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Synergies between biodiversity conservation and drinking water protection in an agriculture dominated landscape – Case study of the Lower Savinja Valley in Slovenia

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ABSTRACT

The growing world population and global market competition are putting pressure on high-yield food production, reducing the space available for low-intensity agricultural practices that support high biodiversity. In search of synergies between different environmental policy instruments, the potential of drinking water protection zones (WPZ) for high nature value (HNV) farmland conservation and connectivity in the Lower Savinja Valley in Slovenia was examined. In drinking water protection zones, restrictions of fertilizer and pesticide use are enforced, which have demonstrated beneficial effects on biodiversity. Overall, HNV farmland covered 25.8% of the area, of which 6% was protected in almost equal proportions by Natura 2000 sites and WPZ. Zonation prioritization assigned higher average scores to cells in WPZ compared to Natura sites and unprotected areas indicating high value of WPZ for HNV connectivity. The proportion of WPZ receiving the highest Zonation prioritization scores ranged from 23% to 70% depending on connectivity scale. Simulation of conversion of arable to HNV farmland on WPZ added 58.2 ha, and increased overall HNV farmland cover in the Lower Savinja Valley from 25.8% to 26.3%, further reinforcing the importance of WPZ for connectivity. Drinking water protection zones under different levels of protection cover approximately 20% of the territory of Slovenia. Given their large extent, we suggest that when planning for HNV farmland conservation and ecological networks within intensive agriculture dominated landscapes, WPZ should be evaluated for their potential and integrated into planning. Analysis focused on the spatial configuration of HNV farmland but lacked information on habitat quality, species presence and management practices in WPZ. Further studies of the effect of WPZ management restrictions on biodiversity are needed.

1. Introduction

Agricultural intensification has been recognized as one of the main threats to biodiversity due to the conversion of complex natural ecosystems into simplified homogeneous ecosystems and the increased use of agrochemicals (Stoate et al., 2009; Tscharntke et al., 2005). According to the 2020 State of nature in the EU report, agriculture was the most frequently reported pressure on habitats and species (European Environment Agency, 2020). The loss of high nature value (hereafter HNV) farmland has been well documented in Northern and Western Europe with 96% decrease in semi-natural grassland cover in south-eastern Sweden (Cousins et al., 2015) and half of the semi-natural grassland area lost between 1960 and 2015 in a boreal study area in Norway (Aune et al., 2018). In Dorset (UK) 97% of all semi-natural grassland was converted to agriculturally-improved grassland or arable land (Hooftman and Bullock, 2012).

In addition to habitat loss, the fragmentation of the remaining habitat has been reported to have negative effects on biodiversity (Haddad et al., 2015; Ibáñez et al., 2014), although the relative importance of habitat connectivity compared to habitat loss has been extensively debated (Fahrig, 2017; Fahrig et al., 2019; Fletcher et al., 2018). A recent modelling study has shown that the effects of fragmentation depend on the total amount of habitat within the landscape, with negative effects of fragmentation being more pronounced in landscapes with a lower amount of total available habitat (Rybicki et al., 2020). Previous studies have proposed that below the threshold of 10–30% of available habitat within the landscape, the rate of change in the species loss or reduction in population size would be greater than

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would be expected from habitat loss alone (Andren, 1994; Gustafson and Parker, 1992; J. Q. Radford et al., 2005). In landscapes with high habitat fragmentation, elements such as corridors and stepping stones have been proposed to maintain and enhance ecological connectivity (Chetkiewicz et al., 2006; Hilty et al., 2020).

To reduce the negative impacts of agriculture on biodiversity, wildlife friendly farming methods that reflect traditional low-intensity agricultural practices have been proposed (Green, 2005; Kleijn et al., 2011). In Europe these have been implemented with the aid of EU Common Agricultural Policy (CAP) measures, providing financial compensation to farmers for income loss. Since CAP 2014 these include a set of mandatary rules (comprising Statutory management requirements and Good agricultural and environmental conditions), Eco-schemes in Pillar I and Agri-environment-climate-measures (AECMs) in Pillar II. In Slovenia, the AECMs with specific HNV grassland conservation objectives mostly prescribe limited use of fertilizers, low cattle stocking rates and delayed date of mowing or grazing (Kaligarič et al., 2019). However, similar restrictions in the use of fertilisers and additional restrictions on pesticide use are also enforced for the protection of drinking water, which in Slovenia is mostly extracted from groundwater resources (Brenčič et al., 2009). Nitrogen fertilization has been shown to have negative effects on grassland plant diversity (Gaujour et al., 2012), therefore drinking water protection measures could also have a positive impact on farmland biodiversity even though the designation of drinking water protection zones (hereafter WPZ) is based on aquifer characteristics and societal needs (Brenčič et al., 2009), rather than on their nature conservation value.

By seeking overlapping interests between different environmental policy instruments that protect diverse ecosystem services, the EU Action Plan for Nature, People and the Economy encouraged the member states to improve synergies in the implementation of different EU Directives. Investigation of links between the EU Birds Directive (Directive 2009/147/EC), Habitats Directive (Council Directive 92/43/EEC) and the Nitrates Directive (Council Directive 91/676/EEC) has shown that the application of good agricultural practices to regulate nitrates in the aquatic environment can also have positive effects on water-dependent terrestrial habitats and species (Stein et al., 2019).

In this paper, the overlapping interests of biodiversity conservation and drinking water protection in the agriculture dominated landscape of Lower Savinja Valley in Slovenia were explored. The study area is designated as strategically important for food production at the national level (The Official Gazette of the Republic of Slovenia 71/16), where biodiversity interests are limited to Natura 2000 sites and expansion of protected areas and implementation of ecological corridors are restricted. However, several WPZ in the area fall under national environmental protection with restrictions on fertilizer and pesticide use thus dictating low-input agriculture. We examined the potential of WPZ for conservation and connectivity of HNV farmland by focusing on its spatial configuration within Lower Savinja Valley. Therefore, the aim of this study was to examine the proportion of HVN farmland under WPZ and Natura 2000 protection and compare their significance for enhancing ecological connectivity of HNV farmland within this lowland. The impacts of a hypothetical expansion of HNV farmland within WPZ (by conversion of arable into grassland) on WPZ value for connectivity were tested.

2. Materials and methods

2.1. Description of the Lower Savinja Valley study area

The selected study area is a predominantly agricultural Lower Savinja Valley in Slovenia which was delineated according to the geographical boundaries of the aquifer of river Savinja, with a total area of 10,420 ha (Fig. 1). It is located in eastern Slovenia, approximately 60 kilometres northeast of the capital city Ljubljana. It lies between latitudes 46.2400° N and 15.2700° E with elevation ranging between 200 and 400 m above sea level (MNRSP, 2005). Climate is continental with average annual temperature around 10°C and mean annual precipitation around 1200 mm, with peaks in spring and autumn (ARSO, 2023). The prevalent soil type in the region is Eutric Cambisol on fluvioglacial sediment providing fertile ground for a diverse range of crops (Lovrenčak, 1993).

2.2. Water protection zones and Natura 2000 in the study area

Analysis focused on WPZ designated at the national level according to the Policy on criteria for designation of WPZ in Slovenia (The Official Gazette of the Republic of Slovenia 64/04, 5/06, 58/11 in 15/16), as well as Natura 2000 sites designated according to the EU Habitats Directive and EU Birds Directive.

The study area encompassed parts of five different Natura 2000 sites: Savinja Grušovlje – Petrovče (code SI3000309); Volčeke (SI3000213); Voglajna pregrada Tratna – izliv v Savinjo (SI3000068); Ložnica s Trnavo (SI3000390); Savinja Celje – Zidani Most (SI3000376). The largest segment (210 ha) belongs to the Natura site Savinja Grušovlje – Petrovče, which runs along the Savinja river and represents 66.9% of all Natura protected areas in the test landscape. In this Natura site, protection focused on the river habitat with surrounding forest, for which the qualifying habitat type was Alpine rivers and their ligneous vegetation with *Salix eleagnos*.

For WPZ, Slovenian legislation designates three levels of protection (inner, middle and outer zone), with a fenced abstraction point located inside the inner zone (Brenčič et al., 2009). Restrictions on agricultural practices are the strictest in the inner zone and decrease in the middle and outer zones. The focus of this study was on the inner protection zone, where the use of pesticides and fertilizers is strictly controlled, affecting the yields of agricultural production for which farmers are compensated. The highest level of protection in the inner zones prescribes the following agricultural practices: Prohibition of intensification with conversion of grassland to arable land; Prohibition of the use of pesticides listed on an annually updated list of restrictions; Prohibition of the use of slurry and liquid manure; Restriction of grazing under certain conditions; Fertilization must be carried out in accordance with an annual fertilization program based on soil tests, with the highest nitrogen input from farmyard manure not exceeding 140 kg N/ha per year; Fertilization with nitrogen containing mineral fertilizers is restricted in terms of land use and timing of application. The highest water protection level also prohibits the exposure of bare soil at any time of the year, therefore farmers are obliged to use cover crops on arable land.

2.3. Datasets

Land use in WPZ and Natura sites was examined and compared to unprotected areas, focusing on HNV farmland as a proxy for habitats with high biodiversity conservation value. High nature value farmland uses were identified in the Assessment of the 2014 –2020 Regional Development Fund in Slovenia (Deloitte, 2019). The 2018 Slovenian national land use dataset (MAFF, 2018) was used, comprising 25 land use types, of which only 18 occur in the Lower Savinja Valley. These were classified into four categories: Arable (arable land, permanent crops on arable land, hop fields, greenhouses, vineyards, intensive orchards, other permanent crops, tree plantations, uncultivated arable land), HNV farmland (permanent grasslands, agricultural areas overgrown with scrub, extensive orchards, transitional woodland scrub, marshland), other land use (urban, water) and forest. National open access datasets were used for spatial location of Natura 2000 sites (ARSO Natura 2000, 2018), aquifers (DRSV, 2020a) and WPZ (DRSV, 2020b).

2.4. Prioritization

For spatial prioritization, Zonation software was used, which ranks

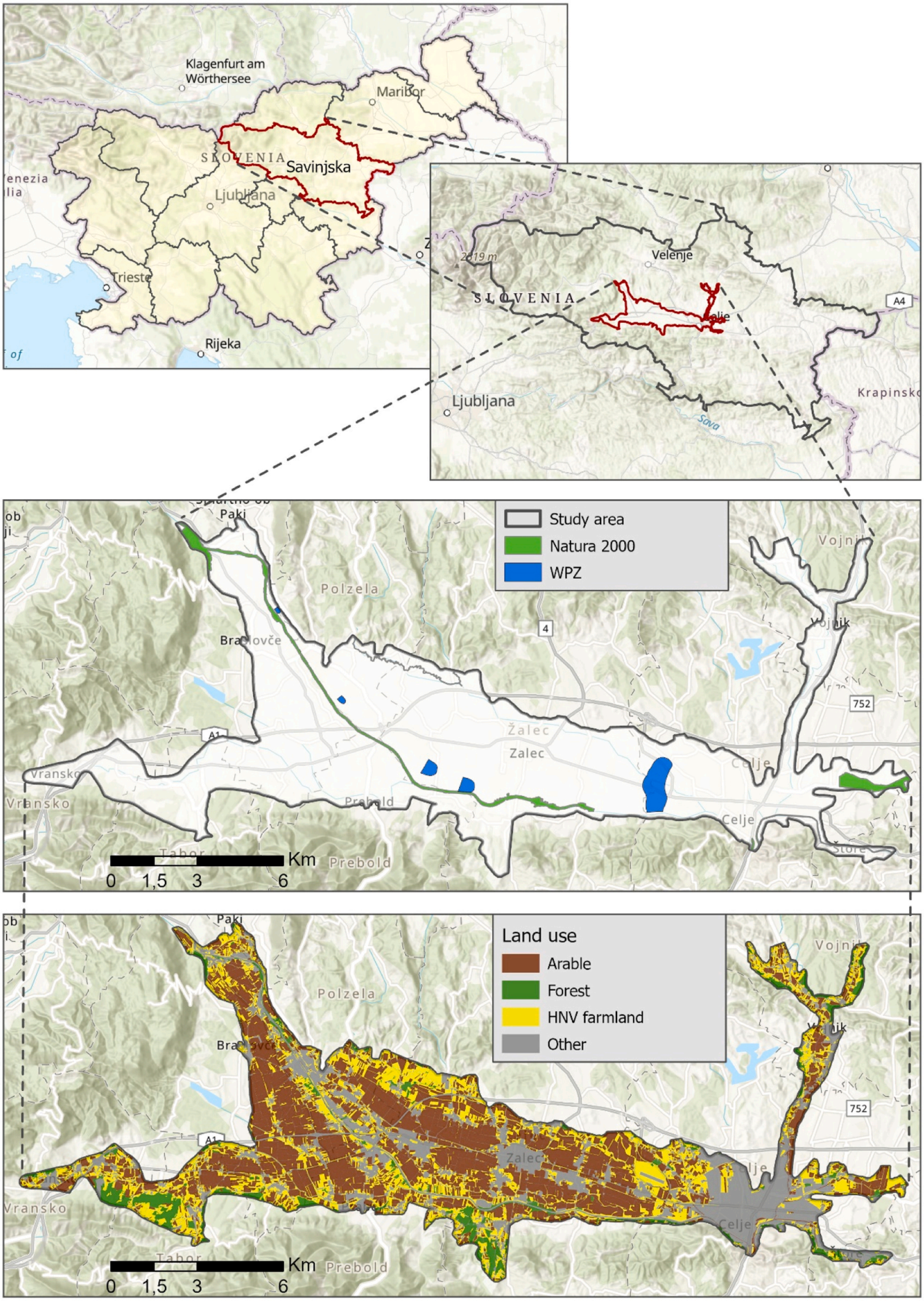

Fig. 1. Location of the Lower Savinja Valley study area in the Savinjska NUTS3 region in Slovenia, location of drinking water protection zones (WPZ) and Natura 2000 sites and distribution of land use types (arable, forest, HNV farmland and other) within the study area.

cells in a landscape according to their conservation value based on occurrence of features (widespread features receive lower value) and their weighting (indicating the relative importance of different features for conservation) in each cell (Moilanen et al., 2005). Prioritization also considered connectivity to other cells with the same conservation features, which is optional in Zonation (Lehtomäki and Moilanen, 2013). Zonation iteratively removed cells with the least loss of conservation value from the landscape, ranking all cells in the landscape from 0 (worst) to 1 (best) (Di Minin et al., 2014).

In the context of the Lower Savinja Valley, prioritization methodology is summarized in flow chart (Fig. 2). It started with the rasterization of the existing land use data using ArcGIS (ESRI ArcGIS Pro 3.1.0). In the next step a value of 1 was assigned to each specific HNV land use category, while a value of 0 was assigned to all other land use categories, namely arable, forest, urban, and water. This rasterization and value assignment process was iteratively undertaken five times, each time focusing on a distinct HNV farmland category. This series of iterations generated five distinct raster layers, each characterized by a uniform grid structure and a spatial resolution of 25 m (Fig. 2). No additional weighting was applied to define relative importance of the different HNV farmland use categories as currently no clear conservation priorities exist for this area.

In the next step, Zonation analysis normalized the feature value of cells according to their range size (Fig. 2), assigning lower values to cells with widely distributed features and therefore removing them earlier in the analysis (Di Minin et al., 2014). To avoid biasing the cells at the edge of the aquifer, a 4 km buffer strip was added, which allowed a more accurate calculation of Zonation values for these edge cells. However, the subsequent statistical analysis of Zonation outputs focused on the aquifer area and excluded the buffer strip.

To account for connectivity, a “distribution smoothing” feature in Zonation (Moilanen et al., 2014) was used, which retained areas

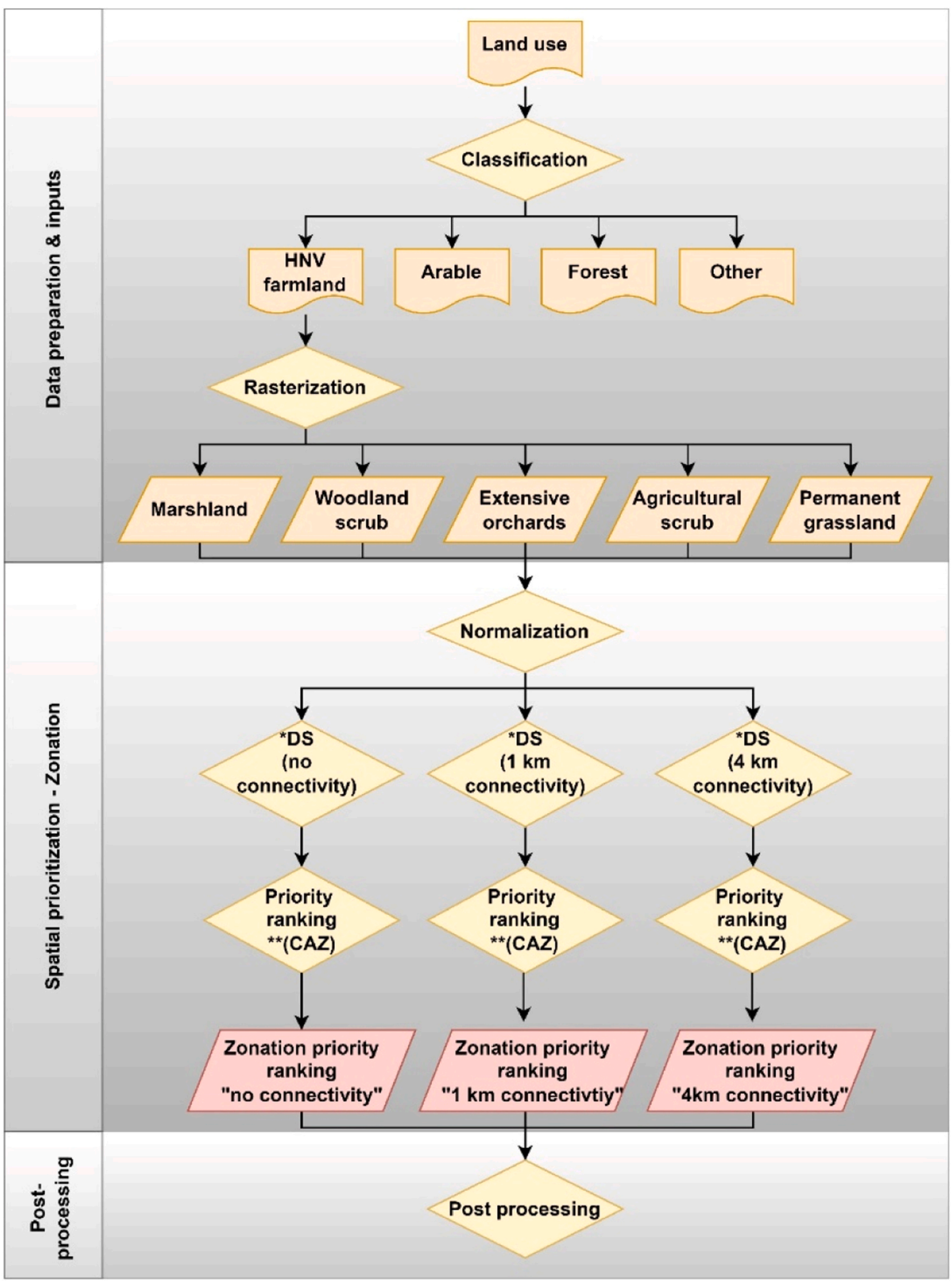

Fig. 2. Flow chart of the spatial prioritization analysis. *DS distribution smoothing. **CAZ core area zonation.

well-connected to other HNV patches (cells surrounded by many HNV farmland cells of the same class received a higher rank). The dispersal ability of species determines what distances the species are able to overcome, which was simulated by altering the dispersal parameter in "distribution smoothing" using two connectivity scales: 1 km and 4 km (Fig. 2). These scales reflect dispersal distances relevant for grassland species (Nowicki et al., 2014; Poniatowski et al., 2016; Soons et al., 2005) and have been used previously in similar studies (Arponen et al., 2013; Krauss et al., 2010).

As there was no overlapping of HNV farmland layers, the "core area zonation" cell removal function was used (Moilanen et al., 2014). The "warp factor" was set to 1 to maintain maximum reliability of output, meaning that one cell was removed in each iteration step (Fig. 2). Additionally, the recommended default settings of "edge removal" were used, where cells were removed preferentially from the edges.

In the "current situation" prioritization analysis, three Zonation runs (no connectivity, 1 km connectivity, 4 km connectivity) were performed on five HNV farmland raster files as inputs. For the "expanded HNV" prioritization analysis, the potential of WPZ was tested in a hypothetical scenario in which all arable land within the WPZ was converted to HNV farmland, more specifically to permanent grassland. Land use was therefore reclassified in the data preparation step and all subsequent Zonation steps were repeated as described above for the analysis of the current situation.

2.5. Post-processing and statistical analysis

The vector GIS files (before rasterization) were used to calculate the area of WPZ and Natura sites and the cover of each of the four land use categories (arable, HNV farmland, forest, other). These calculations were performed using ArcGIS (ESRI ArcMap 10) and QGIS 3.9.0. WPZ and Natura sites smaller than one grid cell (625 m^2) were excluded from analysis. The percentage cover of HNV farmland was compared between WPZ and Natura sites using beta regression analysis for percentage data derived from continuous variables (R package "betareg"; (Cribari-Neto and Zeileis, 2010).

The Zonation ranks of cells located in WPZ and Natura sites were used to estimate their importance for HNV conservation and connectivity compared to the cells outside protection. Spearman rank correlation was used to examine the relationship between the size of WPZ and Natura sites and their mean Zonation rank (using medians) at no connectivity, 1 km and 4 km connectivity scales for the current situation. To compare the Zonation ranks of cells in WPZ and Natura sites with those outside protection, Kruskal-Wallis test with Dunn posthoc test (p-values adjusted according to the Benjamini-Hochberg method) for both the current and the expanded HNV situations was used. All statistical analysis were performed using R Version 4.0.2. The proportion of area receiving the highest Zonation scores (values >0.9) was calculated for each of the three protection regimes (WPZ, Natura, outside protection) for the current and expended situation at the no connectivity, 1 km and 4 km scales.

2.6. Assumptions and limitations

The selected approach had several limitations due to the lack of available information and spatial data. All HNV farmland land uses were assumed to be of high biodiversity value due to lack of more detailed information on the presence of species and habitats of special conservation concern. Furthermore, no detailed spatial data was available regarding different management approaches in HNV farmland such as grazing, mowing etc., which could be used to distinguish areas of higher biodiversity value.

In the connectivity analysis the needs of specific species were not considered but connectivity distances (1 and 4 km) as a proxy for dispersal potential were used instead. We also assumed that matrix land uses (arable, forest, urban, water) do not promote open habitat species conservation and therefore assigned them a value of 0 in the Zonation analysis. Consequently, differences in matrix quality and permeability, which can influence fragment isolation (Donald and Evans, 2006) and enhance the connectivity function of existing corridors and stepping stones (Baum et al., 2004; Revilla et al., 2004) were not considered. One of the five HNV farmland land uses to which all arable land within WPZ would be converted, had to be selected for the HNV expansion scenario. Permanent grassland was selected as the most likely land use conversion accepted by the farmers.

3. Results

3.1. Current situation

The proportion of the Lower Savinja Valley under Natura and WPZ protection was 4.5% of which Natura covered 2.9% (313 ha) and WPZ 1.6% (178 ha) of the area without any overlapping between the two regimes. There were 10 spatially distinct protected areas in the study area (5 Natura and 5 WPZ) with different shapes and sizes ranging from 2.7 ha to 209.5 ha (Fig. 3).

The predominant land use in the Lower Savinja Valley was farmland covering 68.9% of the area, of which HNV farmland accounted for 25.8% (2.816 ha; Fig. 4a). Within the study area, 3.1% (86.4 ha) of the HNV farmland area was under Natura protection and 2.9% (82.9 ha) under WPZ protection.

Farmland was also the main land use in WPZ (79.1%), with HNV farmland being predominant (46.5%; Fig. 4b). In Natura sites farmland was still the main land use (45.2%), although to a lesser extent than in WPZ, of which 28.0% was HNV farmland (Fig. 4c). There were no significant differences between WPZ and Natura sites regarding the percent cover of HNV farmland (r_P=0.13; p=0.137). The most obvious difference in land use between Natura and WPZ zones was the proportion of forest land use, which covered 19.0% in Natura sites and 1.0% in WPZ, with no forest cover in four out of five WPZ (Fig. 4b,c).

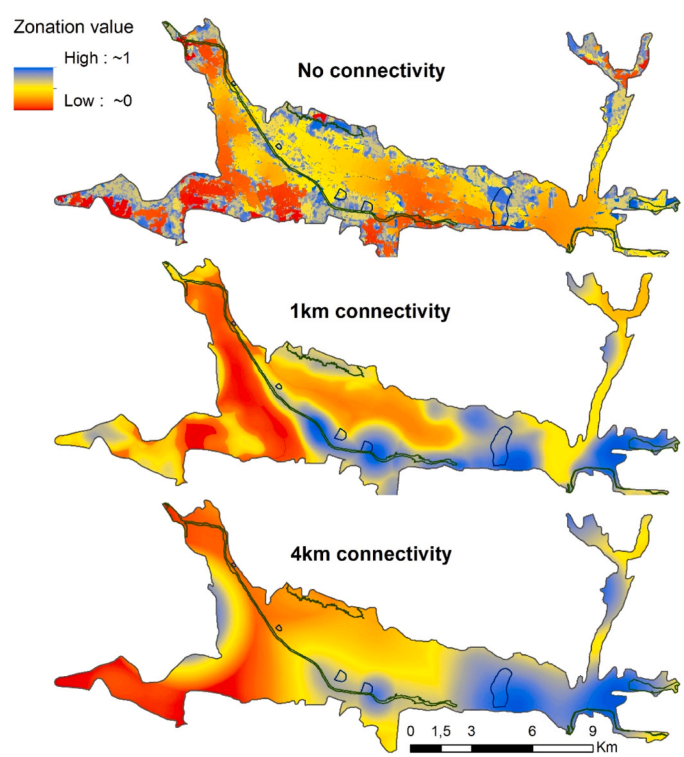

Fig. 3. Map of Lower Savinja Valley Zonation priority rankings of HNV farmland at three different scales of connectivity: no connectivity, 1 km, and 4 km, with colours indicating high (blue) and low (red) conservation priority.

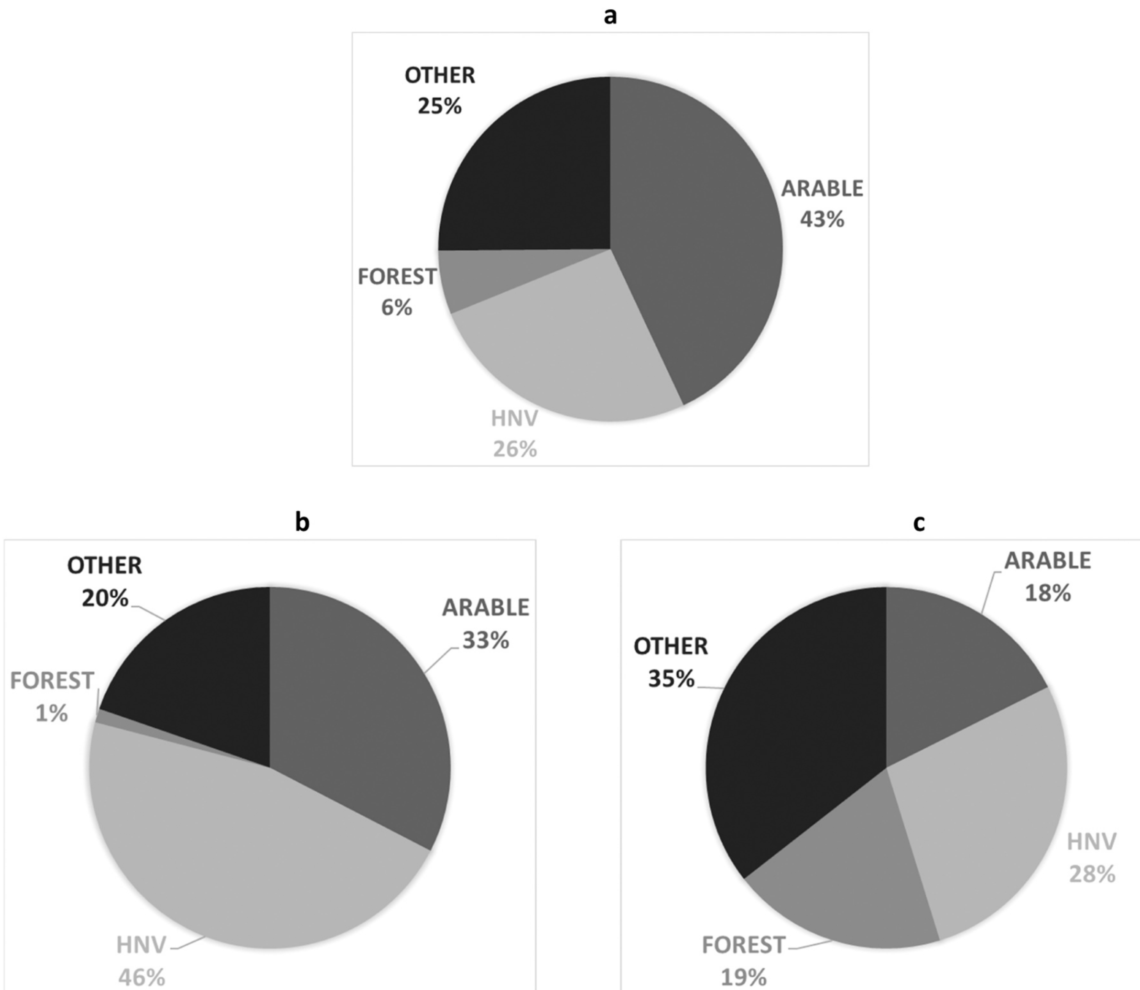

Fig. 4. Percent cover of different land use types (arable, HNV farmland, forest and other) in the Lower Savinja Valley (a) and specifically in water protection zones (b) and Natura 2000 sites (c).

Zonation priority ranking was performed for 924,705 cells, of which 174,585 cells were used in further statistical analysis after exclusion of buffer cells (Fig. 3). A comparison of Zonation priority rankings of cells in the current situation for no connectivity showed that WPZ received the highest ranks (median 0.71), but both WPZ and Natura sites (median 0.57) were ranked significantly higher than the unprotected area (median 0.53; $H(2)=1585$, $p<0.001$; Fig. 5a).

When connectivity at the 1 km scale in the current situation was considered in Zonation analysis, the WPZ again received significantly higher ranks (median 0.88) than Natura sites (median 0.82). Again, both WPZ and Natura sites were ranked significantly higher than the area outside the protection zone (median 0.51; $H(2)=5828$, $p<0.001$; Fig. 5a). At the 4 km connectivity scale the results were similar: the Zonation ranking of WPZ was significantly higher (median 0.94) compared to Natura sites (median 0.78; $H(2)=4576$, $p<0.001$; Fig. 5a).

Although Natura and WPZ covered a small area, a relatively high proportion of those areas received the highest Zonation scores (values > 0.9). These proportions in WPZ ranged between 22.9% (no connectivity) and 70.4% (4 km) for the current situation, and between 61.0% (no connectivity) and 70.4 (4 km) for expanded situation (Table 1). On the other hand, the proportion of unprotected area receiving the highest Zonation scores ranged from 6.2% (no connectivity), 13.4% (1 km) and 13.1% (4 km connectivity).

The size of Natura and WPZ did not affect their mean Zonation priority ranking score in the current situation, neither for no connectivity analysis ($r_S=0.60$; $p=0.069$), for 1 km ($r_S=0.47$; $p=0.166$), or for 4 km connectivity scales ($r_S=0.35$; $p=0.327$; Fig. 6).

3.2. *HNV farmland expansion scenario*

The simulated HNV farmland expansion in WPZ increased its proportion from 46.5% to 79.1%, with 58.2 ha added. At the Lower Savinja Valley level, this increased the proportion of HNV farmland from 25.8% to 26.3%. Expansion of HNV farmland on the WPZ was reflected in their mean Zonation rank, with the median increasing markedly for the no connectivity analysis (from 0.71 to 0.91; Fig. 5b), which was reflected in a high percentage (61.0%) of WPZ cells receiving Zonation score above 0.9 (Table 1). At the 4 km scale the simulated HNV farmland expansion did not affect the mean Zonation ranking of WPZ (Fig. 5b). After expansion, WPZ had significantly higher Zonation values than Natura sites and the unprotected area at no connectivity ($H(2)=4904$, $p<0.001$), at 1 km ($H(2)=6289$, $p<0.001$) and at 4 km connectivity scales ($H(2)=4571$, $p<0.001$; Fig. 5b).

4. Discussion

The proportion of HNV farmland under protection within the Lower Savinja Valley was 6%, of which Natura covered approximately half of the area (86.4 ha) and WPZ additional 82.9 ha of HNV farmland. Despite the low proportion of HNV farmland under WPZ and Natura protection, the relative contribution of these areas to HNV farmland conservation and connectivity was high according to Zonation software

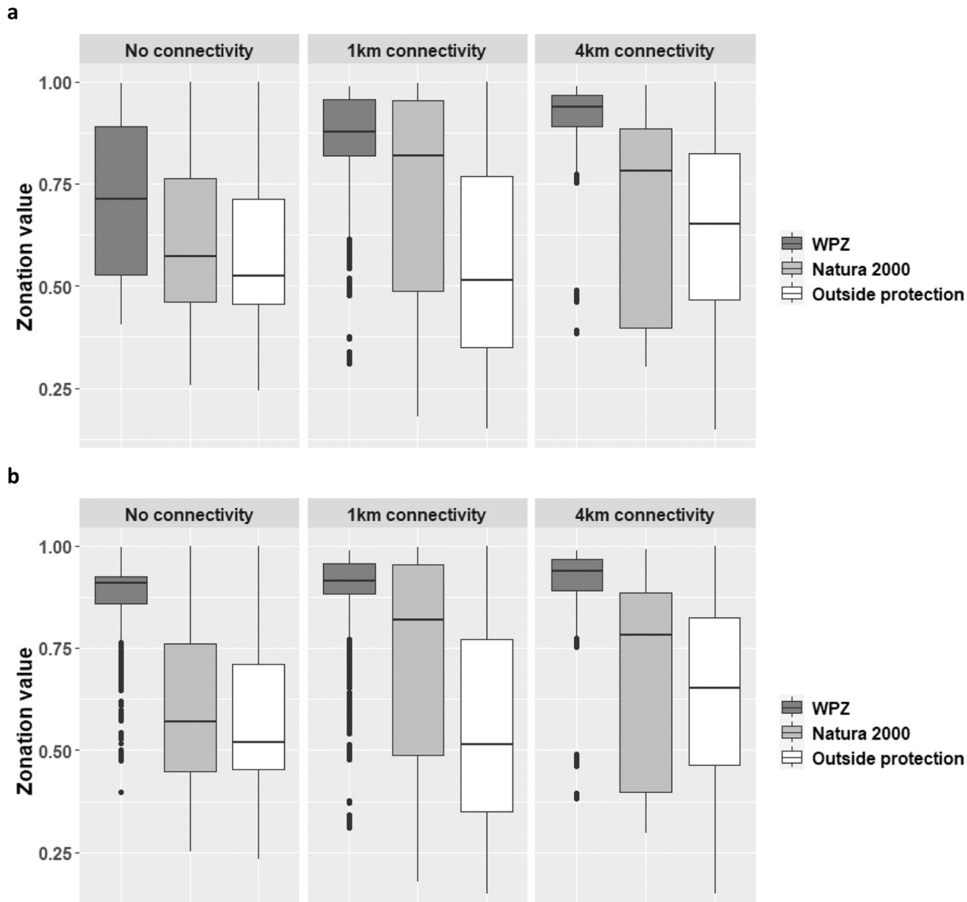

Fig. 5. Median and quartiles of Zonation priority ranking scores at the no connectivity, 1 km, and 4 km connectivity scales of water protection zones (WPZ), Natura 2000 sites, and of areas outside the protection zone for the current situation (a) and the expanded HNV scenario (b).

Table 1
Proportion of the area under three protection regimes (WPZ, Natura 2000, and outside protection) that received the highest Zonation scores (values >0.9) in the current state and the expanded HNV farmland scenario at three connectivity scales (no connectivity, 1 km, and 4 km).

Protection regime (total area)	Scenario	No connectivity	1 km	4 km
WPZ (178 ha)	Current	41 ha (22.9%)	80 ha (44.7%)	126 ha (70.4%)
	Expanded	109 ha (61.0%)	118 ha (66.4%)	126 ha (70.4%)
Natura (313 ha)	Current	61 ha (19.4%)	137 ha (43.8%)	70 ha (22.3%)
	Expanded	60 ha (19.3%)	137 ha (43.7%)	70 ha (22.3%)
Outside protection (10,420 ha)	Current	643 ha (6.2%)	1392 ha (13.4%)	1361 ha (13.1%)
	Expanded	635 ha (6.1%)	1386 ha (13.3%)	1361 ha (13.1%)

results. The “no connectivity” Zonation analysis of the current situation reflected the distribution of different HNV land uses (permanent grasslands, agricultural areas overgrown with scrub, extensive orchards, transitional woodland scrub and marshland) based on their occurrence, with widely distributed land uses receiving lower values. Here, WPZ were rated higher than both Natura and unprotected areas, suggesting that WPZ cover a significant proportion of rare HNV land uses. By using “distribution smoothing” in Zonation, the aspect of connectivity was added and the importance of WPZ and Natura sites for HNV connectivity within the study area was estimated. For the current situation, WPZ were on average more valuable compared to Natura sites for both intermediate (1 km) and for long-distance dispersal (4 km). In addition, the expansion of HNV was simulated in which arable land in WPZ was converted to HNV farmland. This further increased the Zonation value of WPZ and made them more important for connectivity, both compared to Natura and to areas outside protection at all connectivity scales.

The HNV farmland in the Lower Savinja Valley covered 25.8%, which falls within the proposed threshold of 10–30% of available habitat in the landscape. As suggested by previous studies, the negative effects of habitat fragmentation are more pronounced in landscapes with low amount of available habitat (Andren, 1994; J Q Radford et al., 2005; Rybicki et al., 2020). Although such thresholds should be interpreted with caution and in relation to management goals, their existence would imply that reducing fragmentation of the remaining habitat may be an effective management approach within such landscapes (Swift and Hannon, 2010). Therefore, in the Lower Savinja Valley, particular attention should be given to the landscape connectivity of existing HNV farmland to optimize biodiversity conservation.

From a habitat management perspective, existing drinking water protection measures in Slovenia focus on reducing inputs of nitrogen and pesticides and farmers are compensated for resulting yield reductions. However, these measures also affect biodiversity, although WPZ are not designated for their conservation value, and their biodiversity potential in Slovenia has not been explored previously. Both organic and inorganic nitrogen fertilization reduce plant species diversity (Gaujour et al., 2012; Jacquemyn et al., 2003; Spiegelberger et al., 2006). Pollution, mainly from synthetic pesticides and fertilizers, is the second most important driver (after habitat change) of global insect declines (Sánchez-Bayo and Wyckhuys, 2019), with consequences

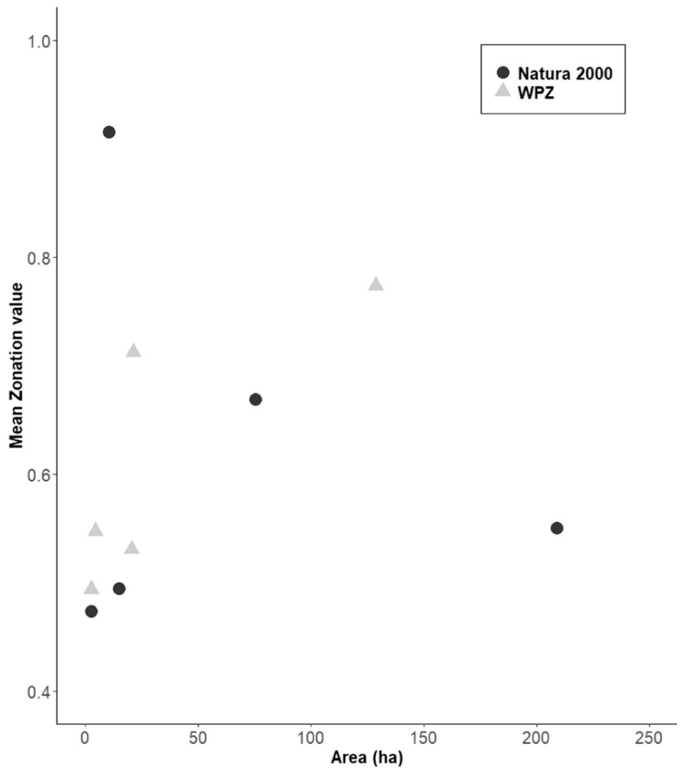

Fig. 6. Relationship between size (hectares) and mean Zonation priority ranking scores of WPZ (triangles) and Natura sites (circles) for the no connectivity analysis of the current situation in the Lower Savinja Valley.

for insectivorous birds, which show the greatest population declines among birds (Wagner, 2020). Similarly, a review of agricultural drivers of farmland bird declines in North America has shown that pesticides have the most predominant negative impact on farmland bird populations (Stanton et al., 2018). Organic farming, a system that prohibits the use of agrochemicals such as nitrate-containing synthetic fertilizers and certain pesticides, has generally shown positive impacts on biodiversity (Fuller et al., 2005; Hole et al., 2005; Smith et al., 2019) although these impacts may vary by organism group and landscape (Bengtsson et al., 2005). Due to limitations in species and habitat presence data, the actual effect of the fertilization and pesticide restrictions on species presence and habitat quality in WPZ was assumed but not examined in this study.

Agricultural landscapes are complex multifunctional systems that provide several important ecosystem services on a limited area (food production, biodiversity, water quality, carbon storage, soil fertility and outdoor recreation) which implies conflicting management approaches (Huang et al., 2015; Swinton et al., 2007). In the process of consolidating different ecosystem services and conflicting management approaches, different environmental protection measures should be explored for potential overlaps. We believe that water protection zones hold potential for upgrading current measures (reduced use of fertilizers and pesticides) with biodiversity enhancing measures such as delayed mowing or grazing dates, however compliance of farmers should be tested. Given that approximately 20% of the territory of Slovenia is under different levels of drinking water protection (Brenčič et al., 2009), the potential of WPZ for biodiversity conservation is worthy of further research.

5. Conclusions

Restricted fertilization and pesticide use are enforced in the inner zones for the protection of drinking water extracted from ground-water resources in Slovenia. Previous studies have suggested that such measures have positive effects on biodiversity in farmland. While WPZ with different levels of protection cover approximately 20% of Slovene territory, their potential for biodiversity conservation had not been explored previously. Our study made the first step in this direction by focusing on the spatial configuration of HNV farmland in the Lower Savinja Valley. Although WPZ cover a small area, results from a Zonation prioritization analysis suggest that they are more important for HNV farmland conservation and connectivity than Natura 2000 sites.

Ever increasing demand for food from the growing population is driving both agricultural expansion and intensification with high inputs of fertilizers and pesticides. Consequently, area available for low-input, biodiversity-friendly agriculture is shrinking, which justifies a search for overlapping interests between different environmental protection policies. We demonstrated that WPZ show potential for enhancing conservation and connectivity of HNV farmland in Lower Savinja Valley in Slovenia. Furthermore, we suggest that policy makers in Slovenia should explore the potential for upgrading current drinking water protection measures with additional biodiversity promoting practices such as postponement of grassland mowing or grazing dates.

CRediT authorship contribution statement

Bertoncelj Irena: Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Kastelic Peter:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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