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INVESTIGATION OF CARBON SEQUESTRATION PROCESSES OF RECONSTRUCTED GRASSLANDS AND WETLANDS TO AID ECOSYSTEM SERVICE-BASED DECISION MAKING

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Summary: In this paper, we analysed the effect of habitat reconstructions on some parameters characterizing the carbon exchange processes of ecosystems. Besides extending our knowledge on the ecophysiological functioning of different plant communities, our work was motivated by international policy goals as well: a considerable amount of degraded ecosystems and their services was declared in the European Union to be reconstructed in the next few years. These kinds of projects need detailed impact analyses and a methodological grounding. We would like to contribute to these goals with the results of field measurements carried out in an extensive habitat reconstruction area in the Egyek-Pusztakócs habitat complex (Hortobágy National Park, Eastern Hungary). In this paper, we analysed the results of carbon and nitrogen contents of soils and biomass samples and the average net ecosystem exchange values of the investigated ecosystem types. Our results show that natural or near-natural, well-structured grasslands have an outstanding carbon sequestration and storing potential in the studied landscape type, the restored grasslands lag behind in every parameters. In the process of secondary succession, the carbon exchange characteristics of the restored grasslands seem to follow mainly the species composition, and the effects of land management can modify the effects of regeneration from the point of view of ecophysiological functioning.

Key words: wetland, grassland, arable land, carbon sequestration, habitat reconstruction

1. INTRODUCTION

Mapping ecosystem services and related spatial assessments may be prerequisites of land use decisions on different spatial scales. Maps of ecosystem funcions and service supply give an overview of the general state of the natural capital of the different sites, while the bundles and tradeoffs between them make the evaluation of land use management alternatives possible. Owing to the many contributions of the recent years, the number of spatial assessment approaches is growing rapidly in this field. These works are necessary also for the methodological grounding of the fulfilment of international policy objectives (implementing the targets of the EU Biodiversity Strategy 2020 on mapping ecosystem services on a national scale and developing Green Infrastructure).

The sequestration and storage of greenhouse gases (mainly of carbon) is one of the most widely recognized and studied regulating ecosystem services. As it has a global relevance, it does not affect the people's well-being directly, but in the context of climate change, it has a clear importance and it can be quantified relatively easily. Thus, there are many experiences of the mapping, modelling and sometimes monetary evaluation of this service (Nelson et al. 2009, Crossman et al. 2011). According to the general groups of ecosystem service mapping methods, mapping approaches of carbon sequestration and storage can also be classified as land cover-based assessments, indicator mapping and spatial modelling.

In the next years and decades, huge territories with degraded habitats will be reconstructed for nature protection reasons. This is a consequence partly of the abandonment of cultivated lands following changes in agricultural policy, of the strengthening of the nature conservation sector, and of direct policy goals (restoration of 15% of degraded ecosystems is prescribed in the EU Biodiversity Strategy 2020). In many cases, the declared aim of habitat reconstruction projects is restoring and increasing the amount of ecosystem services of the study area. It means that it is supposed that there is a clear positive correlation between biodiversity (of which the increase is the direct target of habitat reconstruction projects) and ecosystem services. However these connections (which were discussed as biodiversity-ecosystem function relationships in the literature previously) are not that straightforward, and they should be clarified in some aspects (and it should be investigated and evaluated differentially for the different functions/services). The different ecosystem functions may be connected to certain species or species groups, and the relationships highly depend on the spatial and temporal extent of the investigations (Isbell et al. 2011). Grasslands of different structure and species composition can be studied relatively easily from the point of view of carbon sequestration (which was the main issue in our work) through biomass production and changes in the carbon content of soils (Tilman et al. 2001, Steinbeiss et al. 2008). Another important aspect that should be taken into consideration if we evaluate effects of habitat reconstructions on ecosystem functions and services is the fact that reconstructed communities achieve the targeted state concerning species composition and other important ecological attributes only in the long run. In the case of some weakly regenerating communities, total regeneration cannot be achieved at all. There are a number of studies on the effects of habitat and landscape reconstruction projects on ecosystem functions and services, on different spatial scales (Benayas et al. 2009, Feng et al. 2013). Among these, we can also find investigations of greenhouse gas exchange processes of planted grasslands (Nelson et al. 2008, De Deyn et al. 2011), and budgets dealing with more than one GHG, based on complex flux measurements (Merbold et al. 2014). In most of these works, detailed investigation of the regeneration process was not among the targets. Thus, our field measurements were carried out in order to answer this central problem.

These results, besides providing a valuable input for more detailed ecological-ecophysiological impact assessment of habitat reconstructions, may help in adequately parameterizing different parts of the complex system of sequestering carbon (or other greenhouse gases) in integrated ecosystem service evaluation systems (Kiss et al. 2013) or spatial models. If we derive indicators or proxy values for mapping ecosystem services, it should be taken into consideration that the service supply is highly dependent on the variability of several natural factors (e.g. weather) and on land management intensity (Cseh et al. 2014). Some of the spatial models for ecosystem service assessments developed in recent years were made with the explicit inclusion of land management intensity, on different spatial scales (Petz and van Oudenhoven 2012, Schulp et al. 2012). Greenhouse gas exchange processes of grasslands, arable lands and wetlands are a good example of that, as different abiotic parameters and different forms of agricultural land use, which can be distinguished from the point of view of management intensity (intensive or extensive arable farming, different forms of grazing) affect the greenhouse gas budget heavily. Referring investigations were carried in Hungary as well, in the frame of Greengrass project (Czóbel et al. 2008b, 2012, 2013, Horváth et al. 2008, 2010). Based on that, the aim of our work was to study the intra-annual variability of some important attributes of carbon exchange processes in the investigated habitats. We also give some proposals on the usability of these results and those of previous related Hungarian projects in evaluating the effects of large-scale land use change projects with targeted indicators and evaluation systems.

2. MATERIAL AND METHODS

2.1. Description of the study area

The study area of our work was the Egyek-Pusztakócs habitat complex in Hortobágy National Park (situated in Eastern Hungary), on the borderline region of two landscapes, the Hortobágy and the Tiszafüred-Kunhegyes plain. A large-scale wetland rehabilitation was carried out there during a long-term programme from 1976 to 1997, while between 2004 and 2007, the largest grassland reconstruction project of Europe was implemented (Vida et al. 2010, Török et al. 2011, Lengyel et al. 2012), financed by the LIFE programme of the European Union (on 760 hectares in total). The targeted habitat types of the reconstructions were mainly loess and alkali grasslands, for which reference undisturbed stands are also available in the Egyek-Pusztakócs unit and in the wider area. Besides these, arable lands with different management intensity and wetlands (rehabilitated mainly in the frame of the previously mentioned landscape reconstruction programme) can also be found in the study area. These habitats formed the measurement units of our work, which were compared from the point of view of greenhouse gas exchange processes. The study area is part of the floodplain of the Tisza River. This fact determines the morphological characteristics and, through that, the natural vegetation patterns. As this area is situated west from the „classical" Hortobágy region (a part of it is in another landscape), the morphological variability is higher than in most parts of the National Park. In deeper areas (in former riverbanks and floodplain marshes), wetlands with different inundation lengths can be found, while on positive morphological forms (alluvial plateus), the main natural habitats are dry grasslands. These were intended to be reconstructed in the frame of the LIFE project, with low-diversity seed mixtures. Our measurement points were situated in different-aged reconstructed grasslands (planted in 2005 and 2008), one almost undisturbed natural grassland site, one extensively and one intensively managed arable land as reference stands to characterize the former land use of the reconstructed habitats, and 3 points from a lakeside zonation of a rehabilitated marsh system (Fig. 1).

2.2. Methods

In this paper, we examine net ecosystem CO_2 exchange (NEE), carbon and nitrogen content of soil and vegetation from the attributes describing the ecosystems' carbon budget. Our measurements were carried out monthly in the vegetation period of the year 2011. CO_2 fluxes were measured from grassland (natural grassland, restored in 2005 and 2008), wetland (*Lemna*, *Juncus* and *Eleocharis* dominated stands) and arable land (extensively and intensively managed) sites. Stand level CO_2 flux measurements (NEE) were performed at monthly intervals during the growing period using chamber technique and ADC LCA2 (ADC Bioscientific, UK) portable infrared gas-analyser operated in open system mode. The photosynthetic system was connected to a water clean, portable, non-destructive, self-developed chamber (d=60 cm, made from plexiglass) taking air samples from the connecting (inner and outer) tubes (Czóbel et al. 2004). Carbon dioxide exchange rate has been calculated from the differences or changes in CO_2 concentrations (for more details, see Czóbel et al. 2004, 2005). Stand level chamber measurements were carried out in clear and sunny days between 10:00 and 16:00 in order to avoid the unsteady meteorological paramereters affecting the NEE values. On a peculiar NEE measurement day the carbon flux of each site were measured alternately for an average of 60 min per plot. The mean and standard deviation of the data collected were calculated for each plot. The C and N contents of the soils were measured in two samples (from layers of 0-10 and 10-30 cm) in every measurement points. Soil and water samples were measured once in the first intensive growing phase of the vegetation period, while the biomass was sampled at the end of the vegetation period as well. The C and N content measurements were carried out, after drying till a constant mass state, with Elementar Vario Max CN device, using methods developed for the specific sample types, the positive control was glutamic acid. Water samples were collected from *Eleocharis* and *Juncus* stands measured with Apollo 9000 TOC analysator, by 5 point calibration, using potassium nitrate and calcium carbonate as positive control.

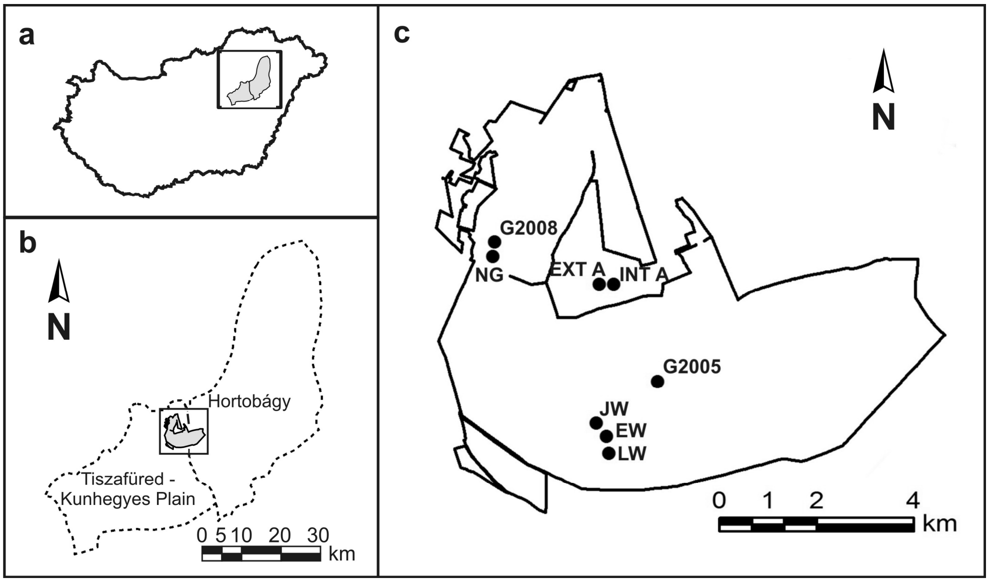

Fig. 1 Location of the two landscapes containing the Egyek-Pusztakócs unit of the Hortobágy National Park in Hungary (a), the habitat complex (b) and the sampling points (c) (G2005: grassland reconstructed in 2005, G2008: grassland reconstructed in 2008, NG: natural grassland, INT A: intensively managed arable land, EXT A: extensively managed arable land, LW: *Lemna*-dominated wetland, EW: *Eleocharis*-dominated wetland, JW: *Juncus*-dominated wetland)

3. RESULTS AND DISCUSSION

The total carbon contents of the two soil layers were considerably low, and the upper layers were observed to be higher at all of the samples (Fig. 2). From the grassland points, the highest C content was measured in the upper layer of the natural grassland, the earlier restored grassland's value was a bit lower (5.4%), and the later restored grassland was much lower (56.7%). The intensive arable land was characterized with higher values in both layers than the extensive arable land (lower layer. 23.5%, upper layer: 13.7%), this is certainly due to fertilizer application. Concerning the total N content of the soils, the ratios between the investigated habitat types are similar, we measured higher N content in the lower layer in two cases (in the grassland restored later and in the extensive arable land). The high C content of the natural grassland calls attention to the high carbon storing potential of these well-structured grasslands with low anthropogenic disturbation. The high C and N content in the soils of the earlier restored grassland can be probably explained by the fact that this is under a considerably intensive grazing, which causes notable increase in these parameters according to the results of previous Hungarian measurements as well (Czóbel et al. 2008a). Another cause can be that the carbon content of the biomass is lower there than in the case of the other grasslands. The plants can affect the soil carbon content through the nitrogen exchange: under vegetation types providing litter with lower C/N ratio the microbial activity can be stronger and the amount of the available nitrogen can increase. This can enhance productivity and the amount of carbon as an input to the soil (Ogle et al. 2004). However the regeneration process that can be characterized with constant organic material input and the exclusion of tillage operations probably contributes to the high soil carbon content of the grassland restored earlier. It should be stated that in the case of most grassland types, to achieve a soil carbon content equal or close to the reference natural grassland, several decades are needed (McLauchlan et al. 2006). In element contents, the values of *Eleocharis* stands were observed to be many times higher (C: 114.08 g l^{-1}), N: 70.24 g l^{-1}) than those of *Juncus* stands (C: 4.78 g l^{-1}, N: 2.22 g l^{-1}).

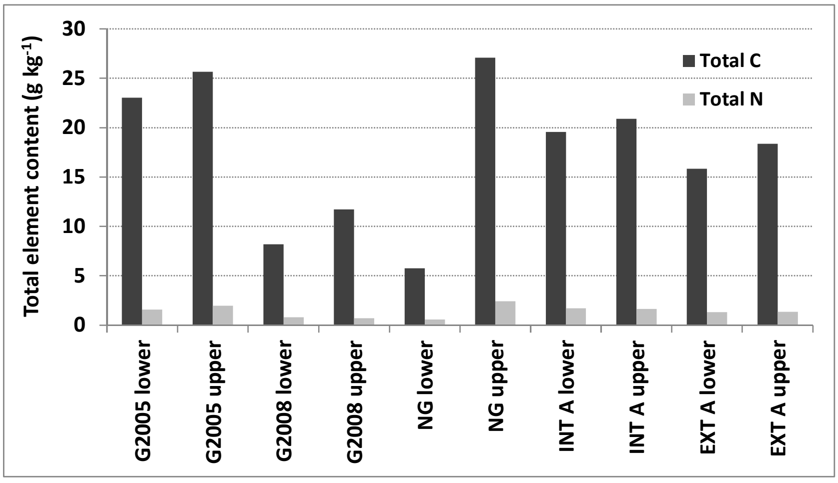

Fig. 2 Carbon content of soils in the grassland and arable land sampling points

We observed lower variability in the element contents of the biomass samples during the year. The value measured in autumn was higher than that measured in spring in the case of the natural grassland. The C content was almost the same at the two arable lands, and clearly higher element contents were measured in autumn in the wetland's samples. A possible explanation can be that in the extremely dry year of 2011, the plants survived the summer period with strong precipitation deficit by allocating C to the above-ground parts. In the case of N content, the ratios between the investigated types were almost the same in the samples collected in spring and autumn, but the intra-annual variability was higher. The increased N content of the grassland restored earlier (compared to the other grasslands) is probably partly a consequence of grazing, which caused the higher N content of the aboveground biomass (Czóbel 2008a).

Table 1 Carbon contents of aboveground biomass samples

	Spring			Autumn		
	TC (g kg^{-1})	TN (g kg^{-1})	C/N ratio	TC (g kg^{-1})	TN (g kg^{-1})	C/N ratio
G 2005	415.9	16.8	24.8	402.9	20.7	19.5
G 2008	436.1	7.8	55.7	431.5	15.8	27.3
NG	427.9	13.9	30.9	440.8	16.4	26.8
INT A	407.7	15.7	26.0	408.5	32.7	12.5
EXT A	406.7	6.4	63.3	412.5	24.8	16.6
LW	289.9	21.6	13.4	416.3	36.3	11.5
EW	386.2	24.4	15.8	398.0	24.0	16.6
JW	407.3	18.9	21.6	428.5	13.4	31.9

We measured the lowest CO_2 uptake values on the arable lands, and the highest ones on wetland points. The three investigated grasslands' average carbon fixation was higher (with 10.6%) than the average value of the two arable lands. The wetlands sequester more than grasslands with one fifth (18.6%) and than arable lands with one third (31.1%) on average. The CO_2 uptake value was lower on the grassland restored in 2005 than that of the one restored in 2008. The higher CO_2 fixation value (with 21.2%) of the latter one is presumably caused by the greater amount of biomass of r-strategist weed species that are present in a high density after the restoration activities (in the first phase of the secondary succession). This is underlined by our aboveground biomass measurements as well. The natural grassland that was not affected by the habitat reconstruction, sequestered more C (with 14.8%) than the regenerating grassland type characterized with the highest CO_2 uptake values among the restored grasslands. The measurements carried out in the different grassland types show that the natural or near-natural grassland community has a very high carbon storing potential, which is above the potential of habitats in different stages of the succession.

The extensively managed arable land sequestered more (with 5.7%) carbon in the measurement period than the intensively managed type. All of the wetlands had higher CO_2 fixation values than the arable lands' values and also than the value of the grassland of 2005. The lowest sequestration values were measured in the *Juncus*-dominated stands, the *Lemna* stand was above it with 10,8%. The *Eleocharis*-dominated habitat's value was higher than it (with 40.6%), this had the highest CO_2 fixation of all of the investigated ecosystem types. The *Eleocharis* stand's potential was around twice as much (181%) as the grassland restored in 2005, which had the lowest values among the studied habitats.

3. CONCLUSIONS

From our results regarding the ecophysiological characteristics of the habitats, we highlight the following: the natural or semi-natural, well-structured grassland types have an outstanding role in the stand-level CO_2 sequestration and in soil carbon storage as well. In the restored habitats, no clear tendency could be observed concerning the carbon budget in the short interval of some years after the reconstruction. The carbon content of the soil is highly affected by grazing intensity after the end of arable farming, and the net sequestration values do not change linearly after the restoration activities. In the first years after seed sowing, the spreading of weed-type species temporarily increase NEE values. This can be observed in the case of other ecosystem services too: Szabó (2012) provided results also from the monitoring of the Egyek-Pusztakócs LIFE project and pointed out that wild bees providing the service of crop pollination appear with highest diversity in new fallows characterized by a high number of plant species. The effects of secondary succession on carbon exchange clearly need further observations, possibly in more landscape types. Some of the models developed for mapping ecosystem services (Petz and van Oudenhoven 2012, Tallis et al. 2013) are suitable for incorporating land management intensity, though it is carried out by changing the parameterization of the carbon pools. Theoretically, it enables differentiating between land management alternatives (at the same land use form). It could be important in the light of the results above and our former studies (Czóbel et al. 2008a, 2008b, 2012, 2013) about the effects of land management on the ecophysiological characteristics of grasslands and other habitats. There are clear differences in element contents of different carbon pools as a consequence of management intensity, which can be considered in indicator-based assessments or modelling works. In impact assessments of the effects of habitat reconstructions on carbon sequestration or other ecosystem services with synbotanical-synphysiological aspects, the indicators or proxy values should be given based on measurements carried out possibly in a similar area, with regard on succession state, land management and its intensity.

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