Assessing impact of land use and climate change on regulating ecosystem services in the Czech Republic

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Abstract. Ecosystem services, defined as benefits provided by ecosystem functioning to society, are essential to human well-being. Due to global environmental change and related anthropogenic drivers, ecosystems are often degraded, which hinders the delivery of ecosystem services. This study aims to quantify the impacts of land use and climate change on two regulating ecosystem services—carbon sequestration and water purification in terms of nitrogen retention in the Czech Republic. While employing approaches of scenarios and modeling, we illustrate current and potential future status of these ecosystem services. Our results show that among the ecosystem change drivers, one of the dominant domestic land-use change of ALARM BAMBU (Business-As-Might-Be-Usual) scenario is change of arable land and grassland to forest area that increases by 4.5% in 2080 compared to 2000. The results of ecosystem service modeling based on BAMBU scenario for the years 2050 and 2080 indicate that the highest yearly carbon sequestration rate occurred in 2000–2050, reaching 640 GgC·yr−1, 2000–2080 shows decline in this regulating service by 16%. Average nitrogen leaching to water streams reached 0.75 kgN·ha−1·yr−1 for BAMBU in 2050 scenario and 0.80 kgN·ha−1·yr−1 for BAMBU in 2080 scenario as a result of decreasing nitrogen load, which suggested a decrease in nitrogen pollution compared to 2000. Since ecosystem services have not been extensively mainstreamed into research and policies in eastern European countries, we aim to contribute to improvement of knowledge on current status and potential future pathways of the provision of regulating ecosystem services in the Czech Republic.

Key words: Czech Republic; drivers; ecosystem services; InVEST; modeling; scenarios; Special Feature: Ecosystem Management in Transition in Central and Eastern Europe.

Introduction

Ecosystem services have become an important subject of research in recent years because of their ability to reflect and describe complex relationships between human society and the environment (De Chazal et al. 2008, TEEB 2010). The currently prevailing definition, presented in the Millennium Ecosystem Assessment (MA 2005), establishes ecosystem services as material and nonmaterial goods and services provided to humans by ecosystems. Although there have been more classifications of ecosystem services (e.g., De Groot et al. 2002, Wallace 2007, Costanza 2008, TEEB 2010, Haines-Young and Potschin 2013), the classification systems brought by MA, TEEB, and CICES are the ones most widely used.

A favorable state of ecosystems and their functioning are the basic preconditions of ecosystem service provision. However, due to the increasing demands of society and the pace of global environmental change, the capacity of ecosystems to provide ecosystem services has been changing at a rate that is possibly historically unprecedented (MA 2005, Verburg 2006).

Land use and land cover (LULC) change has been identified as a major driver leading to the loss of biodiversity and ecosystem services (Foley et al. 2005, Cardinale et al. 2012). The provision of ecosystem services substantially depends on LULC and its composition and spatial characteristics (MA 2005). Therefore, LULC change often...
serves as a visual representation of specific scenarios, conveying potential future development and reflecting impact of other drivers in the environment (Rounsevell et al. 2006). For instance, the conversion of natural land cover and land-use change is leading to changes in the carbon balance and changes in nutrient flows across landscapes (Foley et al. 2005).

Another important driver affecting the distribution and functioning of natural ecosystems is climate change (Parmesan and Yohe 2003), which is expected to increasingly threaten natural ecosystems and biodiversity (EEA 2015). Climate change impacts are already affecting species distribution, range and interaction and are projected to become a more significant threat in the coming decades (EEA 2012).

A robust approach to analyzing potential impacts of LULC change and climate change is the scenario approach, aiming to explore possible future states and consequences of different landscape management options (Rounsevell et al. 2006). The application of multiple future scenarios provides the potential for comparison between the current status and scenario development as well as exploring spatial patterns of ecosystem service provision across the landscape (Nelson et al. 2009).

An example of a modeling tool employing scenarios within the assessment of ecosystem services is the InVEST suite of models, which is primarily based on land use and land cover maps and scenarios (Daily et al. 2009, Kareiva et al. 2011). InVEST enables ecosystem service assessment and evaluation in both biophysical and monetary terms and has been utilized in numerous case studies worldwide, mostly in tight collaboration with local decision-making processes (Nelson et al. 2009, 2010, Cardinale et al. 2012, Goldstein et al. 2012, Johnson et al. 2012, Arkema et al. 2013). Moreover, as a spatially explicit assessment tool utilizing an ecosystem services framework, climate scenarios, and land-use changes analysis, it has the potential to serve as a useful approach for assessing and designing suitable adaptation options (Lorencová et al. 2013).

As in other Eastern European countries, the Czech Republic has encountered substantial land cover change and land-use intensification over the past decades, resulting mainly from socio-political causes (Lorencová et al. 2013). In the period 1948–1989, these comprised socialist industrialization, land consolidation, while interlining and agricultural intensification caused landscape degradation. After 1990, the new political conditions and economic transformation have led to substantial increase in urban fabric, industrial and commercial areas and grasslands (Bíck et al. 2001). These particular LULC changes have been even more substantial in the Czech Republic than in most of the Eastern European countries (EEA 2006, LEAC 2014).

Recently, there have been several studies assessing ecosystem services in the Czech Republic. The first pilot study was a survey on grassland ecosystem services (Hönigová et al. 2012). At the national level, the study on integrated assessment of ecosystem services was conducted using a benefit transfer valuation, which calculated that the average annual value of ecosystem services in the Czech Republic represents 1.5 the current gross national product (Frélichová et al. 2014). On the regional level, Pithart et al. (2010) assessed potential impact of different approaches to floodplain restoration on the provision of flood-water retention and other ecosystem services. Nevertheless, important umbrella ecosystem services, for example, carbon sequestration and nutrient retention, remain hitherto not assessed in the context of the Czech Republic.

The aim of this study was to quantify the impacts of land use and climate change on two regulating ecosystem services—carbon sequestration and water purification in terms of nitrogen retention in the Czech Republic at the national, respectively, local level, taking into account the baseline status (2000), and future scenarios for 2050 and 2080. In our study, we modeled carbon sequestration in the Czech Republic, while at the local scale we assessed nitrogen retention in the Třeboň Basin UNESCO Biosphere Reserve. While employing approaches of scenarios and modeling, the study illustrates current and potential future status of the two regulating ecosystem services.

In the following sections, we first present the methodological framework of our analysis demonstrating how the impact of the drivers, such as climate and land-use change, can be transformed into various future scenarios on national and local scales. Subsequently, we introduce the LULC data sets and scenarios applied, and the modeling approach used to assess the provision of ecosystem services. The last two sections discuss and conclude the approaches illustrated by our case studies.

**Materials and Methods**

**Drivers of ecosystem change in the Czech Republic**

Drivers of ecosystem change may start at different levels; they can be of various kinds and may eventually affect different ecosystem services (Nelson et al. 2006, Butler et al. 2013). We distinguish between indirect and direct drivers. The indirect drivers include, for example, demographic changes, economic growth, socio-political changes, cultural changes, changes in behavior, and progress in science and technology. Furthermore, these indirect drivers influence direct drivers of change such as land-use change, including natural habitat conversion, environmental pollution, climate change, and invasive species reintroduction (MA 2005, UK NEA 2011).

In this study, we utilized a methodological framework (Fig. 1) conceptualizing the impact of direct and indirect drivers on the provision of ecosystem services. Specifically, we applied future scenarios incorporating the influence of LULC and climate change drivers, to assess potential impact on carbon sequestration and nutri-
ent retention in the Czech Republic. Importantly, Fig. 1 illustrates direct and indirect drivers as elements of future scenarios. We applied ALARM scenarios—LULC scenarios including climate change aspects based on IPCC SRES scenarios (for more details, see following section).

**Land use and land cover change and scenarios**

LULC change represents a complex driver, comprising an array of partial drivers such as climate change, economic and demographic changes, technological changes, etc. (Verburg et al. 2004, Rounsevell et al. 2012). We analyzed LULC using CORINE Land Cover (CLC) database, capturing time periods 1990, 2000, and 2006. CLC comprise a spatially explicit database of mixed land use and land cover classification, which enables spatial and temporal analysis of land-use change. The CLC differentiates 30 categories in the Czech Republic, of 44 classes recognized in Europe. CORINE Land Cover serves as the basis for natural capital and ecosystem accounting in Europe, enabling also the construction of so-called land and ecosystem accounts and land cover flows (Weber 2007).

In the case studies, we utilized the CORINE Land Cover 2000 (CLC 2000) data set as the source of baseline maps of land use and land cover. The resolution of CLC 2000 corresponds to a map scale of 1:100,000 and the data sets are based on a minimum mapping unit of 25 ha. This resolution presented a compromise between accuracy and data processing possibilities on both spatial scales (Bossard et al. 2000).

Within this study, we applied ALARM scenarios that are land-use scenarios based on IPCC SRES scenarios, which have been further downscaled from European to country-specific level, for the years 2020, 2050, and 2080 (Spangenberg 2007, Spangenberg et al. 2012, Fronzek et al. 2012). Of the three key scenarios, we selected the BAMBU (Business-As-Might-Be-Usual) scenario that is based on A2 IPCC SRES scenario for years 2050 and 2080. The BAMBU scenario was selected as it is a policy-driven scenario, which reflects and extrapolates current and expected trends in EU policies and includes climate mitigation and adaptation measures as well as biodiversity protection policies. Within this scenario, environmental policy is perceived as another technological challenge (Spangenberg 2007).

**Impact on two regulating ecosystem services in the Czech Republic**

The impact on selected ecosystem services was modeled using InVEST, presenting a tool primarily based on LULC maps and scenarios (Daily et al. 2009, Kareiva et al. 2011). InVEST has been introduced by the National Capital Project initiative and comprises a suite of modeling tools enables ecosystem service assessment and evaluation in both biophysical and monetary terms. These modeling tools are based on LULC scenarios and have two major assets: first, their results are presented in spatially explicit way in the form of maps of ecosystem service provision, which are easily communicable to the public and to decision makers. Second, InVEST provides the option to estimate trade-offs and synergies among ecosystem services under various scenarios. Technically, InVEST Tier 1 models link land cover to the provision of particular ecosystem service through ecological production functions, utilizing a number of parameters (see Appendix S1). The data for each of the parameters are usually based on published field experiments (Bagstad et al. 2013).

We utilized the InVEST modeling tools to assess the impact of anthropogenic activity on regulating ecosystem services, representing the most vulnerable, and at the same time vital group of ecosystem services, which serve as the basis for the provision of other ecosystem service...
types. Furthermore, the level of regulating ecosystem services tends to decrease with increased production of provisioning ecosystem services (Bennett et al. 2009).

The modeled ecosystem services, carbon sequestration and nutrient retention, were assessed on two different spatial scales, national, and local. The reason for modeling on two spatial scales was derived from the spatial character of these ecosystem services: while nutrient retention is mainly relevant for stakeholders on a local scale, carbon sequestration presents an ecosystem service benefiting broader, national scale, area (Costanza 2008). In our regional case study, we modeled carbon sequestration in the Czech Republic, whereas on the local scale we assessed nitrogen retention in the Třeboň Basin UNESCO Biosphere Reserve.

**Carbon sequestration**

Climate regulation mitigates the adverse impacts of climate on human well-being and biodiversity (MA 2005). Carbon sequestration is one of the most widely recognized ecosystem services, particularly with respect to the climate change mitigation potential that has been acknowledged by international treaties like Kyoto Protocol and voluntary carbon offset markets (Conte et al. 2011).

In this study, climate regulation was expressed by the indicator of carbon storage and sequestration in terrestrial ecosystems in the Czech Republic. We assessed the ecosystem service of carbon sequestration for the whole country, since it represents an ecosystem service which is spatially nonspecific in terms of demand and beneficial regardless of the exact location of its production and consumption (Costanza 2008). The amount of sequestered carbon within a particular time period was calculated by subtracting carbon stored at the beginning of the period from the carbon stored at the end of the time period.

The Carbon storage and sequestration tool (InVEST 2.4.4 version) estimates the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time through utilization of four carbon pools: aboveground biomass, belowground biomass, soil, and dead organic matter (see Appendix S1). Aboveground biomass includes all living plant material above the soil level, whereas belowground biomass comprises the living root system of aboveground biomass. Soil organic matter is defined as the organic component of soil, and dead organic matter includes litter as well as lying and standing dead wood. The model aggregates the amount of stored carbon according to the land-use maps and their particular classification. If the current and future land use and land cover (LULC) map is provided, then the net change of carbon storage over time (sequestration and loss) and its social value can be calculated (Tallis et al. 2011).

**Water purification: nitrogen retention**

Nutrient retention is defined as the ability of vegetation and soil to uptake and retain nitrogen from water run-off. It is considered to be spatially related to local water flows and their direction (Costanza 2008), therefore, we assessed nitrogen load and retention on a local scale. The Třeboň Basin is particularly threatened by nitrogen loading from intensively fertilized fish ponds (Musil et al. 1996), which are discharged during regular pond-fishing. Other inputs of the excessive nitrogen load to water streams are nonpoint sources, such as fertilized agricultural land. Nitrogen loading presents a major cause of eutrophication, which adversely affects human health and activities (Anderson et al. 2002).

We utilized the Nutrient retention tool (InVEST 3.1.3. version) to assess the annual level of nitrogen leaching to stream network as an indicator of the ecosystem service of water purification provided by the Třeboň Basin, calculated as:

\[
\Delta N = L - R
\]

where \(L\) represents the amount of nitrogen load, \(R\) represents the amount of nitrogen retained in the landscape as a measure of the capacity to provide an ecosystem service, and \(\Delta N\) stands for the amount of nitrogen leaching annually to the stream network. Nitrogen leaching was calculated for the baseline landscape and the BAMBU 2050 and 2080 scenarios.

In addition to the BAMBU land use and land cover scenarios for 2050 and 2080, we utilized climate projections complying with RCP4.5 scenario to derive conservative estimates for future climate parameters. For additional information on data inputs, see Table 1 (for detailed information see Appendix S1). Further details regarding the modeling process and the parametrization of the Nitrogen Retention model are provided in Harmáčková and Vačkář (2015).

**Results**

**Land-use change within BAMBU scenario in 2050 and 2080**

Changes between baseline (CLC 2000) and BAMBU scenario in years 2050 and 2080 have been quantitatively as well as spatially analyzed. The three major land-use changes of the respective BAMBU scenario years are presented in Table 2. In the BAMBU scenario, the change of arable land to forest shows the highest rate, accounting for 5% of the total area in 2080. Other major changes include replacement of grassland by forest or arable land as well as forest by arable land, accounting individually for approximately 2%, the forest area increases by 4.5% in 2080 compared to the baseline. Urban area increases by 1% in 2080.

Changes in 2050 are more distinct spatially; arable land is being transformed to forest particularly in the north-west and northern parts of the Czech Republic.
Grassland to forest changes occur mainly in the area of northern border and southern area of the Czech Republic. In general, changes between 2050 and 2080 resemble the changes in the previous time period. In 2080, changes of arable land to forest are slightly higher, considerably in the north-west, northern, and partially southern parts of the Czech Republic.

Assessing impact on selected ecosystem services in the Czech Republic

**Calculated carbon sequestration**

Carbon sequestration was calculated based on BAMBU scenario for time periods 2000–2050 and 2000–2080, compared to the baseline CLC 2000. Analyzed land-use categories included arable land, grasslands, forest, built-up, and permanent crops. Yearly sequestration rates under the BAMBU scenario have been calculated for the time periods 2000–2050 and 2000–2080. Average yearly carbon sequestration declined from 640 GgC·yr⁻¹ (8.11 MgC·km⁻²·yr⁻¹) in 2000–2050 to 535 GgC·yr⁻¹ in 2000–2080 (6.78 Mg C·km⁻²·yr⁻¹) and was caused mainly by shifts in land use over time, since the amount of carbon sequestered in any particular scenario was highly interconnected with LULC change.

Carbon sequestration under the BAMBU scenarios is illustrated in Table 3, showing the carbon sequestration rates connected with the most significant types of LULC changes. The highest rates include conversion of arable land and grassland to forest, which accounts for 126 MgCha⁻¹, respectively, 123 MgCha⁻¹.

**Calculated nitrogen retention**

The results (Fig. 3) show that while in the baseline landscape, the most significant amounts of nitrogen were leaching in the agricultural areas in the north-west of the Třeboň Basin, the amount of leaching nitrogen decreased under the future scenarios mainly due to the transformation from arable land to pastures and forests. On the contrary, forested areas were characterized by low nitrogen load, which remained relatively unchanged between the time slices. Although only minor changes in nitrogen load occurred between the baseline and the 2050 scenario (2080, respectively), there was a slightly decreasing general trend. While the aggregate nitrogen leaching for the baseline scenario reached 63.85 MgN·yr⁻¹ (0.93 kgN·ha⁻¹·yr⁻¹), it decreased to 51.52 MgN·yr⁻¹ (0.75 kgN·ha⁻¹·yr⁻¹) for the BAMBU 2050 scenario and 54.89 MgN·yr⁻¹ (0.80 kgN·ha⁻¹·yr⁻¹) for the BAMBU 2080 scenario. Similarly, the two underlying variables, nitrogen load and retention showed a decreasing trend both in 2000–2050 and 2000–2080 (Fig. 4). However, the decrease in nitrogen load and retention in 2000–2050 was more pronounced in 2050–2080. Therefore, the number of subwatersheds with nitrogen leaching exceeding the baseline was higher for 2080 than for 2050 (Fig. 3).

The change in nitrogen load retention and leaching was not pronounced and corresponded to the fact that only subtle changes in land use and land cover occurred between the baseline landscape, the BAMBU 2050 and the BAMBU 2080 scenario. Nevertheless, the most substantial decrease in nitrogen load occurred in

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**Table 1.** Data inputs into water purification and carbon sequestration InVEST modeling tool.

| Data type                          | Source                                                                 |
|------------------------------------|------------------------------------------------------------------------|
| Water purification—nitrogen discharge and retention | European Soil Database (ESDB 2004, Panagos et al. 2012)                 |
| Soil data                          | ZABAGED Contours (Czech Office for Surveying, Mapping and Cadastre)     |
| Digital elevation model            |                                                                        |
| Nitrogen export coefficients       | Reckhow et al. 1980, Musil et al. 1996,                                  |
| Carbon sequestration               |                                                                        |
| Carbon pools (aboveground, belowground biomass, soil, dead organic matter) | Freibauer et al. 2004, CzechTerra 2010, Tallis et al. 2011              |
| LULC                               | BAMBU scenarios (Spangenberg 2007, Fronzek et al. 2012, Spangenberg et al. 2012, CLC 2000 and 2006 |

**Table 2.** BAMBU scenarios LULC change compared to baseline (CLC 2000) in the Czech Republic.

| Type of LULC change | % change | LU change | % change |
|---------------------|----------|-----------|----------|
| arable to forest    | 4.28     | arable to forest | 5.04     |
| grassland to forest | 2.36     | grassland to forest | 2.48     |
| forest to arable    | 2.12     | forest to arable | 1.97     |
Table 3. Carbon sequestration rates related to LULC change under BAMBU scenario.

| LULC change         | Carbon sequestration (Mg C ha⁻¹) |
|---------------------|----------------------------------|
| grassland to forest | 123                              |
| forest to grassland | −123                             |
| grassland to arable | 3                                |
| arable to forest    | 126                              |
| arable to grassland | 3                                |
| forest to arable    | −126                             |

Discussion

General limitations: modeling limitations and uncertainties

This study aims to provide a pilot assessment of selected ecosystem services, as in case of the Czech Republic, there is a lack of ecosystem services assessments using modeling approach. Within the study, we employed scenarios to model current and future

![Carbon sequestration of BAMBU scenario](image)

**Fig. 2.** Carbon sequestration of BAMBU scenario (a) BAMBU 2000–2050, (b) BAMBU 2000–2080.
status of the two regulating ecosystem services. Since specific in situ measurements, which might serve as the basis for direct assessments of ecosystem services, are currently lacking in the Czech Republic, our approach focuses on InVEST modeling approach.

The InVEST suite of models has been recognized as suitable for multiple-scale assessments and allowing for the analysis of multiple services (Nemec and Raudsepp-Hearne 2012). Although it has been challenged as less accurate and noncomparable with process-based models focusing on individual ecosystem functions and services (Vigerstol and Aukema 2011), recent analyses show that the InVEST models are comparable with the outputs of more elaborate modeling tools (Bagstad et al. 2013). Since InVEST does not require an excessive amount of data inputs and utilizes proxy information, but is based on constructing ecological production functions, it presents a compromise between modeling accuracy and feasibility, and is therefore a suitable solution for a pilot assessment in areas less studied from the ecosystem service perspective (Maes et al. 2012, Kareiva et al. 2011).

The results of the study should therefore be regarded as indicative, due to modeling limitations, such as a simplification of the complex processes modeled or a compilation of data sources originating from various spatial scales (Schulp et al. 2014). Furthermore, there are several limitations connected to the combination of scenario and modeling approach that needs to be acknowledged when presenting the results. (a) It is recognized that there will always be uncertainty regarding particular scenario assumptions. Scenarios are not predictions, rather tools to assess future trends and developments (Raskin 2005) that may not adequately reflect the complexity of interlinkages between socio-economic, political factors, climate change and land-use change impacts and changes in ecosystems. (b) Limitation also lies within the relatively broad classification of ALARM scenario land-use categories that combine variety of LULC classes into one category. However, to best of our knowledge, combined climate land-use scenarios with finer land-use categories distinction and resolution are currently not available for the Czech Republic, neither at European scale. This limitation needs to be taken into account while analyzing results. On the other hand, it also provides opportunity to address further research needs concerning scenario development. (c) Another limitation is introduced by an assumption of a linear nature of the ecosystem services provision, while in reality delivery of services is rather nonlinear as it is conditioned by highly dynamic pro-

![Fig. 3. Nitrogen leaching in Tréboň Basin subwatersheds for the BAMBU 2050 and BAMBU 2080 scenarios as compared to 2000 (kg·ha⁻¹·yr⁻¹).](image-url)
cesses in nature. Nevertheless, quantitative measures to overcome this issue are generally unavailable (Koch et al. 2009).

Specific limitations

Nitrogen retention assessments

In terms of water quality, the impacts of the prevailing types of LULC changes were twofold, causing increasing nitrogen load, for example, due to commercial and industrial activities within growing urbanized areas (Camargo and Alonso 2006), whereas the increase in forest area and the decrease in agricultural land provided the potential for improved nitrogen retention under the 2050 and 2080 scenarios. Although transformation of wetlands presents a common cause of nitrogen cycle alterations, the changes in nitrogen load and retention modeled in the Třeboň Basin were not the case, since wetland area has not changed substantially between the baseline and the scenarios.

The resulting net nitrogen balance was more positive for the 2050 and 2080 scenarios than for the baseline landscape, which might seem desirable. However, it should be noted that the positive trend was not caused by an increasing capacity of the landscape to retain nitrogen, but by declining nitrogen loading in the Třeboň Basin.

The average nitrogen leaching was calculated between 0.75 and 0.93 kg·ha⁻¹·yr⁻¹ for the baseline landscape and future scenarios. These results are comparable with modeled nitrogen leaching of 0.26 kg·ha⁻¹·yr⁻¹ in the Šumava National Park, the Czech Republic, for the BAMBU 2050 scenario (Harmáčková et al., in press). The higher value in the case of the Třeboň Basin in this study resulted from the overall area of forests, which comprise approximately 45% in the Třeboň Basin and 59% in the Šumava national park, and substantially smaller proportion of agricultural land within the Šumava national park. On various spatial scales in Europe, nitrogen retention and its impact on water quality have been assessed in several studies; however, their results are not comparable due to different approaches to nitrogen retention assessment and different aspects of nitrogen retention modeled (Maes et al. 2012, Schulp et al. 2014).

It should be noted that the results of modeling nitrogen load, retention and leaching are purely indicative, since there are several sources of uncertainty. Besides the general modeling issues addressed above, localized studies on nitrogen loading levels are not available for the study area, and we thus had to rely on general estimates of nitrogen loads from various LULC types (Tallis et al. 2011, Reckhow et al. 1980). Nevertheless, this has been an issue recognized by other previous InVEST modeling studies (Goldstein et al. 2012).

Carbon storage and sequestration

Compared to other mitigation activities, carbon sequestration is natural and cost-effective processes with numerous ancillary benefits that are immediately applicable, but have finite sink capacity (Lal 2008). Moreover, carbon stored in ecosystems is an important

Fig. 4. Modeled trends in nitrogen load, retention and leaching in the Třeboň Basin for the baseline landscape (2000) and BAMBU 2050 and 2080 scenarios (kg·ha⁻¹·yr⁻¹).
indicator of regulation services potential, which is directly related to land-use disturbances and land management practices (Hönigová et al. 2012).

Based on the National GHG inventory data, Land Use, Land-Use Change and Forestry (LULUFC) sector in the Czech Republic removed 946 Gg C in 2006 (NIR 2012). When estimating annual carbon removals based on the time period of carbon sequestration, scenarios show around half the value, which is caused by different categorization and methodology used. However, in both time frames 2050 and 2080, LULC change under BAMBU scenario in the Czech Republic represents a net carbon sink.

According to Schulp et al. (2008) carbon stocks under the SRES A2 scenario (parallel to the BAMBU scenario) are supposed to decline by 6% between 2000 and 2030, which is in line with the results of this study. Analogically, the authors report an average change in carbon stocks in the majority of the area of the Czech Republic between −11.67 and 13.33 MgC·km−2·yr−1 in 2000–2030, which corresponds with the average of 8.11 MgC·km−2·yr−1 in 2000–2050 estimated in our assessment.

Regarding carbon storage and sequestration, Tallis et al. (2011) states the model limitations that originate in oversimplification of the carbon cycle that allows the model to run with relatively little information. It is assumed that all LULC types contain a fixed average carbon storage level; therefore, changes in carbon storage over time occur only due to changes in LULC type or from wood product harvest. The resulting accuracy depends on LULC classification used. Yet another limitation is that InVEST does not capture carbon that moves from one pool to another (e.g., transfer of carbon between living biomass and dead organic matter). Furthermore, carbon emissions due to management activities (e.g., tractors burning fuel, fertilizer additions, livestock use) are not included in the assessment. Finally, the model assumes a linear change in carbon storage over time, while in reality; most sequestration follows a nonlinear path. Due to data limitation, harvested wood products are not considered in the analysis, which could create a certain overestimation of carbon storage and sequestration results. These factors need to be taken into account when interpreting the results.

**Multiscale approach to ecosystem assessment**

When conducting ecosystem assessment, there is rarely one ideal scale suitable for multiple purposes. Ecosystem services have usually particular scales in space and time, at which they are most strongly expressed, most easily observed, or have their dominant drivers or consequences (MA 2003).

Besides, it is often either undesirable or unfeasible to conduct an ecosystem assessment at a single scale in time and space (Scholes et al. 2013). Because of the nature of the two regulating services—nutrient retention mainly relevant at local scale and carbon sequestration at broader, national scale, we distinguished between local and national scale. Concerning time scale, both case studies were conducted for 2000, 2050, and 2080.

**Decision-making context**

There have been substantial efforts to mainstream ecosystem services into policy and decision making at the European level, for example, the MAES initiative derived from the EU Biodiversity Strategy to 2020, which addresses the need to account for ecosystem services through biophysical mapping and valuation (Maes et al. 2012). However, despite some initial accomplishments in Eastern Europe (e.g., a pilot economic assessment of ecosystem services in the Czech Republic, based on the benefit transfer method (Frélichová et al. 2014)), the mainstreaming of ecosystem services into national policy and decision making needs to be further supported by assessments based on local data and more accurate modeling approaches.

**Links to LULC change in the Czech Republic**

The rate of LULC change in the Czech Republic decreased between the periods 1990–2000 and 2000–2006, comprising 0.81% and 0.33%, respectively. In the EU, the LULC change rate was lower in the corresponding periods, comprising 0.2% in 1990–2000 and 0.1% in 2000–2006 (EEA 2010). In other aspects, LULC trends in the Czech Republic corresponded to the EU, urban sprawl presenting the most important type of land-use change. The only substantial difference between Czech and general European LULC trends was in the area of grasslands, which has been vastly increasing in the Czech Republic, whereas there has been a slight decrease in grasslands on the European level in 2000–2006 (EEA 2010). In the Czech Republic, this has been mainly a result of changes in the system of agricultural subsidies (Bicík et al. 2015).

The impact of the most marked land use and land cover changes comprised a growing proportion of urbanized and built-up areas, together with decrease in agricultural land and a slight increase in forested land. The BAMBU scenario, selected for the analysis, further extrapolates and reflects these LULC trends.

**Conclusions**

Since ecosystem services have not been extensively mainstreamed into research and policies in Eastern European countries hitherto, this study aims to contribute to the improvement of knowledge on the current status and potential future pathways of the provision of regulating ecosystem services in the Czech Republic. Our study applies a spatially explicit assessment of ecosystem services in the Czech Republic, which
allowed us to link the analysis of long-term land-use trends with spatial changes in the delivery of particular ecosystem services. Nevertheless, the combination of scenario and modeling approaches presents a substantial simplification of the complex processes modeled that needs to be acknowledged when interpreting the results (see Discussion).

This study suggests that the carbon stocks in the Czech Republic are likely to decrease in the long term under a conservative, policy-driven business-as-usual scenario. Furthermore, it is important to note that the LULC changes projected under the utilized set of scenarios are rather moderate, and therefore the results could potentially represent low range estimates, provided the current higher pace of LULC change persists in the future.

Concerning the ecosystem service of water purification through nitrogen retention, our regional case study suggests a positive trend in both nitrogen load and retention resulting from the projected LULC changes. However, the modeled decrease in nitrogen load was followed by an even more substantial decrease in nitrogen retention, suggesting a possible exacerbation in the potential of the case study landscape to provide water-quality-related ecosystem services.

Most of the drivers influencing the provision of ecosystem services are influenced by political, societal or individual decision making. Therefore, it is vital to provide decision makers on all levels with science-based information regarding potential impacts of their decisions on ecosystem services and human well-being. Since our study provides the first initial insight into the issue of driving force impacts on ecosystem service provision in the Czech Republic, we recognize the need for future research applying more localized approaches. If available, more detailed models integrating diverse drivers and localized land-use scenarios are suggested to be utilized in the future, together with an increased number of case study areas, in order to provide more accurate estimates as the basis for better-informed and more sustainable landscape decisions.

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