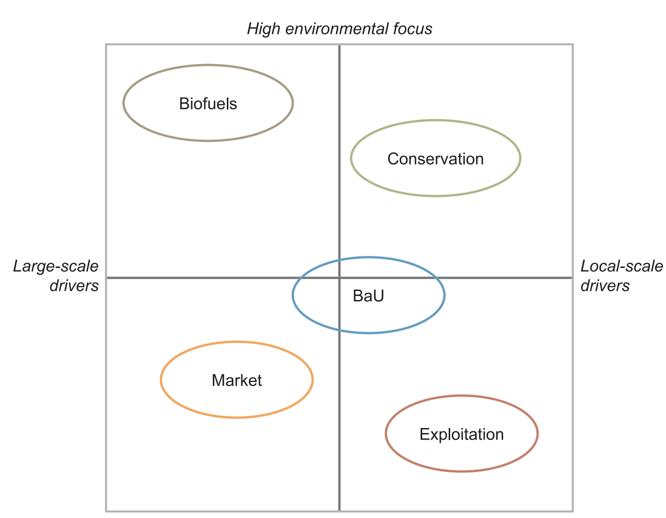

Fig. 3. The location of five scenario narratives to 2050 for Třeboň Basin BR along the gradients of environmental focus and spatial scale of key drivers.

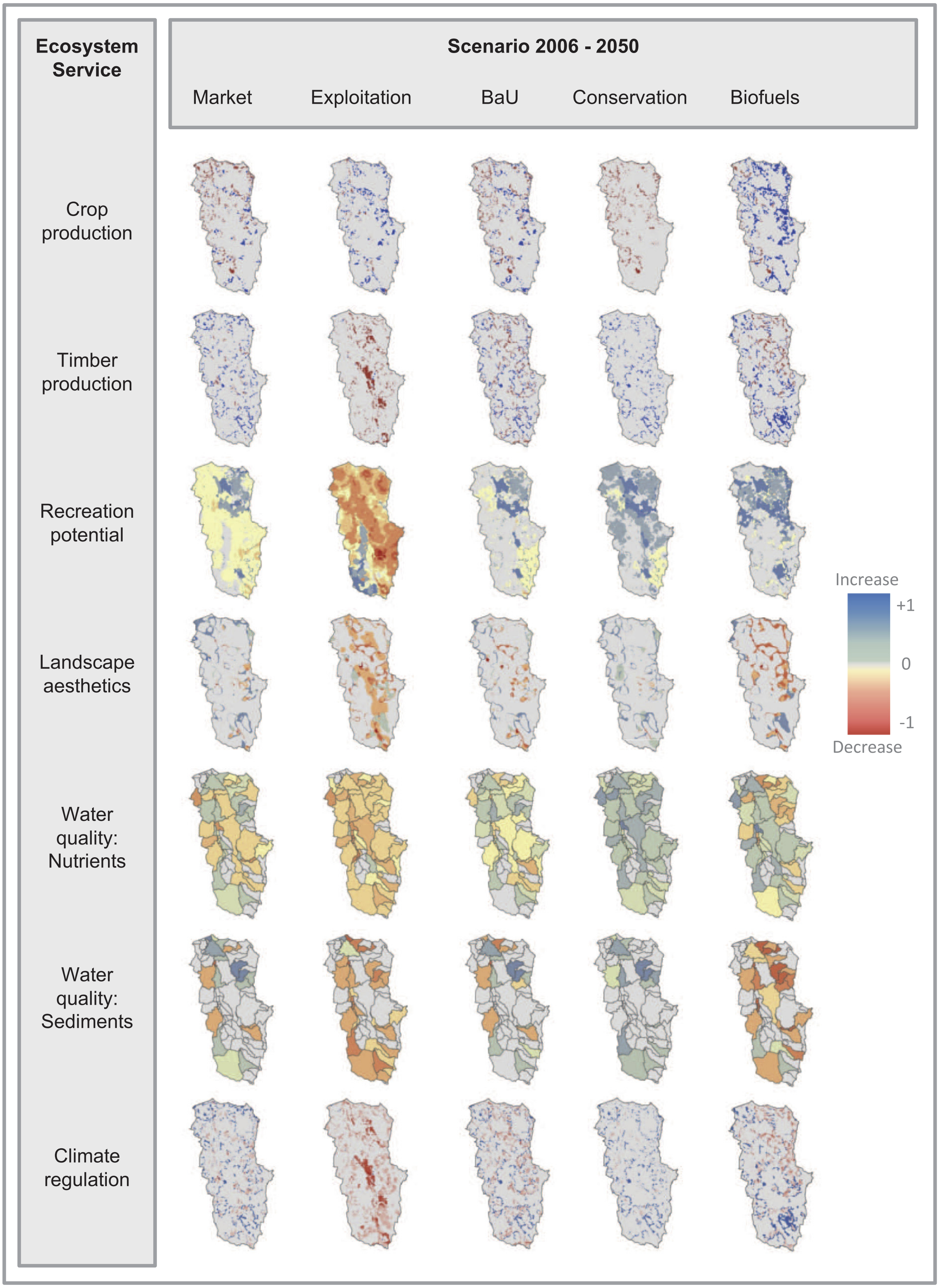

Fig. 4. Spatial patterns of change in ES provision in Třeboň Basin BR for five scenarios to 2050 (compared to the 2006 baseline). The change in ES provision was normalised to interval [−1,1] within each ES. Areas with zero change are rendered in grey.

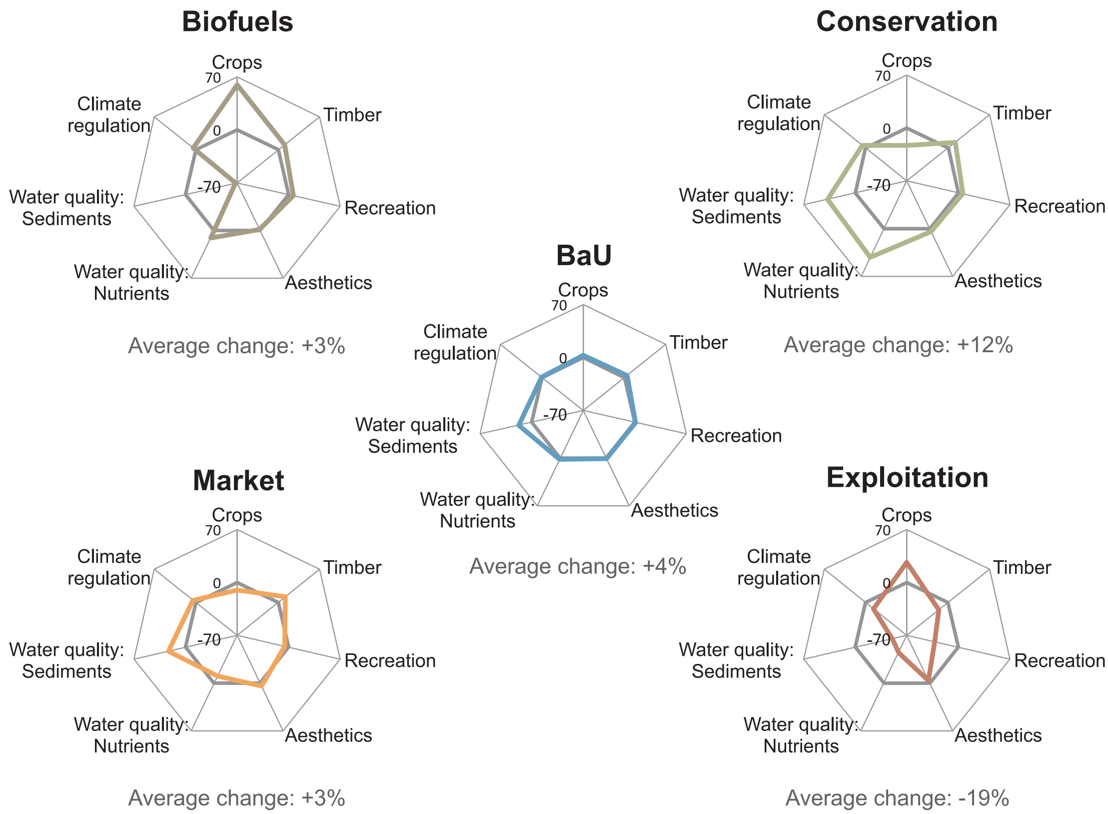

Fig. 5. Relative change in ES provision in Třeboň Basin BR for five scenarios to 2050 (compared to the 2006 baseline) with an aggregated (average) value for each scenario [%].

3.2. Scenario outcomes

3.2.1. Aggregated comparison of scenario outcomes

Contrasting scenario narratives resulted in a range of ES outcomes, including relative change in ES provision, trade-offs and synergies. Relative change in ES provision for each scenario is illustrated in Fig. 4 in spatial terms and in Fig. 5 in aggregate terms. In addition, absolute quantification of ES under each scenario is provided in Table S10.

The most different levels of ES provision occurred under contrasting, locally-driven Conservation and Exploitation narratives. While the Conservation scenario resulted in the highest average increase in ES provision (+12%), the Exploitation scenario was the only one leading to an average decrease in ES provision (−19%). The globally-driven narratives, Market and Biofuels, stemming from entirely different storylines and landscape development assumptions (e.g. contrasting emphasis on environmental issues), resulted in an identical, minor aggregated change in ES provision (+3% in both cases), similarly to the BaU scenario (+4%).

Contrary to the aggregated level of change in ES provision, the Biofuels scenario was characterised by the highest level of trade-offs between different ES, while the Market scenario resulted in a moderate level of trade-offs. The BaU resulted in a minor concurrent increase in the provision of different ES. The Conservation and the Exploitation storylines uniformly resulted in a synergy among ES (although going the opposite direction), with the exception of crop provision.

The within-scenario proportions between the resulting levels of individual ES followed distinct patterns under different scenarios (Fig. 5). Crop production represented an ES most commonly in a trade-off with other ES. Crop production and timber production developed in an opposite direction in most of the scenarios, specifically those assuming a large-scale LULC change (Conservation, Market, Exploitation). On the contrary, increase in potential timber provision mostly occurred in synergy with other regulating and cultural services, mainly due to enlarging forest areas. Most scenarios showed synergies between individual regulating ES (climate regulation, water quality regulation in terms of nitrogen and sediment retention). However, regulating services in the Market and Biofuels scenarios did not change according to this pattern, indicating a trade-off between climate regulation and water-related regulating services. The Biofuels and Market narratives resulted in trade-offs between cultural ES – recreation potential and landscape aesthetics.

The change in individual ES followed various patterns. Water quality regulation by nutrient retention together with crop provision showed high differences in both magnitude and direction of change under different narratives (−45% to +60%), followed by timber provision, recreation potential and climate regulation (−32% to +12%). The absolute level of soil erosion was very low in the study area in general, mainly due to its lowland character; therefore, the resulting sediment export to streams was minor (Table S10), although its relative change in different scenarios reached substantial values (−68% to +38%). The change in landscape aesthetics was not substantially influenced by the diversity in scenario narratives (−4% to +4%).

3.2.2. Spatial comparison of scenario outcomes

The values of MCS for different scenario outcomes (Fig. 6, Table S11) illustrated that the ES bundle maps resulting from individual scenario narratives did not lead to substantially different spatial patterns (MCS ranging between 2.97 and 11.22).

Similarly to the previous aggregated comparison, MCS showed that even in spatial terms the ES provision in the Exploitation scenario represented an outcome most outlying among the other scenarios (MCS of 8.33–11.22), followed by the Biofuels scenario (Fig. 6, Table S11). The Conservation scenario covered a wide range of differences from other scenario outcomes, ranging from very similar (to the BaU scenario, MCS = 2.97) to contrasting (with the Exploitation scenario, MCS = 10.30).

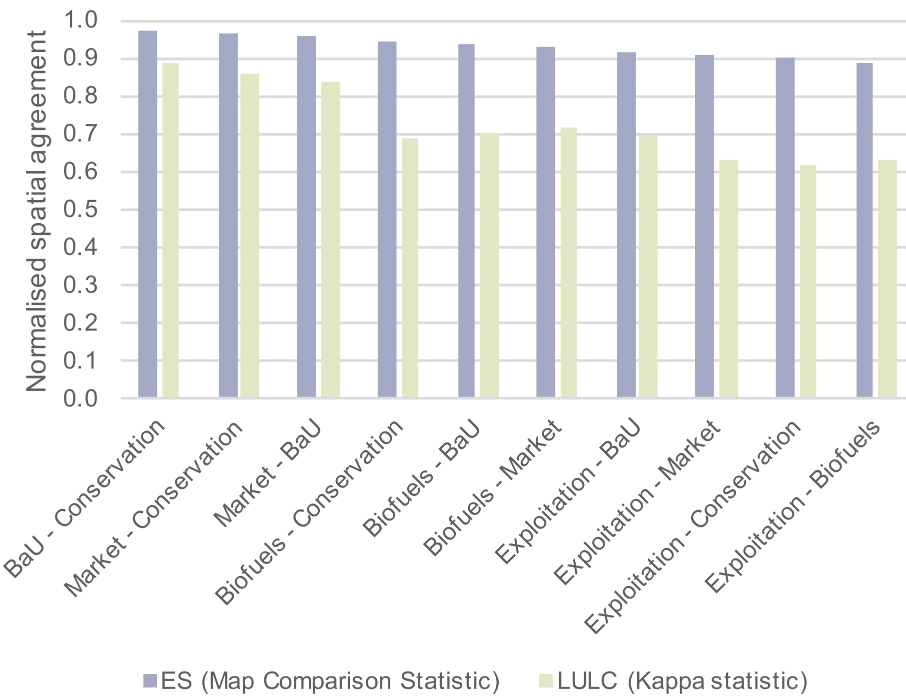

Fig. 6. Spatial agreement between pairs of scenarios in terms of ES provision (Map Comparison Statistic) and LULC (Kappa statistic); the normalised values of both statistics range between 0.0 (no agreement) and 1.0 (full agreement).

Interestingly, in terms of spatial differences, the Exploitation scenario contrasted the most with the Biofuels scenario (MCS = 11.22), and not with the Conservation scenario (MCS = 10.30) as suggested by the aggregated comparison in ES provision above. On the contrary, the Biofuels and the Conservation scenarios, both driven by strong environmental narratives, resulted in only a moderately similar pair of outcomes (MCS = 6.00), which is related to the presence of ES trade-offs in the Biofuels scenario and their absence in the Conservation scenario. The Conservation, BaU and Market scenarios resulted in most similar outcomes in terms of spatial distribution (MCS of 2.97–4.05).

Finally, we examined whether the spatial differences between the scenario outcomes originated from the stage of LULC assignment or subsequent ES modelling, in order to disaggregate the source of difference between the scenarios. For this purpose, we compared the differences between the maps of ES provision (using MCS as described above), and between the intermediate maps of LULC (using Kappa statistic) (Fig. 6, Table S12). The results show that although the similarity between the ES outcomes significantly correlated with the similarity between the underlying LULC maps (Spearman's rho for MCS and the Kappa statistic, $\rho = 0.89$, $p < 0.05$), the level of agreement between ES outcome maps and LULC maps varied across different pairs of scenarios (Fig. 6). For instance, the Market, BaU and Conservation scenarios had very similar values of MCS and Kappa, indicating that most of the agreement between the respective ES outcome maps can be attributed to the underlying LULC. On the other hand, the normalised values of MCS and Kappa converged much less in the case of the Exploitation and Biofuels scenarios, showing that other phenomena than underlying LULC are responsible for the final agreement of the ES outcomes. Interestingly, spatial agreement between the ES outcomes was consistently higher than the agreement between the underlying LULC maps. These results illustrate that while a substantial proportion of the difference between ES outcomes can be attributed to the underlying LULC patterns, the relationship is by no means linear and the complex process of ES provision has a substantial effect on the final difference between scenario outcomes.

4. Discussion

4.1. Uncertainty-related insights

Policies directly or indirectly affecting ES provision may be well defined; still, the ways the system in scope changes in response to them is often difficult to predict. Such situations require policies which will succeed in a variety of situations and explicitly acknowledge the variability uncertainty of the system (Walker et al., 2003).

In this study, we argue that comparing the differences among scenario narratives on the one hand and resulting ES outcomes and trade-offs on the other provides a new perspective on variability uncertainty in scenario planning and is particularly helpful to acknowledge multiple sources of uncertainty in landscape-related decision making. Our approach identifies a range of scenario narratives within which the ES outcomes are converging (or diverging), and thus makes the role of variability uncertainty related to ES provision more explicit. For decision-makers, such ranges of narratives can serve as a basis to formulate landscape development policies and action pathways, plausibly leading to desirable ES outcomes across a wide range of futures, while being robust towards deviations of assumptions related to a specific scenario pathway (Riley et al., 2016).

Our results show that diversity in the narrative scenario space does not necessarily translate to diversity in the space of modeled ES outcomes, and vice versa, that similarity between narratives can result in contrasting scenario outcomes. This discrepancy between the ranges of narrative and outcome spaces explicitly illustrates the role of variability uncertainty in SES, in addition to comparing scenarios as a whole, without explicitly distinguishing between their narrative and outcome part. An explicit analysis of the differences among scenario narratives and outcomes can thus serve as the basis for more profound evaluations of policies and decision pathways over a set of possible futures (Haasnoot et al., 2013) or against specific types of uncertainties (Dessai and Hulme, 2007).

In terms of desirability of scenario outcomes, our results imply that in the case that a certain range of scenario narratives leads to similar ES outcomes, and provided these outcomes include an aggregated increase in ES provision or low-intensity trade-offs, then adopting landscape management policies and decisions within the narrative range have a higher potential to lead to the desired outcome. Furthermore, through including different combinations of local- and larger-scale driving forces in our scenario analysis, we show that there are multiple consistent pathways in which local agency and local-scale driving forces can be steered to mitigate or amplify the larger-scale drivers, and thus navigate to a desirable outcome (or a very similar set of desirable outcomes). While the inherent variability uncertainty of the system remains unchanged in all cases, this insight can help formulating landscape management strategies leading to specific ES outcomes across a wide range of plausible futures, as well as to reduce undesired impacts.

In our case, the results indicate that actions complying with the narrative range between the Market and Conservation scenarios may lead to similar, favourable outcomes in terms of ES provision level and trade-offs (Figs. 5, 6, Table S11). However challenged by multiple pressures, Třeboň Basin BR represents a rare example of an area currently providing a balanced set of provisioning, regulating and cultural ES (Jeník and Přibyl, 1978; Pokorný et al., 2000). While recognizing that all SES are inevitably dynamic and changing (Folke et al., 2010), the results show that keeping status quo is a pathway within a broad range of narratives all leading to very similar ES outcomes with net increase in ES provision and low trade-offs, and thus may represent the most desirable pathway in the local context.

From the scale perspective, while the scenarios emphasising large-scale driving forces (Market, Biofuels) resulted in diverse types of ES trade-offs (e.g. among regulating versus among cultural ES), the primarily locally-driven scenarios (Exploitation, Conservation) resulted in much more synergic and coherent levels of ES provision. The implication for landscape planning under inherently uncertain conditions here is that strong emphasis on steering local driving forces may concurrently affect multiple ES to a large extent (positively or negatively), while following larger-scale development may result in less pronounced change in ES provision, however, leading to a wide range of trade-offs between individual ES.

From the perspective of policy targets, the sustainability-targeted Biofuels narrative did not result in a synergistically increasing set of ES. On the contrary, the trade-offs resulting from this narrative were the most substantial of all scenario narratives in the analysis. This result implies that an outlying narrative strongly emphasising a particular policy aspect (although sustainability related) may lead to a scenario outcomes with unintended negative impacts on ES provision (large trade-offs, decrease in important types of ES), which urges landscape planners and decision makers to treat outlying scenario narratives with caution.

On the contrary, apparently non-outlying narratives can lead to substantially outlying ES outcomes. For instance, the Exploitation narrative did not vastly differ from the BaU (e.g. it presumed merely increasing some of the pressures against local nature protection regime which are present in the area already), but resulted in the most extreme drops in ES provision out of all our scenarios. Interestingly, although the Exploitation narrative did not appear as different from the BaU narrative as e.g. the Biofuels one, it resulted in ES provision much more different than between BaU and Biofuels. In other words, if local stakeholders and decision-makers choose to follow the pathway of weakening landscape protection and opening it to unsustainable profit-making, which might not seem as a substantial change in comparison with the present state, the magnitude of potential impacts in terms of ES provision may be unforeseen and vastly exceeding the extent of change which could be judged upon based on the difference of the Exploitation narrative from the other scenarios.

Finally, the results show that a large proportion of the differences between scenario outcomes emerged already at the stage of the intermediate LULC maps – in all cases, the final ES outcomes showed even less difference than their underlying LULC maps. At the same time, the pattern of convergence between LULC and ES outcomes across scenarios was varied and non-linear. While part of the similarity between LULC and resulting ES levels was caused by the fact that provisioning services were modelled by an LULC-based proxy approach, crop and timber provision represented only two out of seven services aggregated in the assessed ES bundles, which means that their influence on the strength of the correlation was limited. This result implies that landscape planners need to carefully consider the extent of LULC changes, since these determine the range of plausible future ES outcomes. Nevertheless, the results also illustrate that the complex and non-linear nature of ES provision needs to be accounted for in addition to LULC changes. Accordingly, both the process of LULC change and ES provision need to be reflected in uncertainty assessments accompanying landscape planning.

4.2. Interpretation implications

In this section, we discuss the interpretation issues related to the comparison approaches we applied in this paper to derive uncertainty-related insights. These interpretation-focused considerations are particularly relevant for scientific contributions and reports providing the knowledge base for the science-policy interface (Goldstein et al., 2012; Nelson et al., 2009).

Our results show that the extent to which scenario outcomes appear similar depends on whether they are analyzed spatially or aspatially, since various approaches highlight different aspects of the scenario similarity. While the aggregated approach suggests that the ES provision differs the most between the Exploitation and the Conservation scenario, from the MCS spatial perspective, Exploitation differs the most from the Biofuels scenario. Since aggregated representation and visualisation of ES outcomes is very common when reporting the results of scenario analysis (McInnes, 2013; Meacham et al., 2016; Mitchell et al., 2014), this observation highlights the need to apply multiple spatial and aspatial approaches in parallel to analyse differences between scenario outcomes (such as in Schulp et al., 2014), in order to capture all aspects of their convergence or divergence. This needs to be taken into account both by ES researchers providing the knowledge base for decision makers, as well as by practitioners when interpreting the results of scenario analyses. In this respect, the MCS provides a useful tool for formally assessing spatial similarity across many ES maps.

In addition, this study highlights the importance of reporting the absolute values of ES provision (Table S10) and spatial comparison between scenario outcomes (Figs. 4 and 6) in addition to focusing merely on the relative change between the baseline and scenarios when reporting the results (such as in Goldstein et al., 2012; Nelson et al., 2009). While low relative changes may unintentionally imply a stable, non-exacerbating development, this may in fact mean sustaining an undesirable or low level of ES provision. On the contrary, high relative change in ES provision compared to baseline may still mean keeping low absolute values of ES provision in the baseline landscape (e.g. such as in the case of sediment retention in this study).

Even though this study presents a transparent approach building on well-established methods, several challenges need to be taken into account. An aspect requiring attention is that any approach comparing a single number or aggregated index for each scenario outcome (including ES bundles, the average relative change in ES provision or the MCS in this study) may partially conceal some of the differences between respective scenarios and lead to stronger correlations between the measures of similarity among scenario outcomes, which needs to be acknowledged and communicated to the audience of the research. Furthermore, a challenging aspect of the comparison of scenario narratives is that their differences are assessed qualitatively, based on their linguistic similarity. Although such an approach to the comparison of scenario narratives has been well established in the scenario literature (e.g. Hunt et al., 2012), it is characterised by substantial epistemic uncertainty and may be further developed e.g. by using fuzzy-set based approaches (Kok, 2009), in order to increase the robustness of the comparison results. These observations highlight that simple approaches to compare scenario narratives and outcomes can be highly informative but need to be interpreted and communicated with caution, especially when aiming to inform strategic environmental decisions and landscape management (Metzger et al., 2010).

5. Conclusions

This study discussed uncertainty-related insights derived from the assessment of the differences among scenario narratives on the one hand and scenario outcomes on the other. We applied a feasible semi-quantitative approach, transparent for the audiences of ES assessments such as landscape managers and decision makers. We argue that the uncertainty perspective we suggest may bring a different angle in landscape management considerations, acknowledging the range of the variability uncertainty space that decision makers operate in.

This study illustrates that substantially different scenario narratives may lead to similar levels of modelled ES provision, and vice versa, that similar narratives may result in contrasting scenario outcomes. At the same time, we emphasise that different approaches to assess the differences among scenario narratives and outcomes need to be applied and reported with caution to avoid misinterpretations. In particular, combining both spatial and aspatial approaches to the comparison of scenario outcomes is important to highlight different aspects of their convergence or divergence.

Finally, we conclude that analysing the distinctions among scenario narratives and among resulting ES provision outcomes may help decision-makers to account for the inherent level of uncertainty in the system in scope when formulating landscape management decisions and policies.

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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.ecoser.2018.06.005.

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