Supplementary Material

S.1 Details on section 2.4 Hydromorphology

Following Gellert et al. (2014) twenty-five individual hydromorphological parameters were mapped for 100 m river segments and compared to natural reference conditions. Their deviation from reference conditions is assessed on an ordinal scale ranging from unchanged with just minor deviations (class 1) to heavily degraded (class 7). Scores of the 25 parameters were aggregated to six main parameters: (1) “channel pattern”, (2) “longitudinal profile”, (3) “channel bed features“, (4) “cross section“, (5) “channel bank features“, and (6) “floodplain conditions“.

S.2 Details on section 2.2 Riparian landuse

Orthoimages obtained for this study were and were mostly CIR and some RGB images with a 0.2 m resolution (0.4 m for some few older RGB images). Only orthoimages taken between April and August were used in order to match the vegetation period. In case images from different years were available for the same area, the ones taken closest the year most macroinvertebrate sites were sampled (2010) were selected.

Orthoimages were processed in an object-based image analysis (OBIA), consisting of image segmentation and classification of resulting objects. The segmentation was done using the multiresolution segmentation algorithm in Trimble’s eCognition software (Version 9.3.0) based on the pixel values of the colour bands. The resulting objects were classified using a support vector machine (SVM) classifier. This SVM classifier was developed based on a training dataset of objects from 40 representative orthophotos (n = 14 RGB, n = 26 CIR), which had been first classified using a supervised nearest-neighbour classification, then visually checked and the classification manually corrected if necessary. The SVM classifier distinguished woody vegetation, other forms of vegetation (grassland, cropland), and non-vegetated areas (built-up areas or bare soil) based on shape, colour and

brightness of the objects, as well as the Visible-band Difference Vegetation Index (VDVI, RGB images) or Normalized Difference Vegetation Index (NDVI, CIR images). This SVM classifier was applied to the orthophotos using the R package e1071 (version 1.7-3; Meyer at al., 2021). General accuracy of segmentation and classification was assessed visually. Additionally, accuracy of the SVM classifier was assessed using cross-validation on the training dataset. Woody vegetation objects identified on the orthoimages replaced ATKIS landuse patches of the categories, “arable land”, “grassland”, “natural vegetation”, “urban green space”, and “urban”. Improving the spatial resolution of landuse data in close proximity to the river was a prerequisite to correctly quantifying the percentage cover of near and far-upstream WRV.

References

Gellert, G., Pottgiesser, T., Euler, T., 2014. Assessment of the structural quality of streams in Germany — basic description and current status. *Environ. Monit. Assess. 186 (*6), 3365–3378.

Meyer, D., Dimitriadou, E., Hornik, K., Weingessel, A., Leisch, F., Chang, C. C., ... & Meyer, M. D. (2021). Package ‘e1071’. The R Journal.

Table S1: Macroinvertebrate multimetric index (MMI) scores for the sub-datasets in lowlands (LL.1 – LL.3) and mountain (M.1 – M.11) streams. Sub-datasets, in which woody riparian vegetation had a significant effect on the MMI, are grouped as indicated by superscript letters if no significant differences in mean MMI exist following Tukey's honest significant difference and an analysis of variance (ANOVA). Mean and median MMI scores along with the 25th and 75th-percentiles are given.

		Multimetric index (MMI)			
Sub-dataset	n	25th-perc.	mean	median	75th-perc.
LL.1 [a]	34	0.215	0.383	0.375	0.529
LL.2 [b]	100	0.481	0.584	0.620	0.722
LL.3 [a]	227	0.243	0.366	0.377	0.492
M.1 [c]	132	0.649	0.713	0.744	0.820
M.2 [d]	149	0.495	0.592	0.629	0.720
M.3	90	0.431	0.547	0.612	0.696
M.4	43	0.230	0.357	0.340	0.512
M.5 [e]	65	0.238	0.424	0.437	0.566
M.6 [f]	45	0.042	0.175	0.139	0.281
M.7	41	0.455	0.591	0.620	0.733
M.8 [g]	54	0.010	0.226	0.122	0.423
M.9 [g]	30	0.147	0.354	0.371	0.493
M.10 [g]	69	0.085	0.262	0.206	0.364
M.11	30	0.046	0.121	0.107	0.157

Table S2: Landuse at the catchment and local scales for the sub-datasets in lowlands (LL.1 – LL.3) and mountain (M.1 – M.11) streams. Median cover (%) along with the 25th and 75th-percentiles are given for urban, agriculture (Agric.) and woodland (Woodl.).

		Landuse cover (%)					
		Catchment			Local		
Sub-dataset	Landuse	25th-per.	median	75th-perc.	25th-per.	median	75th-perc.
LL.1	Urban	3.8	4.9	5.6	0.0	2.5	8.1
	Agric.	65.1	70.3	76.3	24.7	55.9	81.9
	Woodl.	6.8	12.4	15.5	5.2	11.5	28.7
LL.2	Urban	1.9	3.1	4.0	0.0	0.4	9.9
	Agric.	23.1	35.2	50.7	2.5	22.0	49.9
	Woodl.	32.2	49.0	64.6	5.4	13.5	38.0
LL.3	Urban	10.3	16.4	26.0	2.5	10.7	33.8
	Agric.	25.5	44.1	60.5	6.5	34.4	64.6
	Woodl.	11.8	21.1	35.0	5.9	12.6	29.9
M.1	Urban	2.3	4.4	6.6	0.0	5.1	19.2
	Agric.	1.2	4.7	7.4	0.0	0.0	0.0
	Woodl.	56.3	71.1	83.2	28.6	53.1	75.1
M.2	Urban	3.6	5.3	7.1	0.0	4.6	32.9
	Agric.	13.4	18.3	23.3	0.0	0.2	10.0
	Woodl.	37.8	49.4	60.5	10.6	42.6	66.5
M.3	Urban	2.4	3.8	5.6	0.0	1.2	7.6
	Agric.	12.9	19.5	24.1	28.5	36.0	56.6
	Woodl.	44.5	55.0	68.2	6.8	11.2	25.6
M.4	Urban	3.4	5.0	6.8	0.3	7.5	27.6
	Agric.	12.0	20.2	25.5	22.7	29.9	43.6
	Woodl.	48.1	58.0	69.9	7.0	12.4	21.5
M.5	Urban	4.7	6.0	7.9	0.0	5.0	18.0
	Agric.	38.3	45.2	58.9	7.1	25.3	48.9
	Woodl.	20.3	31.0	38.7	8.2	17.4	43.4
M.6	Urban	4.6	6.5	7.8	0.0	9.4	32.1
	Agric.	44.5	54.1	64.2	15.1	37.5	63.0
	Woodl.	17.4	26.3	35.1	4.0	8.7	20.1
M.7	Urban	15.0	19.8	30.0	15.0	24.4	63.5
	Agric.	1.6	2.6	4.0	0.0	0.0	0.0
	Woodl.	34.5	50.6	63.0	16.0	35.1	56.0
M.8	Urban	13.7	15.9	21.3	13.3	50.3	86.8
	Agric.	12.8	20.3	33.9	0.0	0.0	0.0
	Woodl.	24.3	37.7	54.8	7.7	11.3	33.7
M.9	Urban	13.2	15.8	32.1	9.5	31.3	70.3
	Agric.	11.0	19.9	31.6	0.8	3.5	6.2
	Woodl.	22.6	28.9	48.7	9.3	22.8	46.7
M.10	Urban	14.8	17.1	25.1	0.2	5.1	14.4
	Agric.	20.7	31.9	40.7	27.9	45.1	65.2
	Woodl.	23.2	32.4	42.6	11.4	16.2	26.6
M.11	Urban	14.2	16.6	28.2	1.4	15.0	38.5
	Agric.	24.2	35.1	52.8	22.6	36.2	71.9
	Woodl.	17.5	21.3	34.7	6.3	12.8	18.3

Table S3: Pairwise comparison of lowland sub-datasets, featuring significant effects form woody riparian vegetation on the multimetric index, regarding urban, agriculture (Agric.) and woodland (Woodl.) landuse cover based on analysis of variance (ANOVA). Values are the difference between mean respective landuse cover (sub-dataset row –column) and asterisks indicate Tukey' honest significant difference at $p < 0.5$ (*) and $p < 0.01$ (***).

		Catchment		Local	
Landuse	Sub-dataset	LL.1	LL.2	LL.1	LL.2
Agric.	LL.2	-0.332 ***		-0.244 ***	
	LL.3	-0.257 ***	0.074 *	-0.160 *	0.084
Urban	LL.2	-0.015		0.023	
	LL.3	0.158 ***	0.172 ***	0.156 ***	0.133 ***
Woodl.	LL.2	0.383 ***		0.078	
	LL.3	0.132 ***	-0.252 ***	0.019	-0.059

Table S4: Pairwise comparison of lowland sub-datasets, featuring significant effects form woody riparian vegetation on the multimetric index, regarding urban, agriculture (Agric.) and woodland (Woodl.) landuse cover based on analysis of variance (ANOVA). Values are the difference between mean respective landuse cover (sub-dataset row –column) and asterisks indicate Tukey' honest significant difference at $p < 0.5$ (*), $p < 0.05$ (**) and $p < 0.01$ (***).

	Sub-	Catchment						Local					
Landuse	dataset	M.1	M.2	M.5	M.6	M.8	M.9	M.1	M.2	M.5	M.6	M.8	M.9
Urban	M.2	0.14 ***						0.03					
	M.5	0.45 ***	0.30 ***					0.29 ***	0.26 ***				
	M.6	0.51 ***	0.37 ***	0.06				0.39 ***	0.36 ***	0.10			
	M.8	0.20 ***	0.05	-0.25 ***	-0.31 ***			-0.02	-0.04	-0.31 ***	-0.41 ***		
	M.9	0.20 ***	0.06	-0.25 ***	-0.31 ***	0.00		0.02	-0.01	-0.27 ***	-0.37 ***	0.04	
	M.10	0.27 ***	0.13 ***	-0.18 ***	-0.24 ***	0.07 *	0.07	0.44 ***	0.41 ***	0.15 ***	0.05	0.45 ***	0.42 ***
Agric.	M.2	0.01						0.04					
	M.5	0.02	0.01					-0.06	-0.10				
	M.6	0.02	0.01	0.00				0.01	-0.03	0.07			
	M.8	0.14 ***	0.13 ***	0.12 ***	0.12 ***			0.32 ***	0.28 ***	0.38 ***	0.31 ***		
	M.9	0.17 ***	0.17 ***	0.16 ***	0.16 ***	0.04		0.22 ***	0.18 *	0.27 ***	0.20 *	-0.10	
	M.10	0.16 ***	0.15 ***	0.14 ***	0.14 ***	0.02	-0.01	-0.06	-0.10	-0.01	-0.08	-0.38 ***	-0.28 ***
Woodl.	M.2	-0.20 ***						-0.09 *					
	M.5	-0.40 ***	-0.20 ***					-0.25 ***	-0.16 ***				
	M.6	-0.43 ***	-0.23 ***	-0.03				-0.40 ***	-0.31 ***	-0.15			
	M.8	-0.30 ***	-0.10 **	0.10 *	0.13 **			-0.28 ***	-0.19 ***	-0.03	0.11		
	M.9	-0.36 ***	-0.16 ***	0.04	0.07	-0.06		-0.22 ***	-0.12	0.04	0.18 *	0.07	
	M.10	-0.36 ***	-0.16 ***	0.04	0.07	-0.06	0.00	-0.29 ***	-0.20 ***	-0.04	0.11	0.00	-0.07

Table S5: Hydromorphology for the near and far-upstream hydromorphological assessment for the sub- datasets in lowlands (LL.1 – LL.3) and mountain (M.1 – M.11) streams. Median assessment score along with the 25th and 75th-percentiles are given.

	Hydromorphological assessment score					
	Near-upstream			Far-upstream		
Sub-dataset	25th-perc.	median	75th-perc.	25th-perc.	median	75th-perc.
LL.1	5.1	5.6	6.1	5.3	5.7	6.0
LL.2	3.2	4.7	5.5	3.9	5.0	5.4
LL.3	4.5	5.6	6.2	4.7	5.6	6.0
M.1	3.3	4.3	4.9	3.2	4.2	4.8
M.2	3.5	4.2	5.3	3.9	4.4	4.8
M.3	3.5	4.1	4.7	3.5	4.3	4.7
M.4	5.4	5.6	6.1	4.7	5.0	5.4
M.5	3.7	4.2	4.7	4.1	4.7	5.2
M.6	5.4	5.8	6.1	5.0	5.7	6.0
M.7	3.3	5.0	5.6	4.0	4.7	5.2
M.8	5.3	5.9	6.3	4.5	5.1	5.8
M.9	4.7	5.6	5.9	4.2	4.8	5.5
M.10	3.6	4.3	4.7	4.4	4.9	5.4
M.11	5.8	6.0	6.3	5.5	5.9	6.1