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The impact of fictitious land use changes on water management related ecosystem services in a Hungarian catchment

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1. Introduction: Background, motivation and objective

Water management is facing an increasing burden of the adverse effects of climate change and the consequent changing needs.

In areas with land use, meteorological and hydrological conditions similar to Hungary (agricultural-dominated land use), drought and inland water often cause problems in the same place in a short time. Such hydrological conflicts, which typically involve multiple interest groups across multiple disciplines, deserve to be addressed in a complex approach. One tool for this could be the mapping of ecosystem services (ES), especially hydrologic ecosystem services (HES).

In our research, we examined the current composition of the HES in the catchment of the Zala River, which is the main tributary watercourse of the largest shallow lake in Central Europe (Lake Balaton). Thus, the quantitative and qualitative status of the water entering the lake is also particularly important. Four HES were quantified: water retention, nutrient retention (TP and TN), and erosion control. For this, we used InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software[1ref].

The results of the four HES were aggregated based on our own classification system. Based on the result obtained in this way, the critical areas (hotspots) were selected, and then the effects of theoretical land use change in these areas were examined.

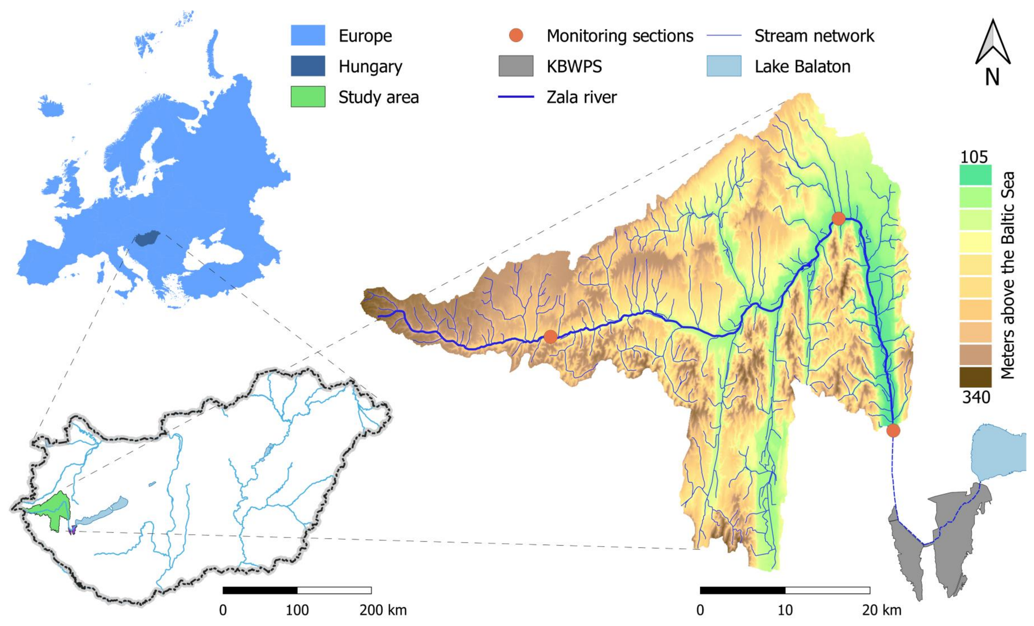

Figure 1.: Overview of Zala River's catchment area

2. Materials and methods

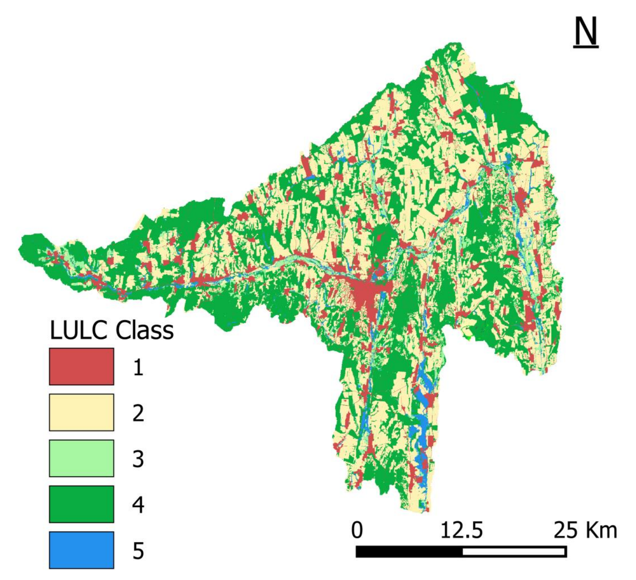

Figure 2/a.: Land use and land cover conditions (1-Urban, 2-Croplands, 3-Grasslands, 4-Forests, 5-Water bodies)

Our analysis was carried out at the Zala River catchment area in Hungary. The watershed's area is almost 1530 km^2, the dominant soil texture is loam and silty loam, the climate is moderately cool and moderately humid, the mean annual precipitation is around 660-800 mm. The land use-land cover (LULC) conditions are dominated by forests (42%) and croplands [including vineyards, orchards] (38%).

We described the four selected HES by using one of the InVEST modules. All of HES interpretation was as follows: we built up two model variants for each HES based on (i) bare soil LULC and (ii) actual LULC, then we quantified the HES by the difference between the two variants (Table 2/a). After that, we first classified each HES using a scoring system (as in Table 2/b, from 1 to 5), then we aggregated these results with their geometric mean per pixel. With the aggregate assessment, critical areas or hotspots with bad ratings (less than 2) could be located in the basin. In these areas, we made a theoretical land use change: we assumed afforestation in all bad classified areas (except populated or infrastructural urban areas and water bodies). The model calibration was successfully in case of flood control, while by the three other services it was not possible yet, because the model doesn't calculate the processes in the recipient water body.

Because the educational and other workload due to COVID-19, we are unable to present the results of future (2020-2050) scenarios indicated in the abstract.

Table 2/a.: Interpretation of the four examined HES

HES	Dimension	InVEST module	Interpretation
Flood control	[mm/ha/year]	Seasonal Water Yield based on Budyko-model	$(\text{Baseflow+Quickflow})_{Bare} - (\text{Baseflow+Quickflow})_{Actual}$
TN retention	[t/ha/year]	Nutrient Delivery Ratio	$(\text{TN export})_{Bare} - (\text{TN export})_{Actual}$
TP retention	[t/ha/year]	Nutrient Delivery Ratio	$(\text{TP export})_{Bare} - (\text{TP export})_{Actual}$
Erosion control	[t/ha/year]	Sedminet Delivery Ratio based on RUSLE	$(\text{Sediment export})_{Bare} - (\text{Sediment export})_{Actual}$

Table 2/b.: Rules of the applied HES scoring system

Score	Flood control and nutrient retention	Erosion control
1	$x < E(X<0)$	$P_{0\%}(X) < x < P_{20\%}(X)$
2	$E(X<0) < x < 0$	$P_{20\%}(X) < x < P_{40\%}(X)$
3	$0 < x < P_{33\%}(X>0)$	$P_{40\%}(X) < x < P_{60\%}(X)$
4	$P_{33\%}(X>0) < x < P_{66\%}(X>0)$	$P_{60\%}(X) < x < P_{80\%}(X)$
5	$P_{66\%}(X>0) < x < P_{100\%}(X>0)$	$P_{80\%}(X) < x < P_{100\%}(X)$

3. Results and conclusions

With the results of the model variant using the actual LULC conditions only one and another (out of 22) sub-watershed received good (5) and bad (1) scores (Figure 3/a). The remaining sub-basins were classified as moderate and weak (2-3). In terms of land use, it can be said that the forests performed the best, their typical aggregate point was almost 3.5, while they covered 80% of the excellent and 72% of the good scored pixels. Croplands performed the worst due to their high proportion of nutrient emission (in the actual LULC version, we have incorporated the nutrient load from the fertilizer application typical of the region). Grasslands and green areas in urban environment performed well. The hotspots (from the point of view of HES) covered the whole catchment's 6%, 92% of them was under agricultural cultivation (croplands). More than half of the hotspots were located within 200m of the watercourse network (Figure 3/b).

In the alternative LULC model variant, we changed the hotspot's LULC to forest (the reason was twofold: the forests performed the best in the actual model variant, while there are civil and governmental efforts to afforest are underway). The afforestation rates were under 17% in the case of each sub-basin (Figure 3/c).

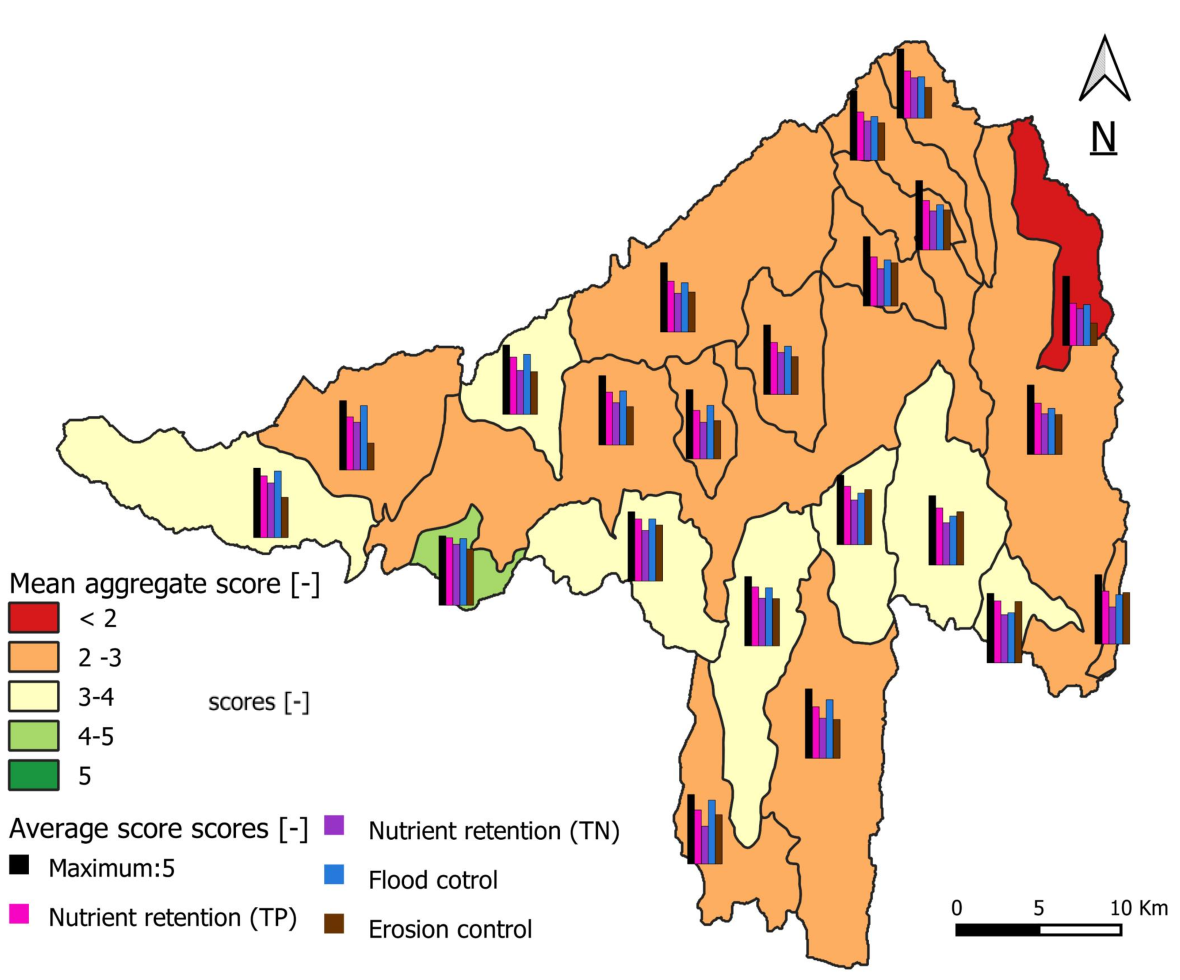

Figure 3/a.: Results of the aggregated and each HES scores per sub-basin (original LULC)

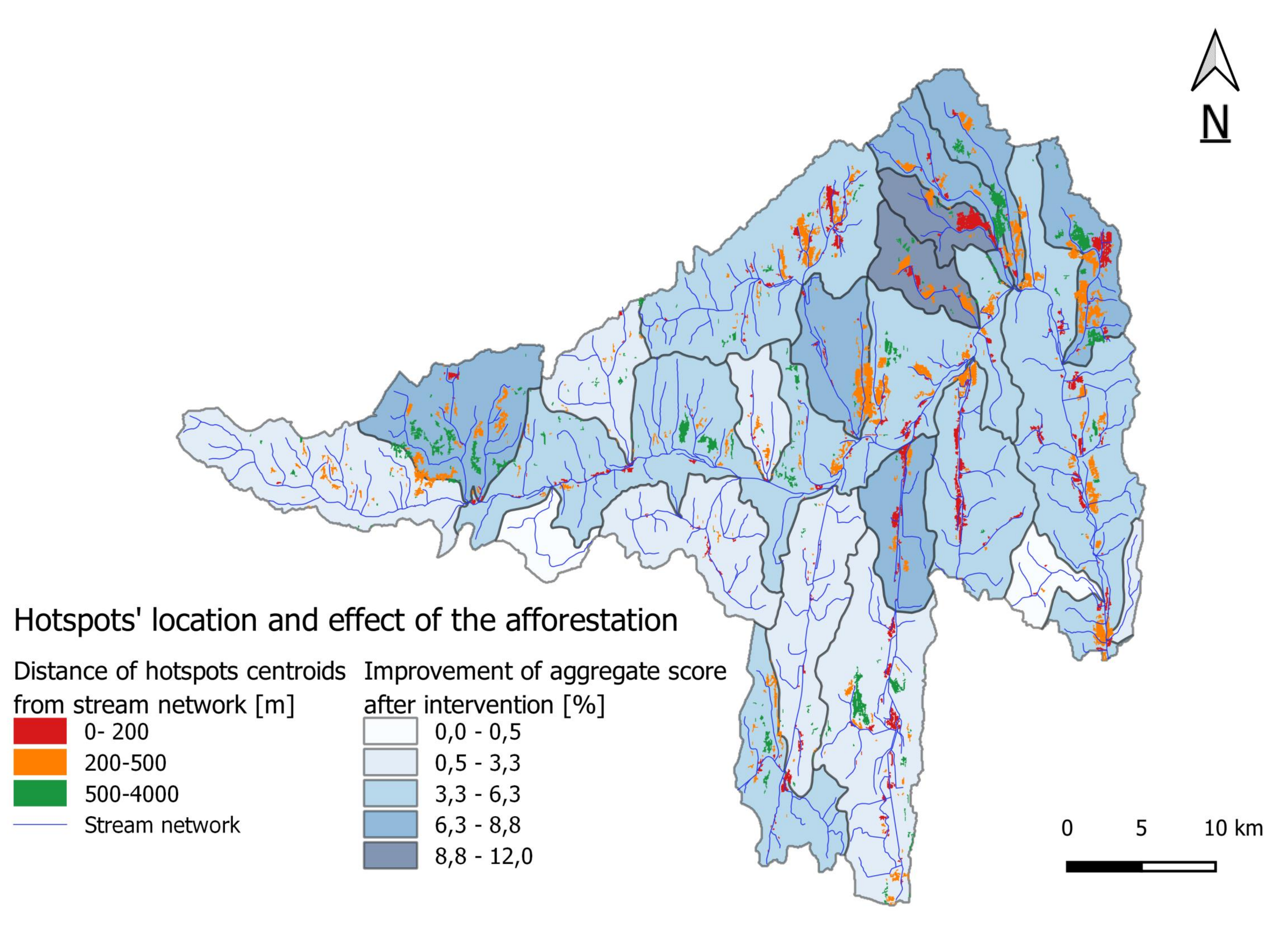

Figure 3/b.: Impact of hypothesized land use-change on aggregate HES scores

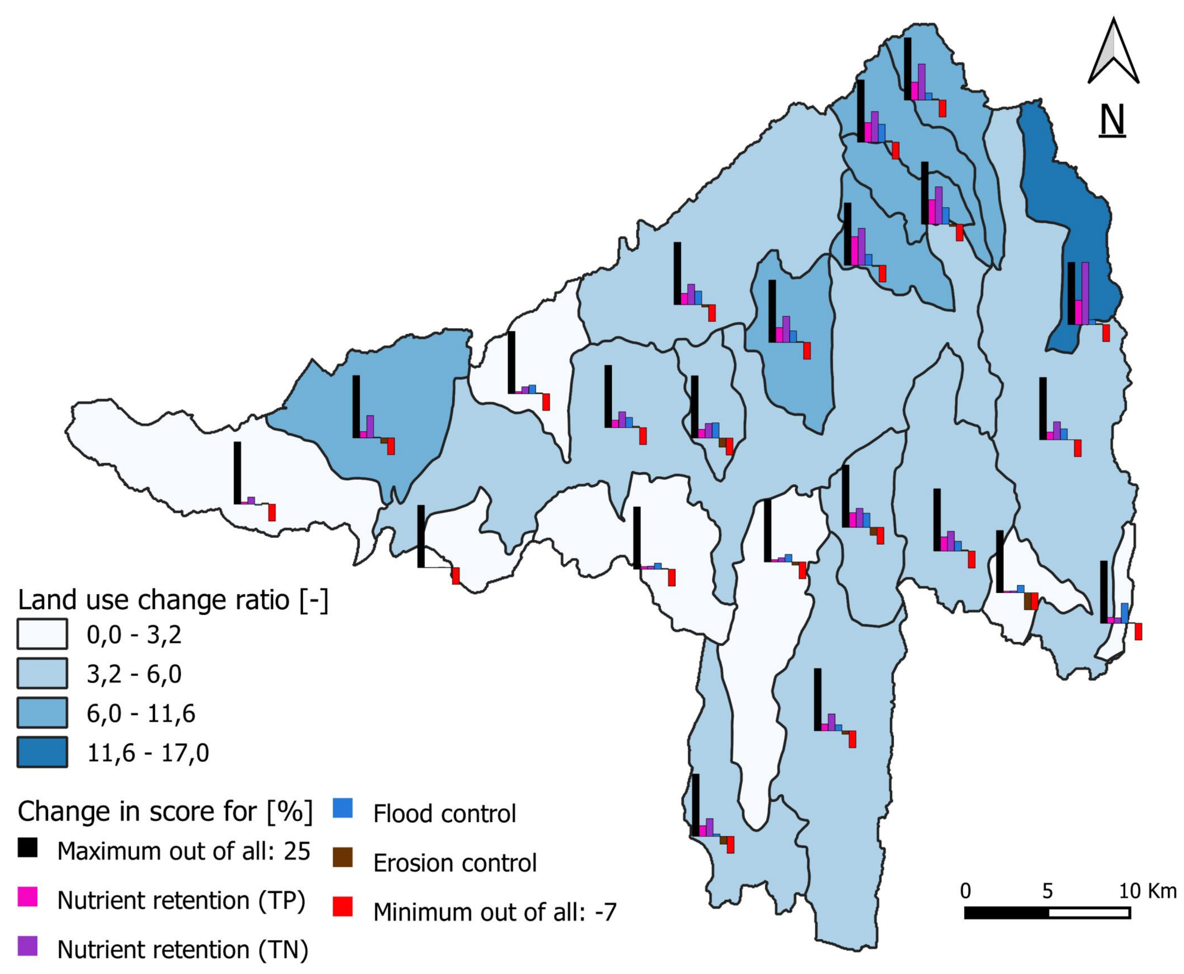

Figure 3/c.: Effects of alternative land use change (afforestation) on HES scores

Based on the results of the hypothesized land use change, it can be said that nutrient filtration, especially Nitrogen retention, was particularly effective (Figure 3/c. and Table 3.). This can be explained by the fact that the land use change affected agricultural areas close to the watercourse network (Figure 3/b.). The intervention also had a significant positive shift in water retention and TP filtration. Based on this, new forests retain 10% more water and TP in the area, while the retained amount of TN also increased by 76%. However, we obtained a positive result in the case of sediment binding.

It is important to note that more ES indicators are needed for a complex assessment, mainly provisioning ES from agricultural cultivation. At the same time, it can be assumed that almost 15% of the arable land in the river basin was converted into forest (in theory), so that 15% of the yield and other subsidies would fall out.

Table 3.: Impact of afforestation on HES, average values for the whole watershed

HES	Dimension	Difference [amount]	Difference [percent]
Flood control	[mm ha^{-1} year^{-1}]	26	8.9 %
TN retention	[kg ha^{-1} year^{-1}]	0.76	75.9%
TP retention	[kg ha^{-1} year^{-1}]	0.02	8.1%
Erosion control	[t ha^{-1} year^{-1}]	0.05	3.5%

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1ref: Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., and Douglass, J. 2020, InVEST 3.8.0.post63+ug.g2fd0aa1 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

BG3.7 Complex case studies for ecosystem responses to climate and hydrological extremes