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Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem services

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ABSTRACT

The establishment of a sustainable land use system is crucial in Hungary (SE Europe) where 30% of croplands lie on former floodplains, and 40–45% of arable lands are drought-prone. We calculated and compared the monetary value of the main wetland ecosystem services, the profitability of land use and the additional costs of grain producer system on land at risk from groundwater inundation on the Hungarian Plain. We show that orchards and forestry generate a much higher profitability in former wetlands than cropland farming. Using the replacement cost method, we prove that the reservoir capacity of restored wetlands with an ecologically optimal 0.5 m water depth could replace 2150 €ha^{-1} flood protection investment cost. The calculated costs of protecting land under the two highest groundwater risk categories between 1999–2005 was 260.2 €ha^{-1} y^{-1} and 104.1 €ha^{-1} y^{-1}, respectively. Although the flood protection benefits of former wetlands may provide an appropriate value base for restoration per se, combined with the potential advantages of land use change from cropland to forest in former wetlands and the carbon sequestration benefit provide 'win-win' solutions for land users and institutional actors interested in flood prevention, environmental protection and climate mitigation.

1. Introduction

With the increasing numbers of humankind, there are increasing pressures on natural areas that can be converted to "productive" uses (Gliessman, 2015). Production-centered approaches consider that the large-scale conversion of natural habitats brings overwhelming benefits, or at least they are unavoidable, and overall, useful for people. This perception has resulted in large-scale habitat conversion that gained speed during the 20th century, with its large-scale mechanisation. As part of this process, many of the continent's rivers were regulated, their courses shortened and straightened, and former floodplains drained and converted to cropland (Pfadenhauer and Grootjans, 1999). The same happened in the central part of the Carpathian Basin (SE Europe) that historically had up to 25% of its area under temporary or permanent inundation, but ca. 98% of these wetlands has been converted to croplands (Koncsos, 2011).

However, provisioning services (e.g. food production; see Table 3) are only one class of ecosystem services (de Groot et al., 2002), and in order to achieve sustainability, other functions and services have also to be evaluated. Human land use activities including agriculture, forestry and energy production are the major anthropogenic greenhouse gas (GHG) emitters (IPCC, 2014). This effect makes habitats that can capture and retain carbon (carbon sinks) very important. Wetlands are habitats with very high carbon storing capacity, to an estimated 830 Tg y^{-1} (Mitsch et al., 2012), but they suffered severe losses globally during the recent transformation of agriculture. Their conversion to arable lands, pastures or artificial surfaces are greatly responsible for global carbon emission of land use (Watson et al., 1995). As a feedback, growing hydroclimatic vulnerability, increasing temperatures and worsening droughts on temperate plains pose a major challenge for land use policy and food security (Ray et al., 2015). With the growing awareness and acceptance of the contribution of ecosystem services to human welfare (The Economics of Ecosystems and Biodiversity, (TEEB) 2010), the value of the former natural areas can now be conceptualised, articulated and better evaluated. In this contribution, we use the example of the croplands on areas formerly under

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inundation on the lowlands of Hungary to show that integrated modelling approaches can improve the sustainability assessment of coupled ecological-economic systems. In particular, we shall argue that through restoring former wetlands currently under unprofitable cropland farming, most of the investment costs of a billion-euro flood protection megaproject in the Hungarian Plain can be saved. We claim that the re-evaluation of communal benefits is a key factor in the implementation of a sustainable land use system. Finally, we propose a zonal land use system that may support social adaptation to the landscape conditions of the once mosaic-like floodplain structure and to the challenge of climate change. Such an integrated perspective is important to support environmental and nature conservation policies and can contribute to current Mapping and Assessment of Ecosystems and their Services (Maes et al., 2012) and TEEB (2010) initiatives.

As a result of climatic, geomorphological and hydrological conditions, 25.3% of the 4.3 million ha of Hungarian arable lands is vulnerable to groundwater flooding (River Basin Management Plan of Hungary – RBMPH, 2010). An extensive canal system protects these arable lands that lie on former wetlands; they channelled an average of $1.77 \times 10^9\ m^3\ y^{-1}$ of groundwater into the river system between 1982 and 2006 (Hungarian Hydrological Yearbooks, 1983–2007).

Additionally, the majority of these drained wetlands are in areas that are the worst affected by droughts (Pálfai, 2004). Risk from groundwater floods is highest in January–March and in June, periods that coincide with the peak of floods. The high waters in June, however, precede the drought-prone summer months. Therefore, the drainage of former wetlands increased the flood risk on such reclaimed lands, and created new arable lands exposed to drought risk. To mitigate the hydroclimatic vulnerability of dry plains, extensification in agriculture (Olesen and Bindi, 2002) and the restoration of former wetlands (Csete et al., 2011; Hungarian Climate Change Strategy – HCCS, 2013; Hungarian Water Strategy – HWS, 2015) are suggested.

According to the Hungarian Water Strategy (2013, 2015), low-lying areas with low agro-ecological potential, which are regularly affected by groundwater flooding and where protection from this threat is disproportionately expensive, must be withdrawn from arable farming and water retention is to be encouraged on them instead. On the northern part of the Great Hungarian Plain, the relevant management plan (RBMP of Tisza, 2010) recommends the creation of protective puffer zones along 90% of streams, land use conversion in areas sensitive to nitrate pollution, and water body rehabilitation along more than 70% of the small and medium-sized streams.

The current river and groundwater flood protection system of the Hungarian Plain was established during the 19th–20th century agro-modernisation (Pinke, 2014). Today, 2940 km of dykes and 42,600 km of canals protect low-lying lands from groundwater flooding (Somlyódy, 2011). The sustainability of this extensive dyke and channel system was put to the test by extreme hydrological events in the late 1990s, just when Hungarian agriculture left governmental protectionism behind for the first time since the late 19th century (Morkre and Tarr, 1995; Kopsidis, 2008). The recognition that, under the conditions of post-communist market economy, revenues from farming are unable to finance the flood defence of such low-lying arable lands generated a paradigm change in Hungarian landscape ecology and water management (Szlávik, 2000). Although agro-experts, environmentalists, hydrologists and spatial planners recognised the necessity of restoring formerly reclaimed wetlands (VATI, 2004), due to the lack of well-established economic strategies for wetland utilization including detailed assessments of the ecosystem services, public dispute turned into polemics of an almost religious intensity (Koszorú and Szántó, 2011).

Participants of this intense debate were unable to reach a consensus on the size of areas to be involved in wetland restoration. These disputes highlighted two very important facts. First, agricultural and economic planners could not (or were not willing to) redefine the traditional land use approach, in which *'wetlands were viewed as a waste of valuable land that could only be improved through drainage and destruction of the wetland'* (Woodward and Wui, 2001). Second, the profits from cultivating these lands prone to groundwater flooding cannot cover the protection costs and water hazards, which discredited the sustainability of the present land use and water management systems (Forgóné Nemcsics, 2000; HCCS, 2013; HWS, 2015).

Hydrological planning reduced the complexity of ecological, social and economic aspects of hydroclimatic vulnerability of the lowlands to a simple flood protection plan (Vásárhelyi Development Plan – hereafter VDP, 2004), suggesting the creation of overflow reservoirs with ca. 700 million m^3 storage capacity (Table 5). However, long term flood security in the Tisza Basin requires retaining ca. 1.5–2 billion m^3 of water during flood peaks (VATI, 2004; Koncsos, 2006). Reserving this amount of water in a small area selected for this purpose (Table 5) can only be achieved by relatively deep reservoirs protected by dykes. The land use in these emergency reservoirs is dominated by crop farming, but the crop cannot survive when the reservoir is flooded to several m depth. So, the government is expected to compensate the land users of these reservoirs after each flood event. The concept was widely criticised, because it disregarded economic, ecological and geomorphological considerations (Gábris et al., 2004; Ungvári and Kiss, 2013). A cost-benefit analysis found that water retention in 19 low-lying floodplain locations along the Tisza River (Fig. 1), assuming a 1.5–2.5 m deep water in them, plus raising the height of the dyke system by 0.5 m above the critical flood level would be a far cheaper solution than implementing the VDP (Koncsos, 2006).

Retaining billions of m^3 of water infiltrating into the soil and evaporating in a wetland system may greatly reduce flood and drought risk on dry continental plains (Kerekes et al., 1994). Due to the prohibitively high investment and maintenance costs of flood defence systems, flood protection services provided by wetlands have outstandingly high value (Stürck et al., 2014; Mitsch and Gosselink, 2015; National Flood Resilience Review, 2016). Thus, we hypothesised that the flood defence service could be a core factor to integrate global and local targets, including food security and carbon capture in an ecologically and economically sustainable land use system in the drought-prone parts of the Hungarian Plain.

Economic undervaluation of the ecosystem services provided by wetlands (Clare et al., 2011) is a crucial factor hindering their conservation, maintenance and restoration. To improve this situation and move towards an integrative land use planning in the flood- and drought-prone Hungarian Plain, we assessed the value of two important wetland-related ecosystem services (flood protection, carbon sequestration in floodplain forests), and compared them to the value of the relevant provisioning services (livestock, crop and timber production) and the additional groundwater flood protection costs of the current grain producer land use system.

2. Materials and methods

2.1. Study area

The 9331 km^2 large study area lies in the centre of the Hungarian Plain, east of the Tisza River (Fig. 1). Almost half of the areas highly prone to groundwater flooding and one-third of the areas with the highest drought frequency and intensity in Hungary is concentrated here (Fig. 1). These flood-prone surfaces cover 59.6% of the study area; additionally, 30.8% of the landscape is also affected by salinization. This lowland region is one of the largest

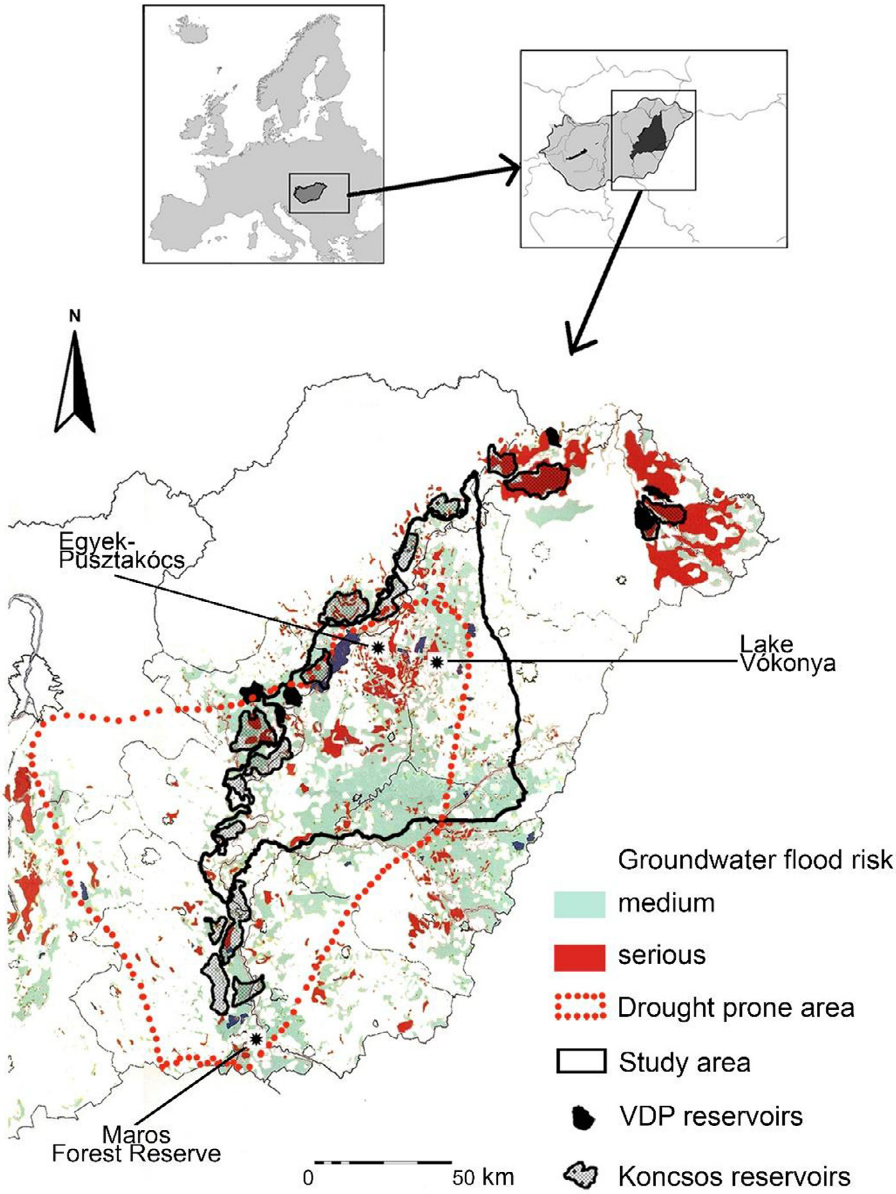

Fig. 1. A map of the study area, with indication of areas prone to drought and groundwater flood in the Hungarian Plain, the reservoirs of the Vásárhelyi Development Plan and the locations of additional reservoirs suggested by Koncsos (2006).

natural grasslands in Europe, and includes an UNESCO World Heritage site, the Hortobágy landscape, as well as extensive protected wetland reserves. It is also the location of two examined wetland restoration projects: the Egyek-Pusztakócs marshlands and Lake Vókonya (Fig. 1).

2.1.1. GIS data sources

We used the 100 m $\times$ 100 m grids of the 'Ecotype-Based Land Use Analysis of Hungary' (ELUAH) (Centeri et al., 2006) based on the measured physical, chemical and hydrological conditions of soils and on climatic conditions (Table 1 line 3). There are four categories of the areas experiencing groundwater floods (Table 1, line 5): those prone to serious and frequent floods (recurrence interval (RI) = 1–5 y), medium exposure (RI = 5–10 y), moderate exposure (RI = 10–20), and scarce exposure (RI > 20). This categorization was used for selecting the zone of 'Areas with regular groundwater floods' in the Hungarian Spatial Plan (2013). Data used in the zonal analysis, except for the Ecotype-Based Land Use Analysis of Hungary, are from open access datasets (Table 1).

2.1.2. Zonal classification

While preparing the water protection zone system, we considered aspects of environmental policy, nature protection, suitability for cropland farming and afforestation, vulnerability to drought, groundwater flooding and to contamination by nitrates (Table 1). To tackle the problem caused by the different spatial scales of the studied databases, we adjusted the scale of output maps to the one with the crudest resolution of the input datasets (1:100000).

Table 1
GIS data sources used for the zonal selection.

Database	Scale	Data host
Areas vulnerable to nitrification	1:100000	MEPH, 2008
CORINE Land Cover	1:50000	EEA, 2012
Ecotype-Based Land Use Analysis of Hungary (EULAH)	1:100000	SSAC HAS, 2008
Environmentally Sensitive Areas (ESA)	1:10000	MEPH, 2008
Inland water flooding risk database	1:100000	Pálfai, 2004
National Ecological Network	1:50000	MEPH, 2008
Natura 2000 network	1:10000	EEA, 2011

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Areas belonging to Zone 0 were excluded from the analysis. These were artificial surfaces (settlements, roads, railroads, etc.), lakes and water streams, as well as land classified as of excellent agro-ecological potential in the ELUAH.

Zone 1 covered the areas exposed to serious or medium groundwater flood risk, and the intersection of areas under medium risk and either natural reserves or areas vulnerable to nitrification, as identified by the RBMPH (2010, 2015) and the Hungarian Government Decree No. 221/2004 [VII. 21.]. Here the RBMPH recommended groundwater retention citing ecological and water protection reasons.

Zone 2 comprised areas prone to drought and groundwater flooding at a medium level but not under nature protection. These areas are suitable for excess surface water retention from the aspects of ecology, economy (Table 3) and water quality. The main environmental problems of crop farming here are diffuse water pollution from agriculture (RBMPH, 2010, 2015), drought vulnerability, flood proneness (Pálfai, 2004), the low agro-ecological potential of soils formed under water effect (Sisák et al., 2009) and a low level of biodiversity.

Zone 3 covered the intersection of areas falling into the three most suitable categories of afforestation in the ELUAH and Zones 1 and 2. These areas of water retention are suitable for afforestation.

2.2. Economic assessments for supporting landscape planning

So as to have a broad picture on the economic effects of current and planned land use in areas prone to groundwater flooding intended for restoration, we made an evaluation of the profitability of current land use types in areas prone to groundwater flooding, two analyses for carbon sink potential and flood protection values of the restored wetlands and a calculation of additional costs of keeping arable lands functioning in the face of groundwater threat. Our goal was to obtain results that can contribute to a landscape planning process, thus we made estimations of monetary values per unit area. We used Schaubroeck et al. (2016) and Cabral et al.'s (2016) collections of ecosystem services as models.

The efficiency of the agricultural sector has a particular importance in the investigated land use problems. Thus, we first evaluated the food production potential for arable lands, grasslands, orchards and wetlands, together with the timber production in the area. Second, relying on the calculations of biomass growth by using the CO2Fix 3.2. model (Masera et al., 2003; Schelhaas et al., 2004), we calculated the monetary value of carbon capture capacity of indigenous floodplain forests on the Hungarian Plain. Following the examples of wetlands in Washington State (Leschine et al., 1997); the River Rhine and Meuse deltas (Brouwer and Van Ek, 2004) and the Biebrza Valley in Poland (Grygoruk et al., 2013), we used the replacement cost method (de Groot et al., 2002; Brander et al., 2006) to compare the investment costs of storage capacity per m^3 of two restored aquatic ecosystems with the storage capacity of the six completed reservoirs of the VDP. We also considered the maximum sustainable water per ha (de Groot et al., 2010), and regional land prices (Iftekhar et al., 2016). Finally, we estimated the spatial average of the costs of protection against, and the damage caused by groundwater floods in the affected arable lands.

2.2.1. Evaluation of selected provisioning services of the current land use forms

Assessing the most important provisioning services, trade-offs and the relevant regulating services of wetlands may expose some drivers behind land use conflicts (Kovács et al., 2015). Here we evaluated the monetary value of the food production potential of arable lands, grasslands and wetlands, and the productivity of forests in areas prone to groundwater floods (market price method, based on national-scale datasets Table 3; Supplementary Table S8). Given the production boundary, we separated human inputs from natural ones to distinguish ecosystem services and benefits as clearly as possible. Therefore, we estimated the net profitability of the studied land use categories by subtracting the incurred production costs from the revenues.

The monetary valuation of agricultural profitability was based on the annual cost and revenue analyses of the Hungarian Research Institute of Agricultural Economics that estimated net profitability through the calculation of sectoral profit datasets (Beládi and Kertész, 2009, 2010, 2012). As the profitability of different crops and fruits varies greatly, we weighted the profit figures of land cover categories using the country-wide share of different cultivated plants (Hungarian Central Statistical Office (HCSO), 2017). Since there are no datasets available at regional or municipal levels, we calculated the sectoral profit using the national agricultural Producer Price Indices (HCSO, 2017). We calculated the grassland value as the average of the profitability value of meadows and pastures. For the latter, a weighted average of the net profitability of cattle and sheep husbandry was used (HCSO, 2017). The weighting was based on the area use of each in the country, in turn estimated from the country total of heads and average livestock densities (No. of animals/ha, Supplementary Table S8). The profitability calculations were obtained from the sectoral profit datasets in the annual cost and revenue analyses of the Research Institute of Agricultural Economics. There are no similar datasets for the fisheries available, so we calculated the net profitability of fisheries using an agronomy course book analysis (Nábrádi et al., 2007).

Timber production can be evaluated using economic models for timber production, developed by the Hungarian Forest Research Institute (2007). These models give cost and revenue analyses for particular tree species, from planting to logging, for forests on three different soils. The models consist of three parts: (1) thinning-harvest activities, (2) a logging model, and (3) cost and revenue data expressed in monetary value. From the original model, we used the average of model results for the two locally most important tree species, hybrid poplar (*Populus x euramericana*) and pedunculate oak (*Quercus robur*), discounted for the year 2013, with a 1% discount rate, which can be reasonable in economic analyses in forestry, as forest plantations are long-term investments (Marjainé, 2005).

2.2.2. Carbon sequestration benefits of floodplain forests

We estimated the monetary value of carbon sequestration potential by different forests habitats estimated by the CO2Fix 3.2. model in a characteristic forested floodplain area (Maros Flood Catchment Forest Reserve and its surrounding area, Fig. 1) (Kiss et al., 2015). We derived the annual net carbon sequestration values from the carbon stock values (available for every year in the model output) (Supplementary Tables S3–S6), calculated for three characteristic natural forests: white and black poplar (*Populus alba, Populus nigra*) stand, a mixed willow (*Salix alba*) -poplar forest, and a pedunculate oak (*Quercus robur*) stand (Supplementary Tables S1–S2). To calculate the monetary value of the sequestered carbon, the Social Cost of Carbon estimates were used (calculated based on values of climate change impacts – damage cost method – Tol, 2008), with values converted to the study year (2013) using the Producer Price Indices of the subsequent years (GDMA, 2017).

2.2.3. Valuation of the flood protection service of areas exposed to groundwater floods

Here we compared the establishment costs of the restored Egyek-Pusztakócs (Hortobágy National Park, 2008) and Lake Vókonya marshlands (Hortobágy National Park, 2006) and the six overflow reservoirs of the VDP (Water Management of Hungary, 2010) (Table 5). Similarly to the VDP reservoir construction, during the landscape restoration projects, the pre-existing dyke and channel network affecting local groundwater conditions were demolished and new engineering structures of water management were installed. To calculate reservoir capacities, we assumed a 0.5 m deep temporary or permanent water coverage (ca. 5000 m^3 ha^{-1}) as an ecological optimum on wetlands to be restored in the Tisza Valley (Derts and Koncsos, 2012).

Additionally, we included the cost of land that the new reservoirs now permanently occupy. The average price of arable land in the Northern Hungarian Plain Region in 2007 was 1512.1 €ha^{-1} (±48.6%) (Vinogradov, 2009). In 2008, land prices ranged from 796.0 €ha^{-1} to 9154.2 €ha^{-1}, depending on the type of land use (cropland, meadow, vineyard, or orchard). Lower quality land, e.g. areas affected by groundwater floods, was sold at even lower prices (796.0–3582.1 €ha^{-1}) because of the high production risk (Biró, 2009).

2.2.4. Estimation of groundwater flood protection costs and damage per unit in highly flood-prone areas

The research into additional expenses related to groundwater protection was considerably hampered by limited access to data. This non-transparency of groundwater flood protection costs was also emphasised in the RBMPH (2015).

In the calculation below we only included the operational costs that were incurred during floods, and include pumping, and the additional reinforcement of dykes to prevent bursting. These are related to the frequency of use of the canals, i.e. positively related to the frequency of groundwater flooding. Other types of costs, such as costs of construction, maintenance and amortization of defence systems were ignored.

At a country scale, operational costs of the groundwater protection system including the maintenance expenses amounted to 10 million €y^{-1} between 1999 and 2010 (Somlyódy, 2011). The length of the groundwater canal system is 42,600 km and the total protected area is 45,000 km^2 (Szatmári et al., 2011), giving an average density of ca. 1 km canal length km^{-2}. Thus, the estimated average of inland water protection costs between 1999 and 2010 was 234.7 €km^{-1} y^{-1}.

There are no data or estimation available for canal densities in areas classified into different groundwater risk categories. Due to the topographic character of the catchment area, the highest density of canals can be found in the deepest floodplains, which are the most vulnerable areas to groundwater floods, while the canal system is less extensive in less flood-prone areas. In the absence of precise data (Kozma, 2013).

We assumed that half (≥50%) of all canals (42,600 km/2 = 21,300 km) was situated in areas under serious and medium groundwater flood risk (Supplementary Table S7) (Somlyódy, 2011). On the base of this ratio, we calculated the density of canals in two groups: (1) serious and medium inundation risk, (2) areas under moderate or low groundwater inundation risk (Supplementary Table S7). The length of canals within the four groundwater risk categories was estimated using the proportion of the area under groundwater risk group 1 vs. group 2 above (details see in Supplementary Table S7). The operational costs are linked to the frequency of use, i.e. the frequency of inundations, thus we calculated the cumulative length of canals in use over a 30y period in the various risk categories. Considering the operational costs and the area served category-by-category, we arrived at an estimated cost of protection/ha in the various risk categories (for further details, see Supplementary Table S7).

Groundwater flood damage on arable lands and was estimated at 60.3 million €y^{-1} between 1999 and 2005 at a national scale (Pálfai, 2006). On average, 164,800 ha were inundated (Hydrological Yearbooks, 2000–2006), and 52.4% of this was arable land (Table 2). So, the majority of annual damage was caused on 86,355 ha of arable land.

Table 2
Land use categories of inundated areas in Hungary between 2002 and 2010 (ha).

Year	Arable land	Meadow	Other	Sum
2002	1825	1650	970	4445
2003	54,158	38,793	11,213	104,164
2004	10,326	15,558	5457	31,341
2005	56,345	37,640	8689	102,674
2006	135,606	80,592	28,336	244,534
2007	927	1189	3964	6080
2008	830	1030	2260	4120
2009	21,037	15,320	12,525	48,882
2010	61,240	33,295	12,765	107,300

Source: Ministry of Agriculture, 2010.

3. Results

3.1. Economic assessment inventory for supporting landscape planning

3.1.1. Evaluation of land use profitability in areas prone to groundwater floods

The net profitability values were lowest in grassland (20.7 €ha^{-1} y^{-1}), followed by arable land (50.7 €ha^{-1} y^{-1}), forest

Table 3
Estimation of monetary value of various activities of current and planned land use and their spatial validity.

Issue	Type	Value, €ha^{-1} y^{-1}	Spatial validity	Source
Net profitability of different agricultural sectors				
Profitability of arable lands	Food production, provisioning services	50.7	Local, national, EU	National data and descriptive analysis – market price method*
Profitability of forests	Timber, provisioning service	96.3	Local, national, EU	National data and descriptive analysis – market price method*
Profitability of grasslands	Provisioning service	20.7	Local, national, EU	National data and descriptive analysis – market price method
Profitability of orchards	Food production, provisioning service	150.9	Local, national, EU	National data and descriptive analysis – market price method*
Profitability of wetlands	Fish production, provisioning service	380.3	Local, national, EU	National data and descriptive analysis – market price method*
Monetary values of				
CO2 sequestration in floodplain forests	Mitigating global warming#	5–24	Global	Monetary evaluation of model outputs, damage cost method
Flood defence service	Replacing investments#	2150	National, EU	Replacement method
Benefits from avoiding costs related to floods				
Costs of flood defence	Avoiding protection costs#	8.37	Local, national, EU	Data from descriptive analysis
Costs of flood damage on arable land	Avoiding damage costs#	365.9	Local, national, EU	Data collection and descriptive analysis

Regulation ecosystem service, * Beládi and Kertész (2009, 2010, 2012).

Table 4
Amount and monetary value of carbon sequestration of the studied forest types.

Forest type	Rotation length (y)	Maximum amount of stored carbon ($tCha^{-1}$)	Average carbon sequestration rate ($tCha^{-1}$ y^{-1})	Value of the average carbon sequestration (€ha^{-1} y^{-1})
Poplar stand with native species	40	74.9	0.25	5.16
Mixed near-natural forest	No management activity	124	1.02	21.1
Oak stand	120	267.5	1,15	23.8

Table 5
The main parameters of the completed VDP reservoirs and the two restored wetlands.

Name	Area, km^2	Reservoir capacity, 10^6 m^3	Total cost, 10^6 €	Investment cost, €m^{-3}
VDP reservoirs				
Hanyi-Tiszasülyi	55.7	247	68.7	0.28
Nagykunsági	40.0	99	40.7	0.41
Cigánd- Tiszakarádi	24.7	94	63.7	0.68
Tiszaroffi	23.0	97	29.3	0.30
Beregi	52.3	58	92.3	1.59
Szamos-Kraszna közi	51.1	126	61.2	0.49
Total	222.1	721	355.9	0.49
Restoration projects				
Egyek-Pusztakócs marshland	50	25	1.04	0.04
Lake Vókonya	20	10	0.83	0.08
Total	70	30	1.87	0.06

Table 6
Land use structure of target areas to retain excess surface water.

	Ratio in study area, km^2 (%)	Occupancy of current land use forms, km^2 (%)		
		Arable lands	Meadows	Woods
Study area total	9331 (100)	6232 (66.8)	905 (9.7)	341 (3.7)
Zone 1	3978 (42.6)	1826 (45.9)	1482 (37.3)	289 (7.3)
Zone 2	890 (9.5)	794 (89.4)	49 (5.5)	29 (3.2)
Zone 3	847 (9.1)	738 (87.2)	61 (7.2)	26 (3.0)

(96.7 €ha^{-1} y^{-1}) and orchards (150.9 €ha^{-1} y^{-1}). The highest value, 380.6 €ha^{-1} y^{-1} was obtained for wetlands (Table 3; Supplementary Table S8).

3.1.2. Modelling the carbon sequestration benefits of floodplain forests

Floodplain forests have a rotational length of 40–120 y, and during this cycle, they can store 75–268 $tCha^{-1}$, which is estimated to worth 5.2–23.8 €ha^{-1} y^{-1} (Table 4). A longer rotation cycle results in higher average carbon sequestration rates in slow-growing oak stands, for which the model returned the highest values (Table 4). The monetary values of carbon sequestration were between 20 and 30 €ha^{-1} y^{-1}.

3.1.3. Valuation of the flood protection service of areas exposed to groundwater flooding

The reservoir capacity cost per m^3 the two restored wetlands was 0.43 €m^{-3} cheaper than that of the VDP reservoirs (Table 5) which means that the reservoir capacity of restored wetlands with an ecologically optimal 0.5 m water depth could replace 2150 €ha^{-1} flood protection investment cost.

3.1.4. Estimation of groundwater flood costs and damage per unit in highly flood-prone areas

The estimated operational costs in areas with serious and medium groundwater risk run to 260.2 and 104.1 €ha^{-1} y^{-1}, respectively, between 1999 and 2005 (Supplementary Table S7 column 10).

The estimated groundwater flood damage to arable lands between 1999 and 2005 amounted to 365.9 €ha^{-1} y^{-1}. This, nonetheless, is not the average of the damage in areas with serious or medium groundwater risk, but the average on the actually inundated areas.

Regarding the fact that half of the national total of areas with serious or medium groundwater risk is situated in the study area, approximately half of the costs related to such floods at a national level occurs in this area.

3.2. Land use zonation

Although only 28.1% of the study area was classified into the excellent and good agro-ecological suitability categories, almost 66% of the landscape is currently used for monocultural cropland farming (Table 6), The implementation of the RBMPH (2010, 2015) requires water retention in Zone 1 where land use conversion on flood-prone arable lands under environmental protection extends to 19.6% of the study area (Fig. 2). The results of the zonal analysis indicated that 28.1% of the study area should be converted from arable land to wet meadows, forests or marshlands. The percentage of arable lands is also outstandingly high in Zone 2 where land use change is ecologically and economically justified (Table 6). While 26.5% of area is suitable for economically reasonable afforestation, most of these, especially in loess ridges, overlap with areas of good or excellent agro-ecological suitability. Currently, woody vegetation that comprises forest (2.9%) and shrub categories of the Corine covers less than 4% of the study area (Table 6).

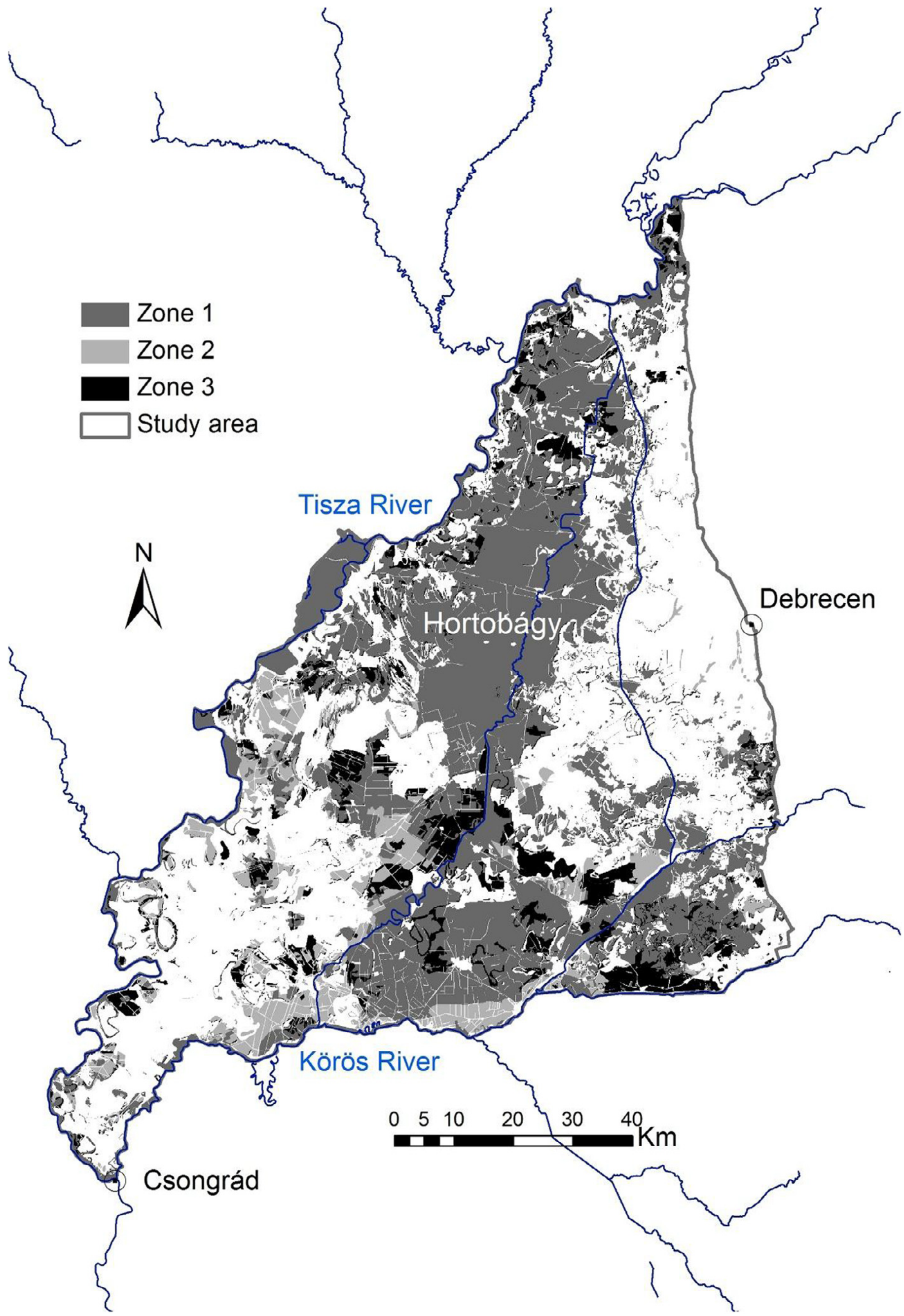

Fig. 2. Suggested water protection zones.

4. Discussion and conclusions

Our analysis showed that the current land use pattern on the examined flood-prone areas of the Hungarian Plain had an overall negative economic balance (Table 3). The resulting profitability values of land use forms can be used in comparisons and trade-off analyses with other services. The calculated potential savings, even when considering only a few of the potential ecosystem services, constitute strong arguments for land use conversion on 52.1% of the study area (Table 6). Such conversion would lead to multiple and substantial economic benefits.

Land users could use their land to gain tangible benefits both to themselves and the community instead of continuing to produce commodities financed by subsidies. Some benefit transfers are financed by the EU or governmental agri-environmental measures, but ecosystem services which land users transfer to the community, especially in the case of wetlands, are generally underfunded (Sweeney et al., 2004; Clare et al., 2011; Pendleton et al., 2016). If land users relieve the community (e.g. by flood or drought protection) from expenses tied to maintaining the current land use pattern, and abandon their former attitude of seeking maximised yield gains (Hardin, 1968), they would be entitled to benefit from the value of the transferred services.

The lack of detailed economic analyses on land use in relation to hydrological regimes and omitting the evaluation of wetland ecosystem services contributed a great deal to the derailment of the Tisza Valley flood protection strategy in the early 2000s (de Groot, 2006). Arguably, the grain production system in the former wetlands of the Hungarian Plain has been in permanent crisis since its beginnings (Hamza et al., 2011; Pinke, 2014). Climate variability is one of the most important factors influencing crop yield in the highly drought-vulnerable reclaimed wetlands of the Hungarian Plain, where temperature maxima during the cereal growing season are frequently above the tolerance threshold (Sisák et al., 2009). In Hungary, mean temperatures rose significantly from 1951–1980 to 1981–2010 and grain production has an outstandingly high vulnerability to climate change: a 1 °C temperature increase cut back the yields of the four main cereals by 9.6–14.8% during 1981–2010 (Pinke and Lövei, 2017). Besides recent climate change, transformation of the Common Agricultural Policy will aggravate difficulties of crop production in the studied wet areas with low agro-ecological suitability.

Natural reserves, and especially the remains of the highly endangered forest-steppe lying in areas prone to groundwater floods are generally water-dependent habitats (Molnár et al., 2012). Draining them caused landscape-wide water shortage, which grossly degraded these habitats, and their restoration is indispensable (RBMPH, 2010). Furthermore, patches of retained inland water is to be linked to the creation of a self-sustaining habitat network that provides paths for energy and material fluxes and for the migration of species (Claire et al., 2010). Thus, corridors of the National Ecological Network are important elements of the outlined zonal water protection system.

The targeted integrated landscape restoration would mostly result in large areas of marshlands, wet meadows and floodplain forests with mixed vegetation potential. Establishing Zone 3 that covers flood-prone areas suitable for afforestation could facilitate the increase of forest coverage. The success of completed afforestation programs in the Hungarian Plain in the past decades suggests (Agricultural Operation Office, 2009) that most of the conflicts between water retention and arable farming can be resolved by properly allocated subsidies for public afforestation in this zone. In par with other examinations in the wider region (Paletto et al., 2015; Wutzler et al., 2011) our results are within the range of values of net carbon sequestration by forests, mainly below 2000 kg $Cha^{-1}\,y^{-1}$ (Table 4). The valuable carbon capture, flood reservoir and water purification capacity of wetland forests would make even significantly increased subsidies for wetland reforestation reasonable (Jenkins et al., 2010; Maes et al., 2012). The high sequestration rates of the studied mixed near-natural forests (Tables 3 and 4) underline the role of undisturbed or lightly managed floodplain forests in mitigating climate change (Luyssaert et al., 2008).

Climatic conditions of the study area do not allow forests to form a closed canopy, which is reflected in the current categorisation of afforestation suitability. Still, intrazonal effects of water coverage may make forestation possible even in areas under adverse climatic conditions (Pályi, 2004). Trnka et al.'s model (2011) indicates that recent climate change "could cause a significant loss in crop production and revenue in regions where no additional water sources are available". Consequently, the mitigation function of wetlands will become even more important at landscape scale (Kerekes et al., 1994; Lo, 2016). Historical examples confirm that shallow water coverage and high groundwater would support the evolution of biodiverse sylvi- and pomiculture in currently drought-prone areas (Gyulai, 2010). The fact that the areas suitable for reasonable afforestation economically overlap areas with good and excellent agro-ecological suitability creates a conflict with crop production as a land use form. The result of this conflict is the extremely low forest coverage in the study area, which refers to serious discrepancies of the land cover regime. Given the suitability conditions of the landscape and the already existing domestic political will that supports reforestation of the Hungarian Plain as a priority (GR 1110/2004; National Rural Strategy 2012–2020, 2012), raising subsidies for reforestation could lead to the plantation of forests over large lowland areas. The Hungarian Plain lies on the boundary of the forest and the steppe zones, and it is a region seriously exposed to aridity, with the largest secondary saline areas in Europe (Schofield et al., 2001). This gives an international significance to the research and restoration of its wetland forests in the struggle against drought, salinization and desertification.

The findings of the study suggest that the mere flood protection benefit of former wetlands provides sufficient base for landscape restoration, and this is ecologically and economically relevant. The investment costs (considering the cost m^{-3} of stored floodwater) of the current flood defence megaproject on the Hungarian Plain are 6–12 times higher than the establishment costs of the two wetland restoration programs implemented in the same region. The investment costs of VDP reservoir capacity per unit could cover not only the restoration costs of land endangered by groundwater floods, but also the market price of low quality arable lands and pastures in the region. The estimated benefit from the buffer capacity of areas with groundwater hazard provides 'win-win' solutions for land users interested in profitability and for institutional actors interested in flood prevention and environmental protection (de Groot et al., 2010). Our results strengthen the previous findings on the robust flood protection value of restored habitats in comparison to the highly expensive flood defence solutions currently applied (Stürck et al., 2014; National Flood Resilience Review, 2016). The integration of the value of flood protection with carbon capture (Mitsch et al., 2012) and other ecosystem services may transform priorities in an integrative land use planning and management (de Groot et al., 2010; Wolff et al., 2015).

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Author contributions

The study was initiated by ZP; conceptualisation: ZP, MK, with environmental policy input from GLL; analyses & calculations: ZP, MK.; all authors contributed to the writing of the MS.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecoser.2017.09.007. These data include Google maps of the most important areas described in this article.

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