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Past and future impacts of land use and climate change on agricultural ecosystem services in the Czech Republic

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ABSTRACT

Climatic and land use change are amongst the greatest global environmental pressures resulting from anthropogenic activities. Both significantly influence the provision of crucial ecosystem services, such as carbon sequestration, water flow regulation, and food and fibre production, at a variety of scales. The aim of this study is to provide spatially explicit information at a national level on climate and land use change impacts in order to assess changes in the provision of ecosystem services. This work provides a qualitative and quantitative analysis of the impacts on selected ecosystem services (carbon sequestration, food production and soil erosion) in the agricultural sector of the Czech Republic. This assessment shows that, historical land use trends and land use under projected climate scenarios display some shared spatial patterns. Specifically, these factors both lead to a significant decrease of arable land in the border fringes of the Czech Republic, which is to some extent replaced by grasslands, in turn affecting the provision of ecosystem services. Moreover, this assessment contributes to a useful method for integrating spatially explicit land use and climate change analysis that can be applied to other sectors or transition countries elsewhere.

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Introduction

Ecosystem services provided by agriculture receive increasing attention with regard to sustainability of agro-ecosystems and associated economic prosperity and human well-being (Power, 2010; Zhang et al., 2007). The interactions between agriculture, environment and society are very complex and multifaceted. Dale and Polasky (2007) identified three key ways in which agricultural ecosystems and ecosystem services interact. Firstly, agricultural ecosystems generate ecosystem services such as soil retention, food production and aesthetics. Secondly, the agricultural ecosystems are beneficiaries of ecosystem services from other ecosystems, such as pollination. Thirdly, agricultural practices may impact ecosystem services of other non-agricultural systems.

Climate and land use change are recognized as leading global environmental problems (Pielke, 2005; Boyd et al., 2008). Agriculture has been identified as a major land use, connected also to social, economic and cultural activity that provides wide range of ecosystem services globally (Howden et al., 2007). Agricultural systems, namely croplands and pastures, are contributing by 40% to global land cover (Ramankutty et al., 2008). Land-use change provides a significant contribution to global CO_2 concentrations in the long-term (Houghton and Goodale, 2004). Currently, agricultural activities are contributing from 12-14% to global anthropogenic greenhouse gas emissions to global CO_2 emissions, not including land clearing (Power, 2010). However, the precise magnitude of CO_2 emissions from land-use change remains uncertain (IPCC, 2007a).

The impacts of climate change on agriculture are likely to be wide ranging and felt across many regions of the world (IPCC, 2007b). In general, agriculture is highly sensitive to climate change and climatic variations. This may lead not only to differences among regions, but also cause interannual variability of production and disruption of ecosystem services within a single region (Howden et al., 2007). Climate change impacts on agricultural production are associated with impacts on human well-being and welfare. Changes in crop yields will influence crop prices and climate change results in additional price increases of crops (Nelson et al., 2009b).

Change in agricultural systems, driven by socioeconomic changes, greenhouse gas emissions, agricultural policies and other factors, is also affecting natural and managed ecosystems (Zaehle et al., 2007). Consequently, keystone ecosystem services such as carbon sequestration, water flow regulation, food and fibre

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production are influenced by these changes. These two interacting environmental issues as such have the potential to seriously undermine the capacity of multifunctional landscapes to provide the array of vital ecosystem services (Rickebusch et al., 2011).

Land use change occurs mainly at a local level; however it has the potential to determine ecological processes and accordingly the provision of ecosystem services across local, regional and even global scales (Zhao et al., 2006; Li et al., 2007). Climate change, on the other hand, performs at a global scale. Agroecosystems are important for climate change mitigation, both as a sink and a source of carbon. Agricultural land use activities introduce ecologically significant impacts on biophysical conditions in terms of changes in energy budgets, fragmentation and habitat loss. In turn, they interact with atmospheric conditions and determine climate conditions (Pyke and Andelman, 2007).

According to Koomen and Stillwell (2007), not only does land use influence climate, but the relationship is mutual and interdependent, with agriculture itself being extremely vulnerable to climate change impacts (Nelson et al., 2009a). Climatic changes may have an impact on ecosystem services, such as crop yield, fodder and fiber production, genetic variability, soil fertility and erosion risk, water quality, and recreational potential of the area (Žalud et al., 2009). The overall impacts of climate change on agriculture are expected to be negative, despite regionally-specific gains. European agriculture is sensitive to climate change risks as farming is focused on high quality foods (Orlandini et al., 2008). Assessing the vulnerability of the agricultural sector to climate change as such provides a topical, timely and valuable exercise.

There is already a growing demand among stakeholders across public and private institutions for spatially-explicit information regarding vulnerability to climate change at regional and local scale (Preston et al., 2011). As such, there is a need for robust information on how aspects will be affected, but set against a time horizon that is appropriate to underpin the implementation of integrated policy options and adaptation planning over the coming decades (Falloon and Betts, 2010). This research therefore seeks to reflect this need and the spatial variability of climate impacts by analysing trends in climate and land use change at national level. Utilizing an ecosystem services framework, climate scenarios, and land use changes analysis, this study introduces a spatially explicit regional assessment of climate change vulnerability that can be potentially useful for assessing and designing suitable adaptation options. A handful of key, relevant agricultural ecosystem services variables are applied to act as indicators for this study, to quantitatively and qualitatively assess the impacts of climate change and land use change.

This study looks at the impacts of climate and land use change on specific ecosystem services in the agricultural sector of the Czech Republic, which is of strategic national importance. Whilst agriculture only contributes about 2% of GDP, agricultural land use represents more than 50% of the total area of Czech Republic (CZSO, 2011). Its importance rests not only in food and other agricultural production, but it also has great significance for landscape management and landscape conservation. As such, the Czech agricultural sector represents an area of considerable economical, ecological and social value. Moreover, in the Czech Republic, the prevailing contribution to human appropriation of aboveground net primary production (aHANPP) originates mainly from agriculture (50%) and pastures (15%) (Vačkář and Orlitová, 2011).

The methodology section presents our approach to the assessment of climate and land use change, and ecosystem services, and provides an overview of data used. In this paper, we first of all analyze agricultural land use changes from 1948 to 2010, and consider some of the influential underlying socio-political transitions in the Czech Republic. We then use scenarios to assess the impact of climate change on agro-ecosystems in the Czech Republic. Finally, these changes are considered in terms of their influence on the selected agricultural ecosystem services – carbon sequestration, food production and erosion regulation. Outcomes of this study are then summarized and considered.

Methodology

Climate and long-term land use change are taken as the main drivers of environmental change that have an impact on agriculture. Fig. 1 presents the methodological framework that illustrates the work flow of this research. Firstly, we analyzed changes in agricultural land use from 1948 to 2010, utilizing data from Czech LUCC database in combination with data from Czech Statistical Office (CZSO). Secondly, in order to assess potential climate change impacts, we applied ALARM scenarios downscaled at national level for year 2080. As one of the outputs of the exercise, maps represent a basis for the comparison of the trends in land use changes over time period defined. We then describe potential impacts of environmental change on the three indicators of selected ecosystem services. Spatially explicit results of the analysis can be used as a basis for further adaptation planning development.

Land use change assessment

In accordance with Koomen and Stillwell (2007), we understand land use not only as the actual use of the land, but as observable land cover too. Land use is associated with a particular land cover class, sometimes a term "land conversion" is preferred to describe long-term land cover changes. In this case, we are concerned with land cover change, not land use change per se.

The land use category under observation in this study is agricultural land that consists of arable land, grasslands (pastures and meadows) and permanent cultures (orchards, gardens vineyards and hop-fields). Because the category of permanent cultures covers a relatively low proportion of Czech land (3%), and represents a very heterogeneous category, we focused our study on the dominant categories of arable land and grasslands.

Changes in the areas of particular land use subcategories were analyzed. As an indicator of land use change, we applied an index of change (I_{change}) which was adapted from Bičík (1995). The index assesses in percent the change in share of the land between particular land use categories during a given period. We compared the change in shares of arable land and grasslands at national level between years 1948 and 2000.

$$I_{\text{change}}(\%) = 100 \times \frac{A_{\text{y2}}}{A_{\text{y1}}}$$

where A_{y2} is an area of arable land (or grasslands alternatively) in 2000 and A_{y1} represents an area of arable land (or grasslands) in 1948. Year 1948 is a year of reference, which represents 100% state. Lower values in 2000 symbolize a reduction of the total area of the land use category, meanwhile higher values than 100% represent an increase of the area.

Climate change impact assessment

To assess the impact of climate change on the agro-ecosystems in the Czech Republic, we applied integrative scenarios developed in ALARM (Assessing Large-scale environmental Risks for biodiversity with tested Methods) project (Spangenberg et al., 2012; Spangenberg, 2007) that have been downscaled within Ecochange (Challenges in assessing and forecasting biodiversity and ecosystem changes in Europe) project. In general, scenarios are useful tools for environmental assessments, evaluating future trajectories of environmental problems, and testing policy options to resolve

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