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Changes in grassland area in lowlands and marginal uplands: Medium-term differences and potential for carbon farming

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Abstract: Grassland as a part of farmland is important for agrobiodiversity, soil protection and agricultural production (grazing, hay production). In the Czech Republic, grassland area increases with increasing altitude. In this study we evaluated the period 1966–2021 and the change in grassland area in different locations in South Bohemia region: fertile lowlands (Písek, České Budějovice, Tábor districts) and marginal uplands (Český Krumlov, Prachatice districts). Data on land use including the share of grassland were obtained from the Czech Cadastral and Surveying Office and Czech Statistical Office. In the upland districts, there is the largest share of grassland areas in the whole region. The prevalence of grasslands is probably due to the geographic and climatic conditions, which are challenging here. Our research shows the results of changes in grassland areas between 1967 and 2021, with regard to the assessed districts. The difference in the percent area of grassland in 2021 compared to 1967 is –0.04 to –1.77 for lowlands, and +1.45 to +5.99 for uplands. Despite this, uplands farmers practice relatively extensive farming methods and extensive grazing due to low ruminant numbers. Although farmers maintain relevant carbon sinks, it is unlikely to increase the carbon stocks per hectare of extensive grasslands on an annual basis, which would be a barrier to participation in a carbon farming system.

Keywords: climate; extensive management; grasslands; medium-term changes

Grasslands are an element of the agroecosystem that supports biodiversity (Tamm 1956; Critschley et al. 2004; Pavlů et al. 2005; Dvořák et al. 2022) and has an impact on soil biology and soil carbon cycling (Lal et al. 2007; Steffens et al. 2009; Soussana et al. 2010; Lavelle et al. 2011; Jerome et al. 2013). Grasslands improve microclimate as they represent a unit of soil respiration and store carbon in soils. We should not overlook the interrelation between carbon storage in grasslands and the value of grasslands in terms

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of biodiversity (Cizek et al. 2012; Farkač & Chobot 2017) and as areas for grazing, and thus maintaining valuable pasture and meadow habitats. Thus, grasslands remain most relevant as a livestock feed source, despite the decreased livestock production in the Czech Republic since the 1990 s (Honsová 2006). Changes in grassland area are typically associated with extensification of farm management that was, in uplands, found to lead to a loss of species diversity (Hájek & Poláková 2010; Prach et al. 2009). More recently, the supply of renewable energy from biogas stations comes partially from grasslands (Buehle et al. 2012; Fuksa et al. 2012), not to mention the long-term effect of grasslands for improved infiltration rates, erosion and flood control as further functions of grasslands (Milazzo et al. 2023). Grassland includes a category of managed grassland which may be sown with a mixture of grasses and clover, and a category of permanent grassland which is not sown and ploughed for a longer period, at least five years. Permanent grassland is usually found on priority lands in terms of carbon storage (Lavelle et al. 2011; Schils et al. 2022) and biodiversity (Farkač & Chobot 2017), while economically they can be considered marginal, i.e. where annual crops find harsh conditions. Peeters and Nilsdotter-Linde (2019) state that „soils may be too shallow, too stony, too wet, too dry or nutrient poor". Permanent grasslands are characterized by steep terrains or remote location relative to urban development. Traditionally, permanent grassland was grazed, but with decline of livestock in the 1990s, grazing is only maintained by subsidy incentives.

The gap in research we identified deals with the regional differentiation in grassland use and the grassland inventory evolution. The balance of various land uses is addressed in ample literature covering the modern state of Europe (Bicik & Jelecek 2009; Reger et al. 2009; Fanta et al. 2022; Moravcova et al. 2022) and a traditional region of South Bohemia. A parallel thread in literature has dealt with the assessment of climatic conditions in agriculture, particularly in terms of effects on annual crops (Trnka et al. 2009, 2011). While our research draws on this literature, we applied regional assessments in South Bohemia not only to balance changes in grassland areas in the lowlands against the uplands but to do so precisely with respect to understanding the specific links between grassland area, changes in grassland areas and carbon storage and climate.

Overall longitudinal data at a national scale clearly show an increase in grassland area since the early 1990s (Figure 1). In the preceding decades, the dominant trend was a reduction in the area of grassland to cropland as a result of the 20th century land reforms and large-scale consolidation of land for agriculture. Although this trend has been politically driven, it is similar to any era of intensification of grassland agriculture, either through a tendency towards more fertilisation and overgrazing (Cizek et al. 2012; Schils et al. 2022) or land use change to arable management (Pavlů et al. 2005).

Yet, since the early 1990s, due to a number of economic, social and agronomic factors, grasslands have been on an upward trend in Czech Republic. The overall picture masks differences that are very significant at regional and district scales. The gist of our project was to identify the reasons for the differences between districts, in terms of the grassland area evolution. Climate change or the support of grassland under the Common Agricultural Policy (CAP) are

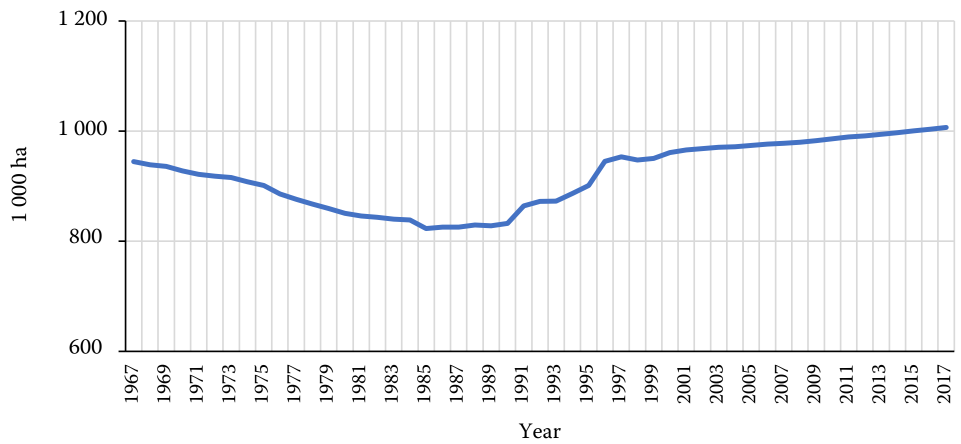

Figure 1. Changes in the evolution of grassland area from 1967 to 2017
Source: Czech Cadastral Register in Czech Statistical Office 1967–2017

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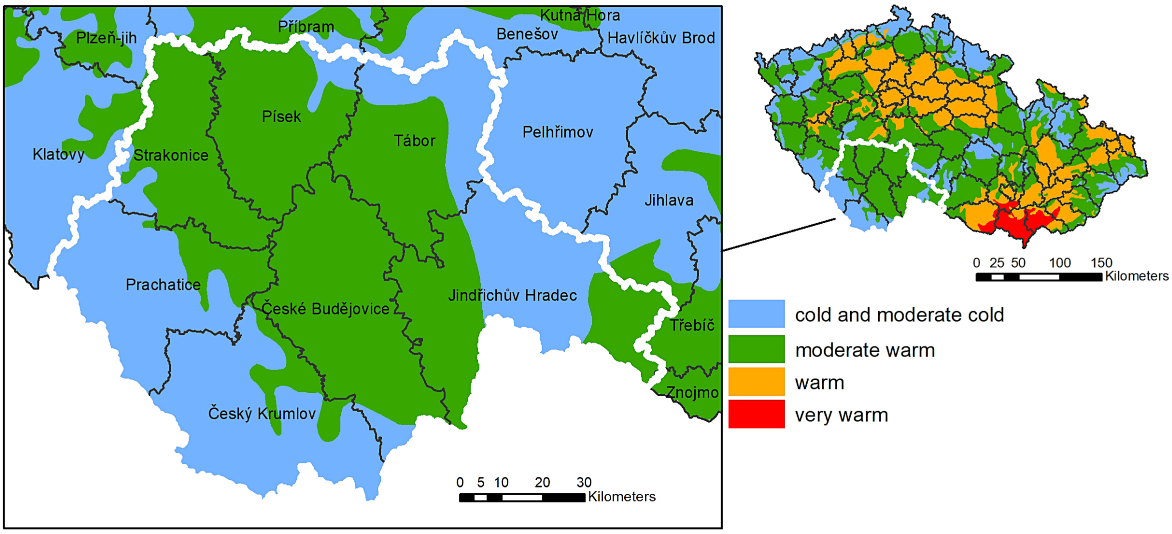

Figure 2. Distribution of climatic regions in South Bohemia (left); location of the study region in the Czech Republic (right)

tested as possible causes. Alongside the historical CAP reforms (Markovic et al. 2012), we note that especially CAP agri-environment schemes have long been a driver for maintaining extensive grasslands (Tankosić & Stojsavljević 2014; Velthof et al. 2014; Galer et al. 2015; Vejvodová 2016a, b).

Grasslands represent relevant carbon storage (Soussana et al. 2010; Lavelle et al. 2011). Carbon farming has been announced to be the output of EU Farm-to-Fork Strategy. Carbon farming is a method of rewarding farmers based on voluntary scheme protocols, in proportion to carbon sequestered in agricultural soils (Paul et al. 2023). Carbon farming will not only help to meet the objective of the Farm-to-Fork Strategy, but also the EU Soil Strategy 2030 (European Commission 2021a), which, in addition to protecting peatlands, also explicitly emphasises efforts to prevent the depletion of mineral soils. Protocols on carbon farming tend to be lenient, although experts in the climate community advocate the need for rigorously measured carbon storage outcomes. Unlike publicly funded agri-environment schemes that incentivize farmers to undertake actions beneficial to biodiversity (Galer et al. 2015; Velthof et al. 2014; Polaková et al. 2022), carbon farming schemes are expected to deliver accurate carbon storage outcomes annually (European Commission 2021b). In Central Europe, such systems are not yet widespread. Compared to Northwest Europe, where carbon farming business models are very active and often focus on intensive livestock sector and peatland restoration, Central Europe would like to see the carbon sequestration rewards targeting mineral soils of arable farms in the lowlands and mineral soils of grassland farms in the uplands.

This research aimed to assess the medium-term evolution of grasslands in comparison of fertile lowlands and marginal uplands. Specifically, the objective was to disaggregate and interpret the national-scale data in terms of regionally meaningful trends in grassland areas in relation to climate and land use. This research more broadly sought to establish where and why soil sequestration and biodiversity are increasing in grassland agroecosystems, and to answer the question whether the trend can be predicted and sustained, particularly in light of the forthcoming carbon farming guidance.

MATERIAL AND METHODS

The studied area. Among the regions of the Czech Republic, the South Bohemia region features clear distinction between fertile lowlands (Písek, České Budějovice, Tábor) and marginal uplands (Český Krumlov, Prachatice). This line of distinction between lowlands and uplands is topographic to the extent that it is climatic. Figure 2 shows the map of the region with a detailed section of the studied districts and their climatic descriptions. The marginal uplands are found in cold climatic region, whereas the lowlands are found in moderate warm regions. The elevation gradient between the municipality of Písek and the most elevated urban settlement in Český Krumlov is 672 meters. Figure 2 shows the distribution of climatic zones in the region in parallel with the overall

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data for the Czech Republic. As shown in Figure 3, the third most common land use in the region is grassland. Of note, the share of arable land is 7% lower in the region. Climate and soil indicators and agronomic conditions do not allow growing crops in uplands, while grassland is 4% more widespread as an agricultural land use in the region than nationally.

Data and methods. Information from the Czech Cadastral and Surveying Office was processed to obtain data on land use. Data on land use in the districts of the South Bohemia Region were obtained here, always as of 31st December of the year under review. We analysed the respective methodology by which the data were collected coherently and consistently in four different time periods. Data from 1967–1993 were in hard copy only. These data were obtained from soil yearbooks available in the study room of the library of the VUGTK (the local acronym for Research Institute of Geodesy, Topography and Cartography) in Zdiby. For the years 1967–1989 the data were given in the Statistical Yearbooks of the Czechoslovak Socialist Republic, in 1990–1993 they were the Statistical Yearbooks of the Soil Fund of the Czech Republic. Since 1994, the data are available in electronic form. These data were obtained from the relevant electronic archive of the Czech Statistical Office. From 1994–2009 these are the Statistical Archives in the form of the Yearbooks of the Cadastral Fund of the Czech Republic. From 2010–2020, the data are available in the Czech Statistical Office's aggregated archive from the Czech Cadastral Register data. In the soil yearbooks methodology, the data collected over time document grassland areas as an aggregate concept, and do not further distinguish the intensity of grassland management.

The data were processed using the computer program Statistica (Ver. 12, 2015). Descriptive statistics showing different aspects of the regionally disaggregated dataset were presented using numerical characteristics on the evolution of grassland area between 1966 and 2017.

By constructing tables and graphs based on these descriptive statistics, the aim was to facilitate their visual analysis and, in particular, to make the assessment as complete as possible within a narrower set of regionally disaggregated data for the configuration of the South Bohemia Region data.

Furthermore, it was monitored whether climatic indicators, in this case temperature and precipitation, had an impact on the changing area of grassland. Two meteorological stations were therefore selected. One of them, Vyšší Brod, documents the climate in uplands, the other is Borkovice, which documents the lowlands. The selection of the stations was guided by a proxy for the altitude of the terrain. This proxy was used to determine the appropriate meteorological station in each district to approximate the mean elevation of the district. For each of the meteorological stations a line graph is created that links the display of mean annual temperatures and annual precipitation. The correlation coefficient for grassland area distribution and climate variables was examined to see if the dependence of grassland area distribution on climate could be demonstrated.

The statistical methods include measuring the central tendency (mean, mode, median, degree of variability) according to a sample of linear trend data at each time point (direct equation of increase/decrease, including adjusted R^2 coefficient). Since only a defined set of regionally disaggregated data was assessed, the

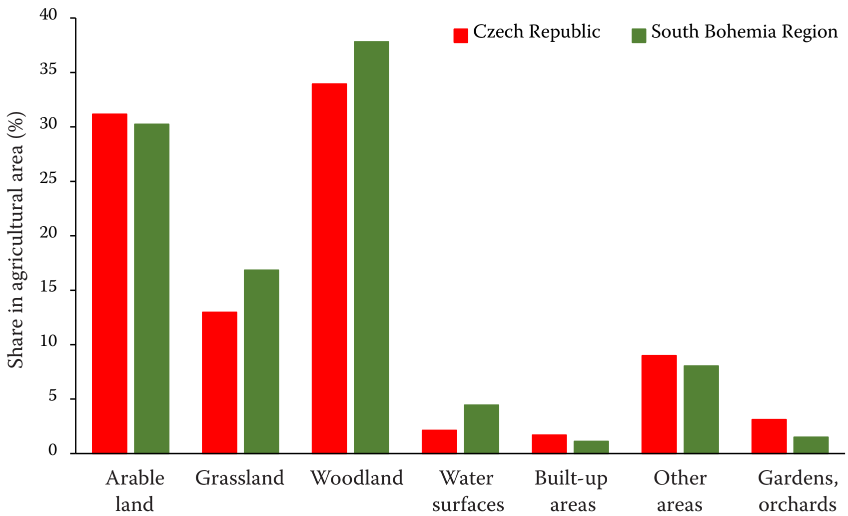

Figure 3. Agricultural land use (share in overall area) in terms of comparison of the country and the study region
Source: Czech Statistical Office 2021

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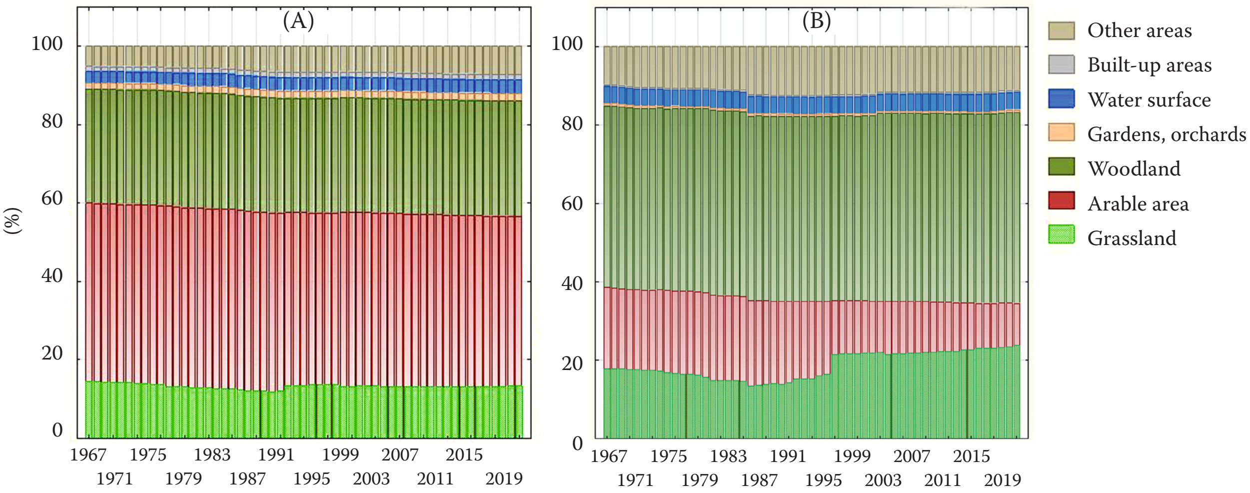

Figure 4. Changes in grassland areas in lowlands (Tábor) (A) and in uplands (Český Krumlov) (B)
Source: Czech Cadastral Register data 1967–2021

methods of classical statistics were not strictly followed, with the calculation of the central tendency measure indicating the typical value for a given trait, and in this case the work did not focus on any particular trait, but aimed at a general evaluation of long-term trends, which was represented by means linear sequence plot graphs over time, while the plot graphs were fitted with regression lines for better illustration and prediction.

RESULTS

Grassland areas. The medium-changes in the evolution of grassland areas were documented in the form of stacked diagrams showing the relative distribution of various land uses including grassland. This method of documentation makes it apparent that changes in grassland area (decreases/increases) can be attributed mostly to the dynamic interrelation with changing forest areas and built-up areas. Moreover, in uplands, changes in grassland areas are correlated with decrease in arable land. Figure 4A documents lowlands, and Figure 4B documents uplands. The visual documentation was created for each district but the cited figures represent only one selected region for the lowland and upland sampling. Other districts are similar. The common denominator is that the beginning of 1990s marked a turn to upward trend in grassland areas, yet this characteristic is much more pronounced in uplands.

Sensitivity analysis is described in Figure 5. The analysis is visualized by box and whisker plots. Grassland area is given in absolute numbers, in hectares.

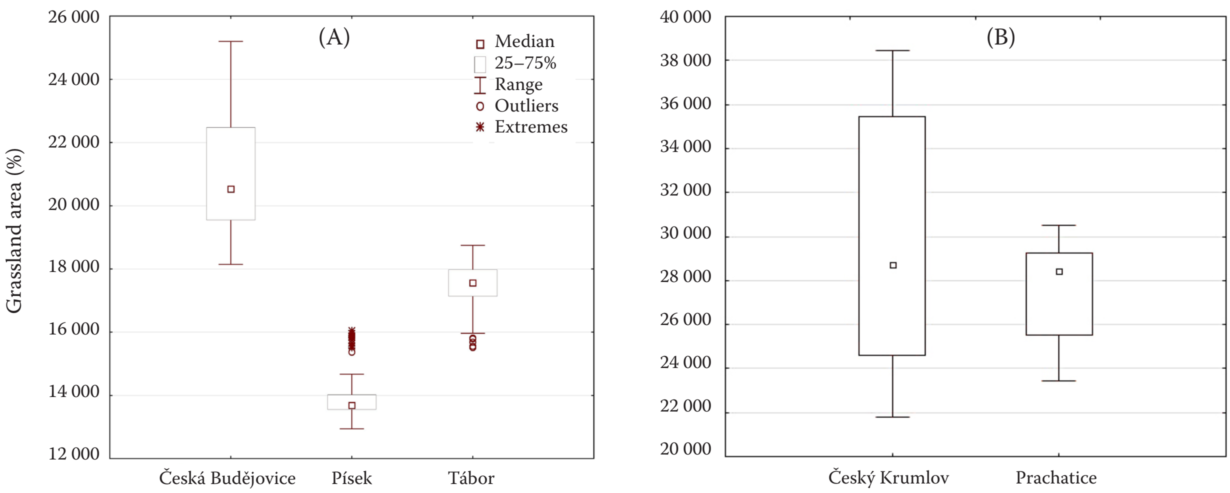

Figure 5. Sensitivity analysis for grassland area changes in lowlands (A) and in uplands (B)

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In Figure 5A (lowlands), the range highest value is in the České Budějovice district, i.e. 1962 ha. It could be concluded that the area of grassland has changed the most over the years. In the other two districts, the range value is about half as large. However, the total area of grassland is also smaller here. There are more outliers and extreme values in the Písek district, suggesting that in some years the values were more skewed from the mean.

In Figure 5B (uplands), Český Krumlov features a difference between the minimum and maximum of 10.3%. This indicates significant changes in the proportion of grassland in the total area. For Prachatice, it is only 2%. Whether this is due to political decisions or climatic indicators will be investigated in future research.

Connection to climate. Figure 6 documents the meteorological station Borkovice (413 m above sea level and 419 m above sea level). The values are typical for the lowland district of Tábor. Temperature and precipitation were assessed separately, and it was found that annual precipitation varies over the years but remains constant on average. The mean annual temperature fluctuates considerably, but trends upwards over time. Therefore, we carried out correlation analysis between the linear trend in grassland areas and mean annual temperature. Figure 6 shows the result. The Pearson correlation coefficient $r = 0.137$ shows that there is very little relationship.

Meteorological data from Vyšší Brod (559 m above sea level) are typical for upland district of Český Krumlov. Data was also analysed in the context of temperature and precipitation. The annual precipitation increases only very slightly, therefore, as with the meteorological station Borkovice, it was not further investigated. The mean annual temperature is increasing, which is the same trend as in lowlands, however the long-term increase in mean annual temperature , in this generally cold climate, is not so steep as in lowlands. The correlation analysis (shown in Figure 7) was evaluated using Pearson's correlation coefficient. A Pearson value of $r = 0.479$ indicates a moderately strong relationship. This is a visibly closer relationship between the increase in grassland area and mean annual temperatures than in the lowlands.

DISCUSSION

In recent years, the importance of grasslands has been increasingly highlighted in terms of their ecosystem functions, which also help to positively influence climate change. Lal (2004, 2008), Ceotto (2008), Carlier et al. (2009) and Aghajanzadeh-Darzi et al. (2017) point out the interdependence between agriculture and climate change, with grasslands having an impact on soil climate-related challenges such as water retention, soil fertility, erosion control, not to mention biodiversity. Jerome et al. (2013) point to the fact that grasslands play an important role in sequestering carbon while reducing greenhouse gas emissions. Carbon sequestration, according to Ghosh and Mahanta (2014), can be increased by sowing favourable forage species, restoring degraded stands, as well as through grazing management.

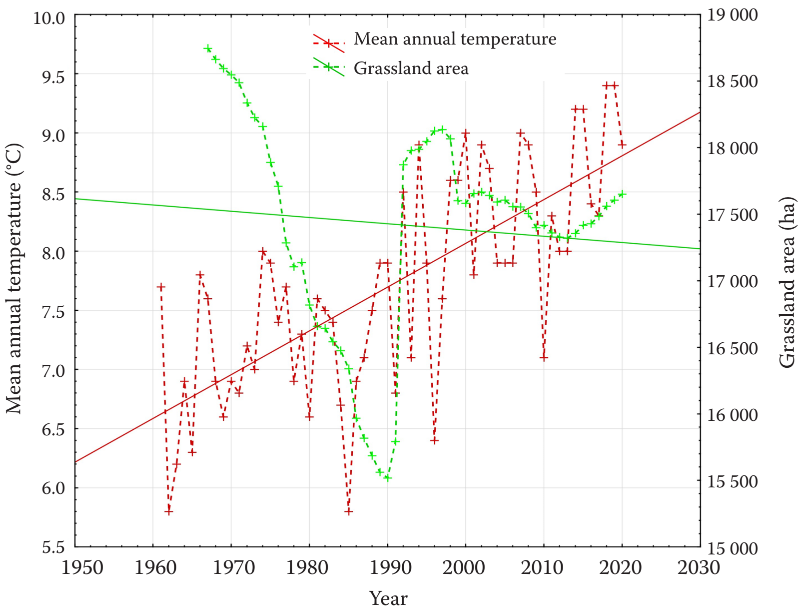

Figure 6. Correlation analysis of grassland areas and mean annual temperature (lowlands – Tábor)
Source: own compilation based on Czech Hydrometeorological Institute

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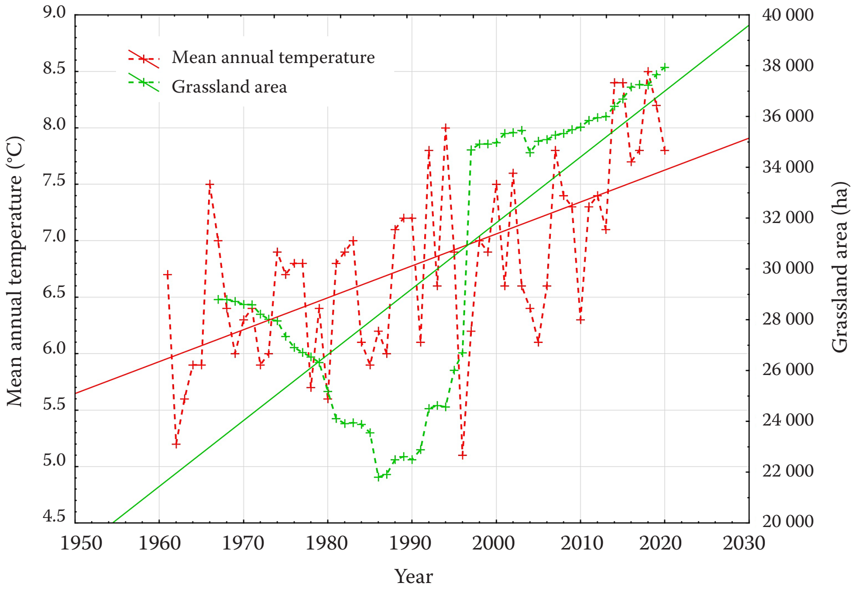

Figure 7. Correlation analysis of grassland areas and mean annual temperature (uplands – Český Krumlov)

Source: own compilation based on Czech Hydrometeorological Institute

Apart from grassland role as climatic unit through soil respiration, Schils et al. (202) note that the conservation of biodiversity in permanent grasslands depends on farming practices, especially grazing intensity and harvest dates. Schermer et al. (2016) examined plots in three European regions to find that the farming practice, such as absence of fertiliser use, is very important. Literature states that for greater diversity it is a good idea to include more grass mixtures, and more leys intensive but also less so when extensive management is valuable for biodiversity. After 1989, there was a change in agricultural policy that responded to the findings about the plethora of ecosystem functions of grasslands (Štych & Stránský 2005). As a result, the so-called Areas with natural constraint received substantial support for the reversion of arable land to grassland (Prach 2009).

Similar land-use changes between arable land and grassland categories were investigated for a neighbouring country by Nitsch et al. (2012). Their study highlighted that the conversion of arable land to grassland (as here in our survey of the South Bohemia uplands) is beneficial for biodiversity, soil, water and climate, with the real value depending on the species composition of grassland, whereas the conversion of grassland to arable land (typically due to agricultural intensification common in German regions) is quite complex and reduces these functions. Lavelle et al. (2011) note that in terms of agricultural land use, grasslands are the second largest carbon storage (following wetlands), although not as significant as forests; yet the conversion to arable land is adverse for climate. Such a trend was observed in the South Bohemia Region early on in the 20th century, not now.

In the upland districts of Prachatice and Český Krumlov there is the largest share of grassland areas in the whole of South Bohemia region. The prevalence of grasslands is probably due to the geographic and climatic conditions, which are challenging here. Our research shows the results of changes in grassland areas between 1967 and 2021, with regard to the assessed districts of the South Bohemia Region. The difference in the area of grassland in % in 2021 compared to 1967 is –0.04 to –1.77 for lowlands, and +1.45 to +5.99 for uplands. Our hypothesis assumed an increase in the share of grasslands similar to the overall data in the Czech Republic, but we were able to confirm the hypothesis only partially, for the uplands districts. In lowland districts, there has been a reduction in the area of grassland. These results do not differentiate between intensive, extensive and abandoned grasslands, and greater differentiation in terms of management intensity would require the use of more accurate modelling methods.

Our outputs have an implication for potential carbon stocks. Grassland carbon stocks should only be traced back to the reference year 1990, based on international agreements. As our computations in Figures 4 show, since that year grassland areas (and hence potential carbon stocks) have almost levelled off in the lowlands and have gone on in a very steep upward trend in the uplands. Further research would be to consider carbon stock change with respect to the

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distribution of climatic regions over the long term. From the literature, it can be assumed that climatic changes and the distribution of climatic regions over time might have had an impact on carbon stock and reduce carbon storage in the grasslands studied. This would certainly be an important indicator; however, in the present study we could not extend the reach to collect such data; so it remains to be seen whether such data can feasibly be gathered for research.

Jerome et al. (2013) point to the fact that grasslands play an important role in sequestering carbon while reducing greenhouse gas emissions. Carbon sequestration can be according to Ghosh and Mahanta (2014), increased by sowing favourable forage species, restoring degraded stands, as well as through grazing management. In the future, as the focus of farmers shifts from policy incentives to market incentives through carbon markets, it will be a major challenge to explain to grassland farmers in such regions as uplands in Český Krumlov and Prachatice, that they cannot participate in carbon farming, even though their pastures represent a large carbon stock; carbon farming is based on the idea that the farmer must increase carbon sequestration per unit area from year to year, and on extensive grasslands, it is hard to see how carbon sequestration could be further enhanced. Equally important would be to ask whether an increase in grassland area is an adverse sign of potential sliding towards agriculture abandonment (Terres et al. 2015; Kizeková et al. 2016), although abandonment is a complex topic that we cannot study here, and its complexity would probably have to consider the evolution of agricultural economics, such that has encouraged the extensification of agriculture in uplands.

CONCLUSION

In conclusion, the aim of the work was to see how the balance of grassland areas in the region has evolved. Region of South Bohemia was divided into lowlands and uplands. This distinction could be characterized as a line between fertile agricultural land and marginal areas. Within these two samplings, several districts were selected to represent the region. It was assumed that the grassland area evolved according to climatic variables – precipitation and temperature. The first conclusion that was found is that the evolution of grassland area depended more on the political decisions that take place under the Common Agricultural Policy.

Secondly, our hypothesis assumed an increase in the share of grasslands similar to the overall data in the Czech Republic, but we were able to confirm the hypothesis only partially, for the uplands districts. In lowland districts, there has been a reduction in the area of grassland.

in the study period 1967–2021, the year 1988 was the year when the grassland area was the smallest in the uplands. The following should be noted for the uplands. Until 1988, the focus was on maximising production and so grassland area declined. After 1988, however, the situation was reversed, but grassland began to increase, to the detriment of arable land. This is particularly evident in mountain areas. This trend has implications for carbon storage, as carbon stocks are also on an increasing trend due to the slowly increasing area of grassland. Despite this, farmers in the Czech Republic uplands practice relatively extensive farming methods and extensive grazing due to low ruminant numbers. Although farmers maintain relevant carbon sinks, it is unlikely to increase their carbon stocks per hectare on an annual basis, which would be a barrier to participation in a carbon farming system.

Thirdly, in the lowlands, we conclude the following. Grassland areas increased after 1990, but after 1998 the areas started to decrease again, and it continued to fluctuate until 2014, when the upward trend starts again. A new CAP reform has been adopted which focuses on the promotion of resource-friendly practices, including support for permanent grassland.

And fourth, the European Commission adopted the Farm-to-fork Strategy in 2018, as part of the preparation of the new Common Agricultural Policy. Until now, farmers have not received incentives for carbon sequestration. Communication on Sustainable Carbon Cycles foresees incentives to business models that reward farmers for adopting farming practices beneficial for carbon sequestration, coupled with outputs for biodiversity. In this context, our research investigated the extent to which farmers in upland grasslands would qualify for benefits associated with carbon sequestration.

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