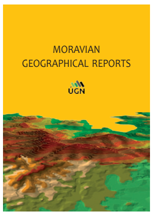

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A GIS-based framework to determine spatially explicit priority categories for flood risk management intervention schemes

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Abstract

The necessity of plural valuation of costs for flood risk management is widely acknowledged, but practical case studies are still scarce. We developed a GIS-based plural valuation framework to determine spatially explicit priority categories for flood risk management intervention schemes on the Drava River, Southern Hungary. A conventional economic evaluation, including land market prices and additional costs due to legal conservation restrictions, was complemented by ecological valuation of vulnerability. The inclusion of ecological vulnerability significantly changed the proposed priority areas for flood risk management interventions: in this case, softwood riparian forests face far less threat, together with other Natura 2000 habitats, in comparison to unprotected wetlands and grasslands. This valuation framework also highlights priority habitats and areas for joint conservation and water management projects, utilising the synergies between several EU Directives as the Birds Directive, Habitats Directive, Flood Directive, and Water Framework Directive. Our framework is adaptable for the other floodplains along major or medium-sized European rivers, assuming that specific local settings are considered.

Keywords: *plural valuation framework; decision support system; ecological vulnerability; riparian forests; wetlands; Water Framework Directive; Hungary*

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1. Introduction

Water resource management aims to secure numerous and varying ecosystem services of wetlands, floodplains, and watersheds, as supplying water for household use, agriculture, industry, heating and cooling, hydropower, transport, and also for leisure; see European Environmental Agency (hereinafter EEA) (2018).

The emerging concept of integrated water resource management reflects the need to harmonise the provision of hydrologic services with the obligations of several Community Directives. The aim of the Water Framework Directive (hereinafter WFD) is the protection of all surface waters and groundwater and to achieve good status in all waters, through the protection of aquatic habitats and generally water resources; see European Council (hereinafter EC) (2000). The 'Birds' and the 'Habitats' Directives (hereinafter BHD) together form the backbone of the EU's biodiversity policy as they protect Europe's most precious species and habitats. These ecologically valuable areas form the Natura 2000 network, which includes the majority of national parks and legally protected areas in Hungary. The objectives of the directives are interrelated, and special attention and coordination are needed where these directives are implemented in the same areas (EC, 2011).

The Flood Directive (EC, 2007), launched as a response to the devastating floods in the first decade of the 21st century, which recurred in the second and third decades (Schindler et al., 2016; CEDIM, 2021), regulates the assessment and management of flood risk. Along with the River Basin Management Plans (hereinafter RBMP), Flood

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Risk Management Plans (hereinafter FRMPs) have been prepared. Flood Risk Management (hereinafter FRM), like river basin management, acts at the landscape level, influencing the existence and living conditions of large human and non-human populations, and also of other components of landscapes, such as natural habitats, aesthetic, cultural, and intrinsic values, together with the ecosystem services (hereinafter ES) provided by them. It creates and maintains safe shipping ways by shortening and straightening the river course (cutting off meanders). Furthermore, it employs dikes to protect agricultural areas and human settlements from flooding. At the same time, FRM interventions also have negative effects on other floodplain ESs. They may lead to riverbed incision and floodplain desiccations, thus weakening their biodiversity conservation (habitat maintenance) potential, which is perhaps the most often mentioned ESs of floodplains (Blackwell and Pilgrim, 2011; Haines-Young and Potschin, 2013). The intervention of FRM may also damage aesthetic, cultural, and intrinsic values temporarily or even irreversibly.

According to FRMPs, most European countries have designated flood retention areas to manage flood events and to avoid unsuitable land uses. Flood retention areas are usually situated in the lower-lying parts of active floodplains, where high wetland biodiversity is preserved under less intensive land-use; consequently, they often overlap with nature conservation areas within the Natura 2000 network (EEA, 2016). They host a wide array of habitats of community interest and their rich flora and fauna. Large parts of floodplains are parts of the Natura 2000 network (EEA, 2016), and protected also by national conservation legislation, often as national parks. To fulfil all legal obligations, even to resolve their contradictions, flood risk management (FRM) interventions have to be harmonised with the WFD and Birds and Habitats Directive.

Furthermore, FRM has to build consensus among all stakeholders to secure the interests of land users, as interventions, especially if they involve economically valuable areas such as arable lands, often cause immediate or delayed economic damage to landowners. Whether this impact is easily mitigated, or causes long-lasting damage, depends on many factors, e.g. on the type and area of the intervention, on the method of rehabilitation (if any), and on the landscape context (e.g. habitat types, or invasion routes of invasive alien species).

Monetary valuation techniques of ESs are increasingly widespread and accepted. A range of practical methods are developed and tested, and numerous case studies are published, including those from floodplains and wetlands (e.g. Meyer et al., 2012; Pinke et al., 2018). At the same time, it is to be remembered that monetary valuation only represents one component of ES valuations (Boeraeve et al., 2015), and monetary and non-monetary approaches should equally be applied (EC, 2012). To consider the full diversity and complexity of ESs in decision-making, a scientifically well-founded plural valuation of costs and benefits is indispensable, and the number of such studies in this field are increasing (Jacobs et al., 2016). Plural valuation, proposed by several authors, is more relevant for practical use if it is embedded in local settings (Meyer et al., 2009; Pinke et al., 2018).

Our framework is innovative in that it extends the above-discussed conventional valuation framework to include ecological aspects. For this extension the concept of ecosystem vulnerability is chosen. Ecosystem vulnerability, besides resistance and resilience, is one of the key issues in ecosystem ecology. It is considered as a potentially useful measure in risk assessment and management (de Lange et al., 2010), especially in the case of wetland habitats (Weisshuhn et al., 2018). Ecological or ecosystem vulnerability "is an estimate of the inability of an ecosystem to tolerate stressors over space and time", and it is determined by the characteristics of the ecosystem (Williams and Kaputska, 2000), e.g. a certain habitat type. The application of the vulnerability concept to ecosystems is still an emerging topic (Weisshuhn et al., 2018), such that the development of general indicators is an open question at this time. Beroya-Eitner (2016) expressed the opinion that …"ecological vulnerability assessment and the development of indicators … should be conducted at smaller scales and must be context-specific". A categorical system, based on local expert judgment may be an appropriate tool for a robust evaluation, and a further advantage is the use of state-of-the-art knowledge and local expertise (De Lange et al., 2010).

According to the recent review by Weisshuhn et al. (2018), vulnerability to invasive species is a preferred topic in vulnerability studies. Ecological vulnerability can be assessed through biological invasion, as the presence and abundance of invasive alien species (hereinafter IAS) are regarded a good indicator of the local deterioration caused by many types of FRMs (Janssen et al., 2016). Invasive alien species are considered as one of the main conservation challenges, second only to habitat loss (Rabitsch et al., 2012), both globally (Mölder and Schneider, 2011), and also for Europe (Maes et al., 2014; Schindler et al., 2016). The presence of IAS is used as an indicator of recent global biodiversity decline (Butchart et al., 2010); and is also one of the European biodiversity indicators (Rabitsch, 2012). IAS are considered as threats at the river-basin or floodplain scale (Apostolaki et al., 2019; Ortmann-Ajkai et al., 2018).

River valleys are particularly vulnerable to biological invasions (Dyderski and Jagodzinski, 2016). Disturbance increases invasibility (Stanković et al., 2019). Regular floods destroy or damage large parts of the riparian vegetation, creating suitable habitats for the colonisation by different species, of which IAS are the most successful ones due to their outstanding competitiveness (Pyšek and Prach, 1993). Rivers may act as dispersal agents transporting downstream propagules of IAS (Aguiar and Ferreira, 2013). Wetlands are especially endangered by IAS, as neophytes have a stronger affinity to wet habitats and disturbed woody vegetation, while archaeophytes tend to be more common in dry to mesic open habitats (Chytrý et al., 2008). In Europe, warm lowlands as the Po and the Danube basins (where our study area is situated), are the most invaded areas (Chytrý et al., 2009).

To balance all aspects and interests, the multifunctional floodplain management concept (Schindler et al., 2016), landscape function classification (Stejskalová et al., 2012) and the ecosystem service approach (Maes et al., 2014, Grizetti et al., 2016) are suggested as tools to aid decision makers in finding more sustainable solutions. Monetary valuation techniques of ESs are increasingly widespread and accepted. A range of practical methods are developed and tested and numerous case studies are published, including those from floodplains and wetlands (e.g. Meyer et al., 2012, Pinke et al., 2018). At the same time, it is to be remembered that monetary valuation only represents one component of ES valuations (Boeraeve et al., 2015), monetary and non-monetary approaches should equally be applied (EC, 2012). To consider the full diversity and complexity of ESs in decision making, a scientifically well-founded plural valuation of costs and benefits is indispensable, and the number of such studies are increasing (Jacobs et al., 2016). Plural valuation, proposed by several authors, is more relevant for practical use if it is embedded in local settings (Meyer et al., 2009; Pinke et al., 2018).

Nevertheless, few studies apply plural valuation at the local scale, relevant to decision making (e.g. Stejskalová et al., 2012, Pandeya et al., 2016). Our study fits into this research gap. Its main goal is to provide a plural valuation framework for supporting science-based decision-making during the planning process of FRM interventions. This framework consists of two parts. First, an economy-based approach is presented; then it is extended to include the non-monetary costs of risk to threatened habitat types of European importance.

2. Study area and methods

2.1 Study area

2.1.1 Physical features

Our study area is located on the floodplain of the Drava River. The Drava drains waters from the south-eastern Alps. It originates at the western end of the Karnian Alps, South-Tyrol (Italy), at 1,192 m elevation. Its length is 896 km, its total drainage area is 43,238 km^2. Its largest tributary is the Mura, which flows into the Drava from the left side, between 236.0 and 237.0 river km. The Drava water regime is controlled by the alpine headwaters (Schwarz, 2017). Highest discharges occur between May and July. Another discharge peak in autumn is due to the Mediterranean precipitation pattern in the middle and lower courses of the river. Long-term mean discharge on the Lower Drava is 526 m^3/s with absolute minimum around 70 m^3/s and maximum of 850 m^3/s at high water. The discharge for the 10-year flood is about 2,100 m^3/s and for the 100-year flood about 3,200 m^3/s.

Since the beginning of water regulations (mid-18th century), it has been affected by human activities of various kinds and extent. Consequently, the river channel and, in parallel, groundwater levels are sinking continuously since the regulations, due to channel incision (Lóczy et al., 2017), which is disadvantageous for the riparian vegetation as demonstrated by Škarpich et al. (2016), for the conditions of Natura 2000 habitats along the river.

The area of the present study is situated in the Lower Drava active floodplain, from the Mura confluence down to Drávaszabolcs village, where the Drava leaves the country (Fig. 1). For most of its length the river forms the national border between Hungary and Croatia. The area of the active floodplain in this section amounts to 297 km^2. According to its geography, administrative and hydrology management, it consists of two sections. From 236.0 to 140.0 river km there are high banks on the left, Hungarian bank, so there are fewer flood protection dikes. The active floodplain extends over both Hungarian and Croatian territory. The second subsection lies between 140.0–70.2 river km, where the active floodplain is bordered by flood protection dikes on the lower left bank. As the whole study area is situated in the active floodplain, its role is water retention, but in case of extremely high-water levels, floods can be even devastating. As the Drava River is mainly influenced by snowmelt in the Alps, it is hazardous that as global warming and climatic extremes continue to occur, very high flood events are not to be excluded. Consequently, there is a need to invest in water management at least in the larger rivers. There were some larger floods (above 2,000 m^3/s) in the 1970s, and again in 2014 (DDVIZIG, 2020).

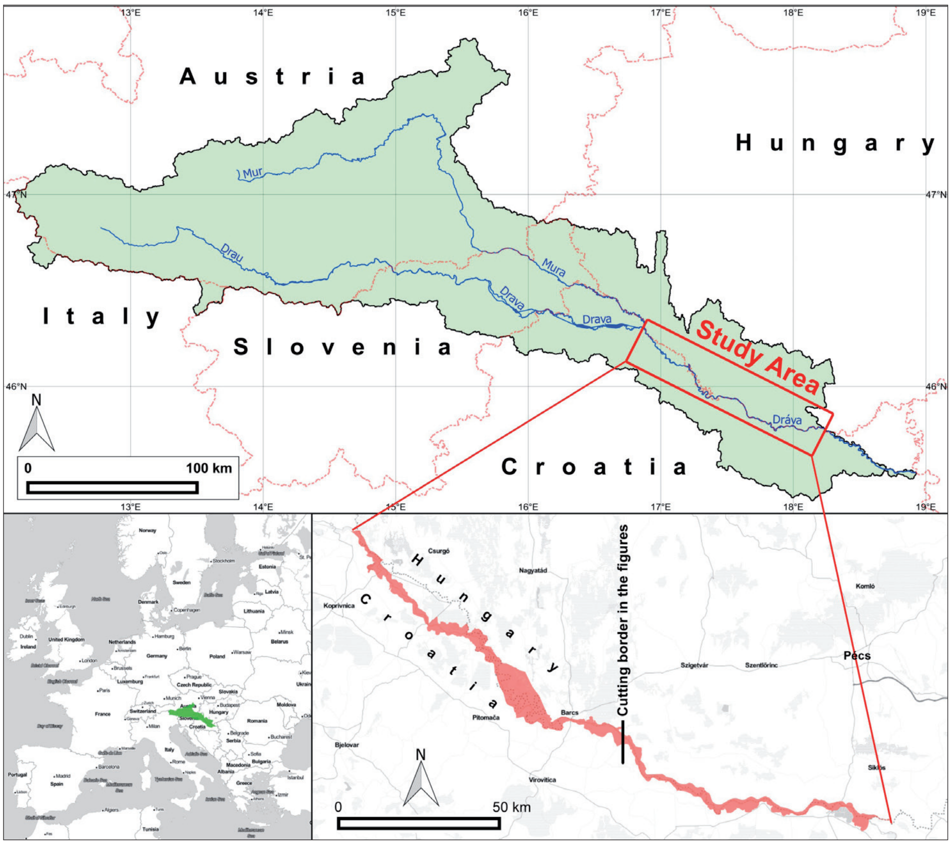

Fig. 1: Overview map of the study area. Source: authors' elaboration

2.1.2 Land-use, habitats and conservation

Among the medium-sized rivers of Europe, the Drava stands out in its naturalness. In its active floodplain, more or less regularly flooded every year, a rich array of more or less undisturbed wetland habitats are present (Kevey, 2018; Ortmann-Ajkai et al., 2018a). The majority of the habitats are of European importance (for codes see Tab. 1). Typical are the small backwaters with rich euhydrophyte and riparian vegetation; pioneer mud vegetation of temporarily drawing-out surfaces; reedbeds, sedge beds and wet meadows; and close-to-nature alluvial forests. Land uses are dominated by forestry, and to a slightly lesser extent by arable fields. Most of the woody vegetation are willow and poplar forests, oak-ash-elm hardwood forests, and to a smaller extent stands of invasive tree species (*Acer negundo*, *Robinia pseudoacacia*) are also present.

The study area represents an uninterrupted chain of habitats of community significance (Natura 2000 areas, EC 1996, Natura 2000 Network Viewer). It is a European green corridor (the UNESCO Transboundary Biosphere Reserve Mura-Drava-Danube). The Hungarian part belongs almost entirely to the Danube-Drava National Park, to the core area of the Hungarian National Ecological Network, and other NATURA 2000 areas.

2.2 Preparation of the target-oriented base map

A detailed land cover map of the Lower Drava region had not been available before our investigations started. To prepare such a map, data were collected from various sources:

- CORINE Land Cover 2018 (https://land.copernicus.eu)
- Danube-Drava National Park (http://www.ddnp.hu/)
- Hungarian Forestry Web Map (2019): (https://erdoterkep.nebih.gov.hu)
- Hungarian Nature Conservation Information system (2019) (http://web.okir.hu/map/?config=TIR&lang=hu)
- Natura 2000 Network Viewer (2019) (https://natura2000.eea.europa.eu/)
- Nature conservation base maps of Croatia (Ministarstvo gospodarstva I odrzivog razvoja, 2019) (https://www.bioportal.hr/gis/)
- Sentinel-2 database (2019) (https://scihub.copernicus.eu)
- UNESCO (2019): (https://natura2000.eea.europa.eu/ (http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/europe-north-america/croatiahungary/mura-drava-danube/)

Habitat name	EUNIS code	Natura 2000 code	Extension (km^2)	Spatial pattern
Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation	C1	3150	43.92	common
Natural dystrophic lakes and ponds	C1	3160	negligible	small and very rare stands
Rivers with muddy banks with Chenopodium rubri p.p. and Bidention p.p. vegetation	D5	3270	negligible	small temporal stands
Alluvial meadows of river valleys and lowland hay meadows[1]	E2, E3	6440	21.96	patches of varying size
Alluvial forests with *Alnus glutinosa* and *Fraxinus angustifolia*[2]	G1	91E0	106.70	Large stands, dominant habitat type of the study area
Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *U. minor*, *Fraxinus excelsior* or *F.angustifolia* along great rivers	G1	91F0	21.96	large stands

Tab. 1: Natura 2000 habitats and their distribution in the study area (Notes: [1]distinguishable only in the field; [2]Natura 2000 priority habitat). Source: authors' compilation

The land-use classes, which are clearly identifiable from aerial photographs, were manually digitised: built-up area; industrial-commercial area; arable land; pasture, meadow, bush and transitional wood; water surface. The rest of the area was classified using satellite image analysis: close-to-natural hardwood forest (oak, ash, hornbeam etc.); close-to-natural softwood forest (poplar, willow, alder); pinewood; alien tree plantations (primarily black locust and red oak); waterlogged areas. The bands of 3, 4 and 8 of Sentinel-2 Level 2A satellite images of high resolution taken in spring, summer and autumn were classified in ArcGIS Pro environment.

First, the land cover classes identified from Sentinel-2A satellite images were checked using control sites, selected in forest districts of the official Hungarian forest map website. The pixels of control sites were correctly classified to 75–96% by the Support Vector Machine algorithm.

First interpretations revealed that the data of this website are rather generalised, i.e. mostly show only the tree species predominant in the given management unit. Therefore, at the stage of identifying training areas as well as during later checking, the aerial and satellite images were also analysed by a biologist expert for colours, patterns, objects etc., similar to the method of compiling the high-resolution ecosystem map for Hungary (Tanács et al., 2021), or other publications, e.g. Demková and Lipský (2017). It was especially useful in the case of pastures (complex grassland-shrubland patterns) and old-growth softwood riparian forests with non-continuous canopy. For the resulting habitat types and map see Figure 2.

For the "Legal protection" layer of the base map, mapped habitat units were grouped according to legal conservation categories as national parks areas, Natura 2000 areas (outside NPs) and areas without conservational restrictions.

2.3 Development of the plural valuation method

For the robust estimation of monetary costs, which determine the priority ranking of areas to be used for intervention of FRM measures on specific sites, a category-based evaluation procedure was developed. Land-use types were classified according three factors into categories by land price, by legal protection and by ecological vulnerability.

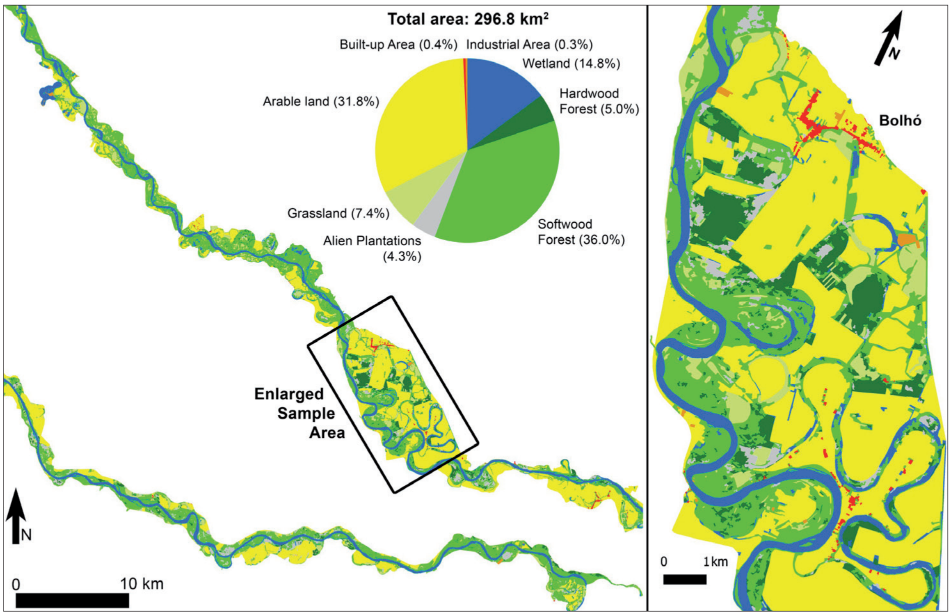

Fig. 2: Habitat map of the study area
Source: authors' elaboration

For land price categories, land prices were determined by the market price method (Meyer et al., 2012) for each land-use type. Sites for FRMs (e.g. dike or canal construction) or water retention are usually expropriated for this purpose, or landowners must be compensated, as they may suffer immediate or delayed economic damage. In the first step, land prices were collected from national databases (AGROINFORM (2019), KSH (2019), with dimensions as EUR/ha and EUR/m^3. HUF prices were exchanged to EUR at the rate 1 EUR = 325 HUF, central parity for EUR/HUF by the Hungarian National Bank for the year 2019 (Hungarian National Bank 2019). In the second step, relative weights were calculated in the following way. For the relative land weights, EUR/ha prices for arable lands, grasslands and forests were averaged; relative weights were defined as percentage values of this average (dimensionless). For wetlands no adequate price database were found. As they are usually regarded as economically useless areas, not appropriate for profitable cultivation, their value was defined empirically as "low". In the case of forests, land prices were further differentiated because softwood and hardwood (including aliens) timber prices are different. Refinement was made by multiplying this value with the value of relative timber weights. Relative timber weights were calculated according to the above-mentioned logic: EUR/m^3 stumpage prices were averaged and relative weights were defined as percentage values of this average (dimensionless). Market prices of different timber types were obtained from the website of the regional forestry management (Mecsekerdő, 2019).

Land price categories were defined by dividing the range of relative land weights (from 0.66 for grasslands to 1.55 for arable lands) to three equal intervals of 0.316, so category A included land types between 0.6–0.92, category B: 0.93–1.21, category C: 1.24–1.55. Therefore, areas in Category A are eligible as priority areas for the intervention of FRM measures; areas in Category C are the least recommended for this purpose. The planning of FRM intervention includes authorising procedures. In areas, where the level of legal conservational protection is higher, there are more legal restrictions and obligations, authorisations is more cost- and time-intensive (Tab. 2). For comparability with other variables, three legal conservation categories were established. Category A includes areas without legal protection, where there is no need for permissions from conservational authorities when changing the mode of cultivation or property changes. Category B includes Natura 2000 areas. Their legal protection level is lower than that of legally protected National Park areas, but certain changes in land use or cultivation modes needs permission of the conservational authority. Category C includes areas with a National Park status. National Parks fall within the scope of stricter legal regulations, where most changes of land use or cultivation modes require permission of the conservational authority. Similar to land price categories, areas in Category A are proposed to be priority areas for the intervention of FRM measures.

Land price and protection are aspects regarded conventionally in water management decision making. For this reason, the next step is to merge these two pillars into the cost – protection category system (PP), which eventually defines the priority order, if only economic aspects are considered. The method of merging is applied to preserve the lower priority rank, i.e. A for merging A and B; also, A for merging A and C (see Tab. 5, Columns 1, 2 and 4). Modifications in industrial-commercial and built-up areas would directly affect the everyday life and work of the human population and structures of traffic and border security (the Drava River here is the state border between Hungary and Croatia, i.e. the external border of the Schengen area). Changes in such areas have to be avoided, so they were excluded from further analysis. As for the Croatian part, there were no data available, so the same categories were applied there too.

The innovation of our framework stands in extending the above-discussed system to include ecology aspects. For this extension we employed ecosystem vulnerability, which can be assessed through biological invasion. Our assessment fulfils three of the four criteria formulated by de Lange et al. (2010): it is based on expert judgment (field experiences, and a rich array of literary sources); includes knowledge of certain stakeholders (landowners, conservation personnel); results are ranked categories and mapped.

Subject of permission	Categories		
	A	B	C
Selling of land	x	x	x
Changing the way of cultivation	x	x	x
Cutting or planting trees outside of forests	–	x	x
Ploughing or sowing of grasslands, or creating tree plantations on them	–	x	x
Cutting reeds, removing aquatic vegetation	–	x	x
Tree cutting in forests during the vegetation period	–	–	x
Grazing or mowing of grasslands	–	–	x
Burning grasslands, reed beds, abandoned arable fields, hay; fire lighting in forests	–	–	x
Use of pesticides, herbicides and other bio-regulators and fertilizers	–	–	x
Vehicle transport	–	–	x
Activities needed for maintenance and management of public roads, railways and energy networks	–	–	x
Entering strictly protected areas	–	–	x
Performing research, experiments, and collection	-	-	x

Tab. 2: Activities subject to authorisation in different legal conservation categories
Source: authors' compilation

The classification of habitats by vulnerability is in line with region-specific Hungarian and international studies. According to an overview of the invadedness of habitat types in Hungary (Botta-Dukát, 2008), riverine woodlands are most severely threatened, marshes and meadows are threatened to a lesser extent, and euhydrophyte habitats are least threatened. Stanković et al. (2019) in their ranking of southern Pannonian Ramsar sites, for the invasibility of wetland habitats, found riparian woodlands the most invasible, with medium invasibility for wet meadows, wetlands with sedge and reed beds and mesic oak-ash-elm mixed forests. Riparian softwood groves are the most threatened according to several sources including Wagner et al. (2017), Lapin et al., (2019), Stanković et al., (2019). Closed (hardwood floodplain) forests are more resistant but not quite resistant to invasion (Chytrý et al., 2009). For comparability with the land price and legal conservation categorisations, three vulnerability categories were distinguished, relying on the above-mentioned sources.

Vulnerability categories were merged with "price and protection" (PP) categories, so PPV categories emerged. This categorisation includes land price, legal protection and ecological vulnerability each. Priority rankings based on PP and on PPV categories (Tab. 5) were compared by Spearman's non-parametric correlation coefficient (Spearman's D), calculated with PAST (Hammer et al., 2001).

3. Results

3.1 Habitats of the study area

The map of habitats of the study region is displayed in Figure 2. The predominant land use type (37.1%) in the study area is riparian softwood forest, a priority habitat of community importance (EUNIS: G1, Natura 2000: 91E0). Like other riparian habitats, they are naturally disturbed due to regular inundation. Dominant tree species are white willow (*Salix alba*) and white poplar (*Populus alba*). Other common tree species are black poplar (*Populus nigra*), sometimes with a trunk diameter above 1 m (see photos in Appendix); *Ulmus laevis* and *Populus tremula*. At this elevation plantations of hybrids and cultivars of poplars (*Populus* × *euramericana* agg.), and willow cultivar plantations are common. Homogenous plantations of *Populus* clones are characteristic in the area, and they are routinely planned in abandoned meadows and for recultivation of areas destroyed by construction. As the herb layer of such plantations is usually like that of close-to-natural habitats, they also can be included in this habitat category, although their conservational value is lower compared to natural poplar stands. Their vulnerability to IAS is also similar.

Riparian hardwood forests cover 5.0% of the study area, in more extensive stands. They also represent a priority habitat of community importance (EUNIS: G1, Natura 2000: 91F0). They are situated on higher elevations of the floodplain. Before river regulations, the natural water regime of the oak-ash-elm forests included some weeks of spring inundation. Presently, as only the deepest parts (former riverbeds) are inundated irregularly, these forests can exist because of the high groundwater table. Dominant tree species are *Fraxinus angustifolia* and *Quercus robur* in varying proportions. The main common natural tree species are: *Ulmus laevis*, *Populus alba*. In the herb layer, hydrophilic species, as *Carex remota*, *Cerastium sylvaticum*, *Impatiens noli-tangere* are driven back by mesophilic ones (e.g. *Galium odoratum*, *Carex sylvatica*, *Veronica montana*, *Galeobdolon luteum*) due to the dropping groundwater level. Woody IAS are less common. Grasslands, meadows, and transitional shrubs are considered as a mosaic habitat type. In the study area, grasslands, mainly wet meadows, cover 7.4%. Some of them are utilised as pastures or mown meadows; others are abandoned with spreading shrub cover. The main utilisation of grasslands in the study area is grazing with different intensity. Therefore, there is a constantly changing pattern of shrubs and open grasslands, so these two land-use types – although they could be delineated on remote-sensed images, but just for the given date – were not differentiated in the analysis. Although these grasslands are representatives of Natura 2000 habitats (E3/6440: Alluvial meadows of river valleys; E2/6510: lowland hay meadows with *Alopecurus pratensis* and *Sanguisorba officinalis*), both overgrazing and abandonment lead to their degradation. Unless the groundwater level is high, wet meadows slowly turn into degraded drier grassland types with lower biomass production.

Open waters and wetlands cover 14.8%. Here the open water surfaces of the river Drava and oxbow lakes, and their connected reed and sedge beds are found. The aquatic vegetation of oxbows (C1/3150: small natural eutrophic lakes) consists of Magnopotamion and Hydrocharition species, as *Hydrocharis morsus-ranae*, *Lemna species*, *Salvinia natans*, *Nuphar lutea*; rarely of *Nymphaea alba*, *Nymphoides peltata* and *Utricularia vulgaris*. *Elodea canadensis* is an IAS which is present everywhere and often monodominant. High emergent vegetation (EUNIS: C5) consists mainly of *Phragmites australis*, to a lesser extent of *Typha latifolia*, *T. angustifolia*, and *Glyceria maxima* in sites of permanent water cover. In sites desiccating for some months of each year, stands of *Carex riparia* and *C. acutiformis* occur. Alien tree plantations, mainly *Robinia pseudoacacia*, less frequently *Quercus rubra* and *Pinus sylvestris* plantations on the higher, hardwood forest level; and spontaneous *Acer negundo* stands on the softwood forest level cover 4.3%. The main type of agricultural land-use are arable fields (EUNIS I1, lesser extent I2) 31.8%. Built-up and industrial areas (EUNIS J) are negligible, under 1% (0.7).

3.2 Land prices and legal protection

Land prices were calculated by the market price method, based on national and regional market databases. The average market price of grasslands, forests and arable lands and the calculated relative land weights are shown in Table 3. For wetlands, there were no generally applicable data, but as their economic value is usually low, so they were put into category A. The average timber price was 51 EUR/m^3, for softwoods (willow, poplar, alder) 39 EUR/m^3; for hardwoods (natives: oak, ash; main alien: black locust) 70 EUR/m^3; with relative timber weights, see Table 3. Finally, land use types were categorised as "low price" (A), so priority for FRM interventions: wetlands, grasslands, and softwood forests (58.2%); "medium price" (B): near-natural hardwood forests and alien tree plantations (9.3%); "high price": arable lands (31.8%): they should be avoided by FRM interventions as far as possible because of economic reasons (Fig. 3).

More than the half of the study area (58.1%), including the entire Croatian territory, is qualified as Natura 2000

	Grasslands	Forests	Arable lands		Native softwoods	Native hardwoods / Alien planted trees
Market price (EUR/ha)	1,780	2,108	4,156	Market price (EUR/m^3)	39	70
Relative weights	0.66	0.79	1.55		0.77	1.38
Land price categories						
Wetlands: „low"	No adequate quantitative data			low		A
Grasslands: 0.66	No further refinement			0.66		A
Forests: 0.79	Near-natural softwood forests: 0.77			0.79 × 0.77 = 0,60		A
	Alien plantations: 1.38			0.79 × 1.38 = 1.09		B
	Near-natural hardwood forests: 1.38			0.79 × 1.38 = 1.09		B
Arable lands: 1.55	No further refinement			1.55		C

Tab. 3: Calculation of land price categories
Source: authors' compilation

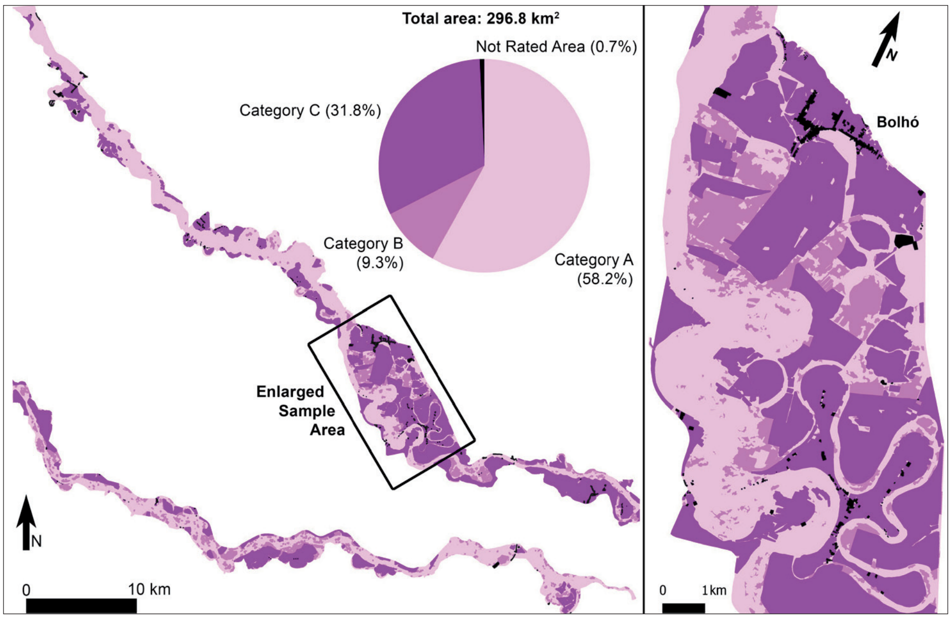

Fig. 3: Land price category map of the study area (Category A: low price; Category B: medium price; Category C: high price). Source: authors' elaboration

area. 30.5% of it belongs to the Danube-Drava National Park in Hungary, only 9.3% is without any kind of legal protection (Fig. 4).

3.3 Reconsidering priority ranks after regarding ecological vulnerability

Based on previous knowledge, and for comparability with the other two aspects, three vulnerability categories were established (Tab. 4). 36.0% of the study area is extremely vulnerable (Category C). It is covered by riparian softwood forests, and all our sources agree that they are the primary target areas of alien plant invasions. Category B extends to 27.2%, it includes near-natural wetlands, grasslands, and closed hardwood riparian forests. Near-natural wetland habitats, mainly reed- and sedge-beds in the riparian zone of small waterbodies, are moderately vulnerable. Their invasibility depends on their naturalness and/or their water supply. With good water supply, they are resistant to alien plant invasion; but degraded, desiccating stands are among the most intensively invaded habitat types. Grasslands are moderately vulnerable because their utilisation (grazing, mowing) effectively prevents the mass spreading of IAS; but if abandoned they often get invaded. Closed hardwood floodplain forest, if in good naturalness state, are also resistant to invasion, due their closed canopy. Nevertheless, if their naturalness is decreased (e.g. because of desiccation, or inappropriate forest management), they are quickly and easily invaded. Not vulnerable habitats (Category A, 36.1%) are arable lands and tree plantations (Fig. 5). FRMs implemented in arable lands will not increase invasion threats because cultivation prevents the establishment of woody IAS. Invasive tree stands are naturally regarded as not endangered, as they often consist of IAS, as e.g. *Robinia pseudoacacia*.

The comparison of priority ranks in cases when ecological vulnerability is disregarded (PP categories) *vs* regarded (PPV categories) are to be seen in Table 5 and Figure 6.

There is no change in 75.7% of the study area; but in 67 hectares (22.7%) the decision on FRM must be reconsidered: there are several reasons which make these areas less appropriate for intervention. The two lists of ranks proved to be significantly different according to Spearman's (non-parametric) rank-order correlation coefficient (Spearman's rs p(uncorr) = 0.00033). Looking at the differences on the habitat level, there is a clear division between the habitats proposed *versus* not proposed for FRM interventions. Regarding only land prices and protection regulation, not protected wetlands, grasslands, and softwood forests were ranked as priority areas. After completing the framework with ecological vulnerability, FRMs are strongly contraindicated in all near-natural habitat types, also in unprotected areas, they are proposed to be relocated into more human-affected habitats such as invasive tree stands and arable lands.

4. Discussion and conclusions

4.1 Ecology issues

There is an expressed need for the plural valuation of effects of water management interventions. Plural valuation must include, besides monetary valuation, an ecological one. Nevertheless, there are few studies, especially of local, practice-oriented investigations, which deal with this issue. Our results showed that integrating the non-monetary cost of risk to Natura 2000 habitats significantly altered the proposed priority ranking of areas for FRM interventions.

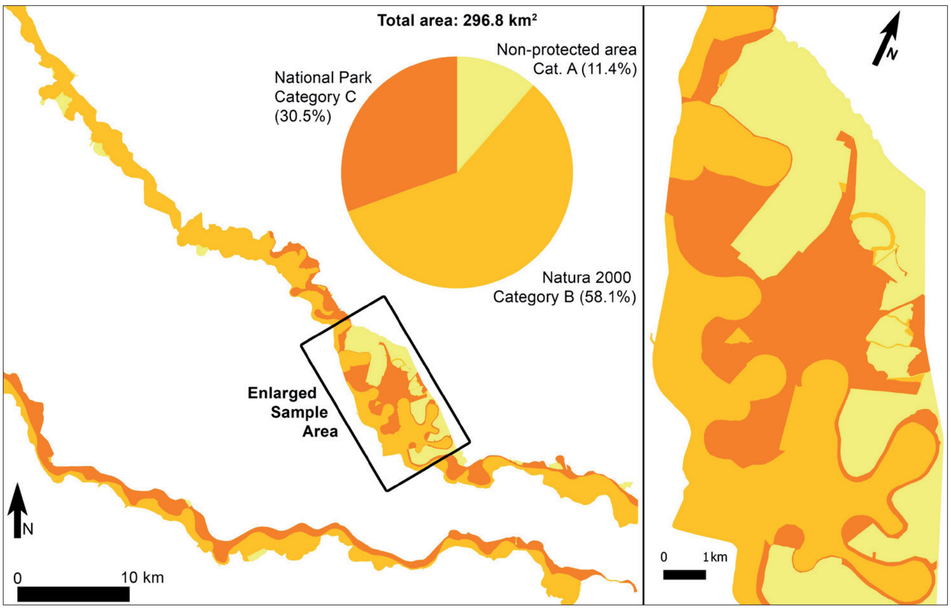

Fig. 4: Legal protection category map of the study area. Source: authors' elaboration

Category name	Category code	Habitats included
Not vulnerable	A	arable lands, alien tree plantations
Moderately vulnerable	B	wetlands, grasslands, closed hardwood riparian forests
Extremely vulnerable	C	riparian softwood forests

Tab. 4: Vulnerability categories with included habitats
Source: authors' compilation

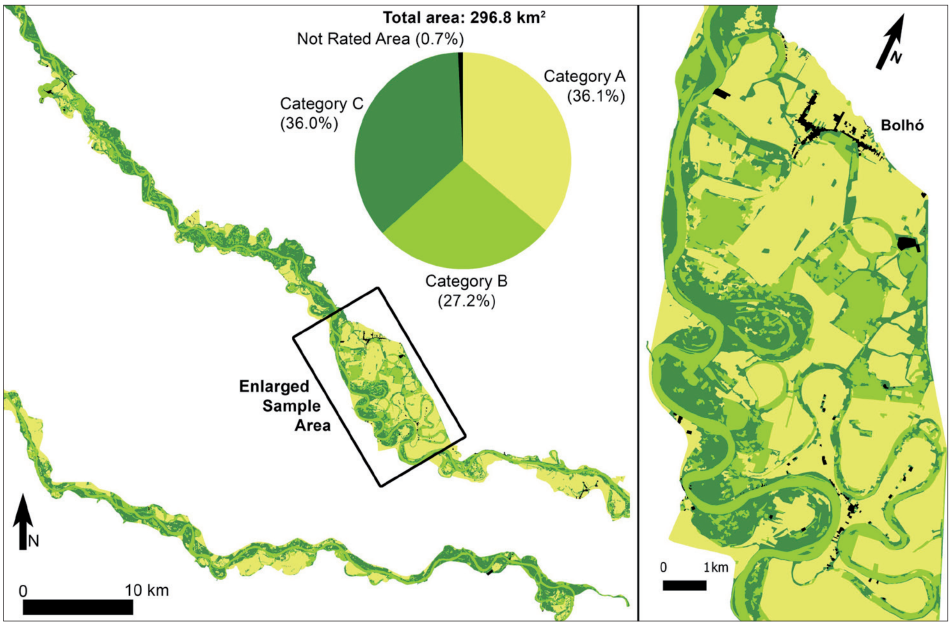

Fig. 5: Vulnerability map of the study area (Category A: not threatened by invasion; Category B: moderately vulnerable to invasion; Category C: extremely vulnerable to invasion)
Source: authors' elaboration

Habitat type	**Land price**	**Protection**	**Vulnerability**	**Price and protection (PP)**	**Vulnerability included (PPV)**	**Category change**
Near-natural wetlands unprotected	A	A	B	A	B	A to B
Near-natural wetlands in Natura 2000 areas	A	B	B	B	B	
Near-natural wetlands in National Park	A	C	B	C	C	
Hardwood forests unprotected	B	A	B	B	B	
Hardwood forests in Natura 2000 areas	B	B	B	B	B	
Hardwood forests in National Park	B	C	B	C	C	
Softwood forests unprotected	A	A	C	A	C	A to C
Softwood forests in Natura 2000 areas	A	B	C	B	C	B to C
Softwood forests in National Park	A	C	C	C	C	
Alien plantations unprotected	B	A	A	B	B	
Alien plantations in Natura 2000 areas	B	B	A	B	B	
Alien plantations in National Parks	B	C	A	C	C	
Grasslands unprotected	A	A	B	A	B	A to B
Grasslands in Natura 2000 areas	A	B	B	B	B	
Grasslands in National Parks	A	C	B	C	C	
Arable lands unprotected	C	A	A	C	C	
Arable lands in Natura 2000 areas	C	B	A	C	C	
Arable lands in National parks	C	C	A	C	C	

Tab. 5: Categorisation of habitat types according to different factors
Notes: PP = categories based on land price and legal protection status; PPV = categories based on land price, legal protection, and ecological vulnerability; Category codes: for land price: A: low land price; B: medium land price; C: high land price. Category codes for protection: A: not protected area; B: Natura 2000 area; C: National Park area. Category codes for vulnerability: A: not vulnerable; B: moderately vulnerable; C: highly vulnerable
Source: authors' elaboration

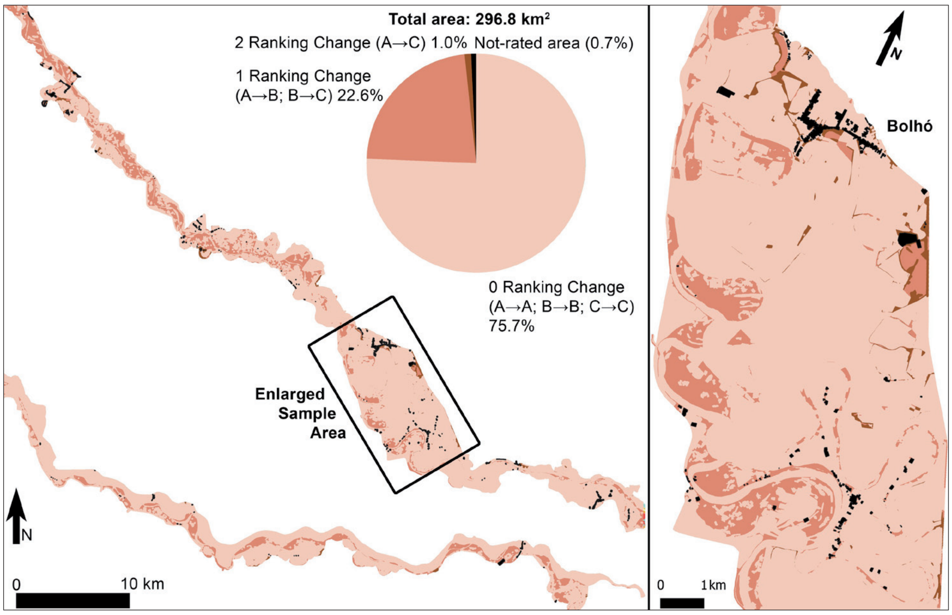

Fig. 6: Change of priority ranks
Source: authors' elaboration

Priority rankings, disregarding or regarding ecological vulnerability, significantly differed according to Spearman's (non-parametric) rank-order correlation coefficient. National Park areas are in the lowest priority category C, i.e. they are relatively well protected against the potential negative effects of FRM measures by conservational legislation, even if ecological vulnerability is disregarded. A National Park's conservation goals are declared in the legally binding management plans, which overwrites economic aspects in most of the cases. At the same time, habitats of high conservational value, such as softwood riparian forests, close-to-natural wetlands and wet or mesic grasslands are in the second, or even in the priority category (B, A) if they are lying outside of the National Park. As habitats in Natura 2000 areas are found in priority category B, it is questionable whether the Natura 2000 network provides adequate protection for these valuable habitat types (Wesolowski, 2005; Miklín and Čížek, 2014) especially in preventing the spread of IAS (Guerra et al., 2018). The situation is deteriorated by the fact that Natura sites are often fragmented and located in landscapes that are heavily invaded (Pyšek et al., 2013).

Regarding ecological vulnerability, four habitat types out of 21 (19%) with an area of 67 hectares (22.7 % of the total study area) have a lower priority for (i.e. less threatened by) FRM interventions: all Natura 2000 habitats, except hardwood riparian forests outside protected areas; and softwood riparian forests within Natura 2000 areas (those already in categories B and C, respectively).

The most important change is in the position of softwood forests. Floodplain softwood (*Salix-Populus*) forests represent the most widespread (36.3%) and most valuable habitat type, the only one of Natura 2000 priority. They belong to the most vulnerable habitat type in the study area and are among the most vulnerable ones at the European level (Chytrý et al., 2008; Janssen et al., 2016; Wagner et al., 2017). The observed intensive spread of woody IAS (their proportion in certain stands is as high as 25–30%) is a serious threat. Most widespread woody IAS are green maple (*Acer negundo*), American ash (*Fraxinus pennsylvanica*), to a lesser extent black locust (*Robinia pseudoacacia*), tree of heaven (*Ailanthus altissima*), furthermore Persian walnut (*Juglans regia*) and white mulberry (*Morus alba*), which are more and more common although not considered as an IAS in Hungary to date. Regarding only economic aspects, softwood stands in not protected areas are proposed as priority areas for FRMs, but regarding their vulnerability, they are relocated into priority category C. They indispensably need regular inundation of 2–8 weeks per year, so in their case conservational and certain FRM aspects are synergetic. Regular waterlogging, as a natural disturbance agent, is needed to maintain their continuously changing architectural structure with many deadwoods, rich tree regeneration and typical biota (Miklín and Čížek, 2014).

Flooding also prevents the spreading of many IAS, as e.g. *Robinia pseudacacia*, *Solidago gigantea*, *Aster* (*Symphiotrichum*) *spp*., but these species usually explode when the inundation fails. At the same time, inundation does not prevent the invasion of some other IAS, such as *Acer negundo*, *Amorpha fruticosa*, *Fraxinus pennsylvanica*, *Echinocystis lobata*. If softwood riparian forests are felled, e.g. for giving place to FRMs, natural regeneration may be made impossible by the invasion of IAS, e.g. a thick carpet of *Echinocystis lobata* or *Humulus scandens* (see photographs in Appendix).

Open waters and wetlands, such as oxbow lakes and their connected reed and sedge beds cover 15% in the study area (44 ha). Regarding only economic aspects, they belong to priority areas for construction works, as their market price is low. At the same time, they represent diverse relict habitats with exceptionally rich flora and fauna, and some of them include Natura 2000 habitats (Ortmann-Ajkai, 2018). Most wetland habitats (aquatic vegetation, reed and sedge beds) face the highest risk on the short term. Construction works may destroy them, but if the site receives proper water coverage after the works, in the longer run, within some decades they may regenerate reasonably well as landscape elements. Nevertheless, it is doubtful to what extent their ecological properties can be restored, even in the long term (Gulati et al., 2008; Bakker et al., 2013). Wetlands in not protected areas were categorised into Category B instead of Category A, which is favourable for their conservation.

Due to their ecological diversity (naturalness, size, species composition, habitat for protected species, pollution, etc.), there is a possibility for local negotiation, which may even help to reach win-win situations in cases of other trade-offs regarding more controversial issues.

There are inconsistencies and uncertainties in the case of grasslands. Similarly, to wetland habitats, grasslands in not protected areas were categorised into Category B instead of Category A. It is partly due to their diversity in ecological, economical and management aspects. This diversity is not represented in the average values used in our framework. As they cover only 22 hectares, 8% of the study area, there is a need and possibility for local negotiation. These negotiations may help to reach win-win situations.

Floodplain hardwood forests are less widespread in the study area, and even more disappeared from Europe, so their protection is of high importance for nature conservation. They need high groundwater levels, but intolerant to waterlogging for several weeks. Due to their more stable structure and slower natural dynamics, floodplain hardwood forests are more resilient to IAS than softwood ones (Chytrý et al., 2009). Older stands with deeply rooting trees survive, but changes in the herb layer indicate that these forests develop towards the mesic oak-hornbeam type (Kevey, 2018). After felling the stands, natural-based regeneration is problematic because of sinking groundwater level. Reforestation is implemented by planting native species. Young plantations need intensive care, which includes the eradication of woody IAS, but if management is improper, as in places which were expropriated from forestry use for FRMs, valuable native species, as pedunculate oak and Hungarian ash may be outcompeted by more generalist species, and aggressive IAS, such as *Robinia pseudacacia*, *Juglans nigra*, *Fraxinus pennsylvanica*, *Ailanthus altissim*a. FRMs, securing natural water retention for 1–2 weeks yearly is beneficial to the naturalness, and even productivity of hardwood forests, although forestry management operations may be hindered.

Invasive alien tree stands did not change category when ecological vulnerability is considered. Due to their economic value, they are not priority areas for FRMs according to our framework. Nevertheless, as they present an exceptional ecological threat to all natural (and sometimes also economic) values, converting them into stands of native species is a current challenge for conservation. FRM intervention may even be regarded as a conservational valuable measure for the eradication of IAS, which may compensate for economic costs.

The eradication of IAS is amongst the foremost serious current challenges to conservational management (Pyšek et al., 2013). There is a huge potential for synergies between water management and conservation, which can result in a more successful acquisition of funds (EC, 2011, Schindler et al., 2013) and attain better and prolonged practical results if the re-establishment of invasive species on the bare constructional grounds is prevented. The transformation of IAS stands to stands of native trees (which within some decades, and in case of availability of propagule sources for mixing tree species and native herbs, may develop into forests of medium naturalness) is one point of synergy between FRM and conservation interventions. Note that simply eradicating stands of IAS trees is not sufficient, since with lack of further management, they will quickly reappear because of their colonisation and competition potential is far higher compared to native species.

The above-mentioned priority rank changes inevitably mean restrictions and even extra costs for FRMs, but further considerations show that more synergies may help mitigate these negative effects. These synergies with the Habitat Directive and Water Framework Directive can and should be utilised in projects aiming at both FRM and conservation, rehabilitation, or even reconstruction of wetland habitats (EC, 2011; EEA, 2016). Vulnerable ecosystems need proper management to preserve their properties (Weisshuhn et al., 2018). In accordance, Pyšek et al. (2013) stress that legal protection needs to develop into the effective management of protected areas. Certain FRMs may act as a means of ecosystem conservation: see the case studies, for example in Gumiero et al. (2013).

4.2 Issues for future investigations

As our approach is quite novel, there remain several open issues which need special attention and may be improved through future applications.

If ecological values are also regarded during the planning process, FRM interventions may cause additional costs to landowners, but they also may have positive indirect economic advantages. They can equally mitigate the effects of floods and droughts. Softwood forests and grasslands may tolerate 1–3 weeks of waterlogging, so weak inundation (but not strong high floods) may even raise their naturalness and biomass production. Redirecting FRMs for present grasslands and arable fields instead of wetlands or softwood stands means higher costs in case of expropriation. But in certain locations, actual market prices of grasslands and arable lands in the National Park and Natura 2000 areas may be lower than average, because of management restrictions, higher flood risk in lower elevation (National Park areas are closer to the Drava river, so in a lower floodplain position), and often their more difficult approach by working machines. Inundation disturbs the work of land users, so raises their resistance, and motivates them to abandon these plots. The abandonment of meadows allows the spread of IAS, e.g. *Amorpha fruticosa*, *Solidago gigantea*, and *Robinia pseudoacacia*. On the other hand, temporal inundation of arable lands, as target areas of water retention, wet meadows can be created, facilitated by sowing the seeds of native grass species: these meadows can be utilised by hay-mowing or cattle grazing.

It must be underlined, that our study only concerns strategic FRM planning. The negative ecological effect of intervention works and destructive flooding, together with positive ecological effects, first of all, the improvement of the water supply of wetland habitats caused by natural water retention, is not possible to assess without exact spatial specifications of the planned FRM in question. When there are synergies between ecological and economic effects, in case of specific FRM interventions these should be utilised in cooperation between conservational and water management institutions during a comprehensive project-planning process involving all stakeholders. In these cases, the maximum precautionary principle should always be kept in mind.

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Appendices:

Appendix 1: Close-to-natural softwood riparian forest, a Natura 2000 priority habitat (91E0) in the study area, along a revitaliSed side arm which dries out at the end of the summer

Appendix 2: Huge Populus nigra in the study area. DBH>1 m

Appendix 3: Invasive species pose a serious threat to Natura 2000 habitats in the study area even in National Park areas, especially on the sites disturbed by construction works

Appendix 3a: On bare grounds left after construction works Symphyotrichium (Aster) species form a dense, thick carpet; Echinocystis lobata begins to creep over any other plants.

Appendix 3b: Softwood forests, are very sensitive to biological invasion, especially when disturbed: Impatiens glandulifera is a very competitive, large-sized nitrophilous species characteristic in these sites; huge curtains of Echinocystis lobata threatens even trees; in the herb layer masses of Solidago gigantea are also common.