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RESEARCH ARTICLE

New indices for assessment of hydromorphological alteration of rivers and their evaluation with benthic invertebrate communities; Alpine case study

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ABSTRACT

1. According to the EU Water Framework Directive, methodologies have to be developed for evaluating the ecological status of every water body. The aim of this study was to develop a methodology (SI_HM method) for assessing the hydromorphological status and to test the developed method with benthic invertebrate community characteristics.
2. In Slovenia 26 different national river types have been identified in the hydroecoregion Alps. Data from 126 sites belonging to 22 river types, affected by a range of hydromorphological alteration, have been analysed.
3. Inventory of the hydromorphological features was made according to the River Habitat Survey (RHS), but for the assessment of the hydromorphological status, modified SI_HM variables were developed. Some of them (SI_HM variables) were based on principles developed in the RHS methodology and were only slightly modified in order to emphasize the characteristics of local river features, whereas others, took into consideration features not included in the RHS.
4. For the assessment of morphological status River habitat quality index (RHQ) and River habitat modification index (RHM) were developed. For hydrological changes the presence of dams and distances from them were considered and for assessment of hydrological status a Hydrological modification index (HLM) was developed.
5. Multimetric indices were developed out of these hydromorphological indices for assessment of Hydromorphological modification index (HMM) and Hydromorphological quality and modification index (HQM).
6. In order to maximise the number of comparable sites, sites from different national stream types were grouped together and tested using one-way ANOVA. According to the results of the test, the selected river types were grouped in two different hydromorphological types. Correlations (Spearman rho) between hydromorphological alteration and benthic invertebrate metrics within those types were tested, but were not sufficiently strong ($r<0.6$). Subsequently correlations between hydromorphological parameters and benthic invertebrate metrics were tested within individual national river type, and these correlations were statistically significant ($p<0.001$) and higher, reaching values of more than $r>0.9$.

KEY WORDS: Assessment, benthic invertebrates, habitat quality, hydrological modifications, hydromorphological indices, impoundments, RHS, SI_HM.

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RESEARCH ARTICLE

Nehirlerin hidromorfolojik değişimlerini belirlemede yeni indeksler ve bunların bentik omurgasız komüniteler ile hesaplanması; Alp örnek çalışması

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ÖZ

1. AB Su Çerçeve Direktifi'ne göre, her su kitlesinin ekolojik durumunu ortaya çıkarmak için yöntemler geliştirilmelidir. Bu çalışmanın amacı hidromorfolojik durumları değerlendirmek için bir yöntem (SI_HM metodu) geliştirmek ve geliştirilen yöntemi bentik omurgasız komünitelerinin özellikleri ile test etmektir.
2. Slovenya'da Alp hidroekobölgesinde, 26 faklı ulusal nehir tipi tanımlanmıştır. Hidromorfolojik değişimle etkilenen, 22 nehir tipine ait 126 istasyondan elde edilen veriler analiz edilmiştir.
3. Hidromorfolojik özelliklerin envanteri Nehir Habitat İncelemesi'ne (River Habitat Survey, RHS) göre çıkarılmıştır. Fakat hidromorfolojik durumun değerlendirilmesi için, yeni SI_HM değişkenleri geliştirildi. Bunların bazıları (SI_HM değişkenleri) RHS yönteminde geliştirilmiş esaslara dayandırıldı ve bölgesel nehir özelliklerini belirlemek için RHS yöntemi çok az değiştirildi. Dikkate alınan diğer özellikler RHS'de bulunmamaktadır.
4. Morfolojik durumun değerlendirilmesi için Nehir Habitat Kalite İndeksi (River Habitat Quality Index, RHQ) ve Nehir Habitat Modifikasyon İndeksi (River Habitat Modification Index, RHM) geliştirildi. Hidrolojik değişimler için barajlar ve uzaklıkları göz önüne alındı. Hidrolojik durumun değerlendirilmesi için Hidrolojik Modifikasyon İndeksi (Hydrological modification index, HLM) geliştirildi.
5. Hidromorfolojik Modifikasyon İndeksi'nin (Hydromorphological modification index, HMM) ve Hidromorfolojik Kalite ve Modifikasyon İndeksi'nin (Hydromorphological quality and modification index, HQM) değerlendirilmesi için bu hidromorfolojik indekslerin dışında multimetrik indeksler geliştirildi.
6. Karşılaştırılabilir istasyonların sayısını maksimuma çıkarmak için, farklı ulusal akarsu tiplerindeki istasyonlar birlikte gruplandırıldı ve tek yönlü ANOVA kullanılarak test edildi. Testin sonuçlarına göre, seçilen nehir tipleri iki farklı hidromorfolojik tipte gruplandı. Bu tipler içindeki hidromorfolojik değişimler ve bentik omurgasız metrikleri arasındaki korelasyonlar (Spearman rho) test edildi, fakat korelasyonlar yeterli derecede kuvvetli bulunmadı ($r<0.6$). Daha sonra hidromorfolojik parametreler ve bentik omurgasız metrikleri arasındaki korelasyonlar, her ulusal nehir tipi içerisinde test edildi ve bu korelasyonlar istatistiksel olarak belirgin ($p<0.001$) ve yüksek olarak saptandı.

ANAHTAR KELİMELER: Barajlar, bentik omurgasızlar, değerlendirme, habitat kalitesi, hidrolojik modifikasyonlar, hidromorfolojik indeksler, RHS, SI_HM.

INTRODUCTION

Aquatic habitats can be defined as the local physical, chemical and biological features that provide an environment for the instream biota. (Jowet 1997). Physical habitat is a particularly useful element to be considered for evaluating river health as it provides the natural link between the physical environment and its inhabitants. Without a suitable living space a given species is unlikely to exist at the particular location (Minshall and Minshall 1977, Maddock 1999). Identifying which physical features are biologically relevant is an important question (Maddock 1999). However it should be considered that channel features are not the only physical features important for the instream biota. Environmental conditions of banks, riparian areas and floodplains also contribute to the quality of instream habitats (Newson and Newson 2000, Gerritsen and Barbour 2000). On the other hand, hydromorphological properties of streams depend on relation between morphology and hydrology of the stream (Sear and Newson 2003) therefore hydrologic characteristics of flow regimes play a major role to ecological integrity of flowing water ecosystems (Richter *et al.* 1996). Human modification of natural hydrologic processes disrupts the dynamic equilibrium between the movement of water and the movement of sediment (Poff *et al.* 1997). Therefore also hydrological characteristics of the sites need to be assessed and evaluated for the complete hydromorphological assessment and evaluation. Dams are the most obvious direct modifiers of river hydrology as they among other change the magnitude and frequency of high and low flow which affects abiotic and biotic characteristics of streams (Poff *et al.* 1997).

The goal of the Water Framework Directive (WFD) (Directive 2000/60/EC) is to achieve good ecological status for all water bodies by 2015. The directive establishes the central role of biological elements in the assessment of the status of surface water bodies, but also encourages countries of the EU to carry out hydromorphological assessment activities to better understand biological data (Erba *et al.* 2006) as the importance of physical habitat characteristics for the quality of instream habitats has been widely recognized.

For the evaluation of the ecological status of every surface water body new methodologies have to be developed. So far several methods have been developed for evaluation of hydromorphological characteristics of rives in Europe. Most methods include only hydromorphological characteristics of the river (Muhar *et al.* 1996, 1998, Raven *et al.* 1998, LAWA 2000, Fleischhacker and Kern 2002, Pedersen and Baattrup-Pedersen 2003, Feld 2004), whereas few also include some biotic characteristics as a response to the pressures (e.g. Petersen 1992). The approaches also differ in the number of the hydromorphological properties that are included in the survey, in the distance of the survey area (the distance can either be defined or can depend on the size of the river) and in the way how different properties are evaluated. But most of the systems include assessment of the channel, banks, riparian areas and floodplains. In general, there are two principles for assessing the hydromorphological state of rivers. According to the first principle, the evaluation is based on the diversity and quality of habitats (e.g. Raven *et al.* 1998; HQA). Methods use a pre-existent draft of properties. In the more basic methods only the presence of those properties is considered and in the more complex methods different values are added to properties under assessment and those values serves as weights in the evaluation of the site quality. Regardless of the complexity of the methods, the habitat reference conditions have to be defined for each water body as those conditions deteriorate with the degree of modification.

The second principle considers the degree of modification of the hydromorphological properties for the evaluation of the hydromorphological state of rivers (e.g. Raven *et al.* 1998; HMS). According to this principle, the changes induced by human intervention causing negative effects on habitat diversity are evaluated. Each site is considered as being pristine and it is given the same starting-point or reference value. Each recorded modification shifts the status of a site toward worse status and finally, if modifications are numerous, the status of a site can be recognized as heavily modified.

RHS assesses a 500 m long stretch of a river so that only site-related variables are considered. Despite extensive discussions on the scale-dependent relation between hydromorphology and biotic communities (especially benthic invertebrates) (e.g. Rabeni 2000, Sponseller *et al.* 2001, Urbanic and Toman 2007) site-related variables seem to be the most important (Feld 2004, Verdonschot 2004), although both the last mentioned authors found catchment-related variables of additional importance. Therefore catchment-related variables, which many authors regards as important for benthic invertebrates distribution were already included in the typology of rivers in Slovenia (Urbanic 2006, 2008a,b) as system B of the WFD was used for determination of river types. In the ecoregion Alps in Slovenia 26 river types were identified ranging from small to medium and large rivers.

Hydromorphological alteration is one of the most significant stressors affecting the stream biota in European rivers (Raven *et al.* 2002, Feld 2004, Lorenz *et al.* 2004). Therefore it is important to develop methodologies for evaluation of the degree of stress in order to identify changes in the stream biota caused by hydromorphological alteration.

The aims of this study were; (i) to compare hydromorphological properties between different river types in the ecoregion Alps, (ii) to develop a methodology for assessment of hydromorphological status of rivers and define type specific hydromorphological reference conditions, and finally (iii) to preliminarily evaluate the developed method with benthic invertebrate community characteristics.

METHODS

Study sites

The study was conducted in the Slovenian part of the ecoregion Alps (Figure 1). In Slovenia, national typology for rivers was prepared according to the system B of the EU Water Framework Directive. Bioregion, size of the catchment area and additional attributes listed in the table 1 were used as river type descriptors (Urbanic 2006). In the present study, 22 national river types were investigated (Table 2) representing small (12), medium (9) and large (1) rivers. All together, 126 sites were selected for assessment of hydromorphological features. At 93 sites data on benthic invertebrate communities were also available. Sampling sites were pre-selected according to the Slovenian national classification for hydromorphological modifications (VGI 2002). The rationale behind this selection process was to cover a gradient from natural sites to heavily altered sites (Figure 2). Only sites where hydromorphological alteration was the presumed main stressor were included in the analyses. All sites that were classified as moderate or worse regarding pollution (Urbanic *et al.* 2006) were excluded from the analyses.

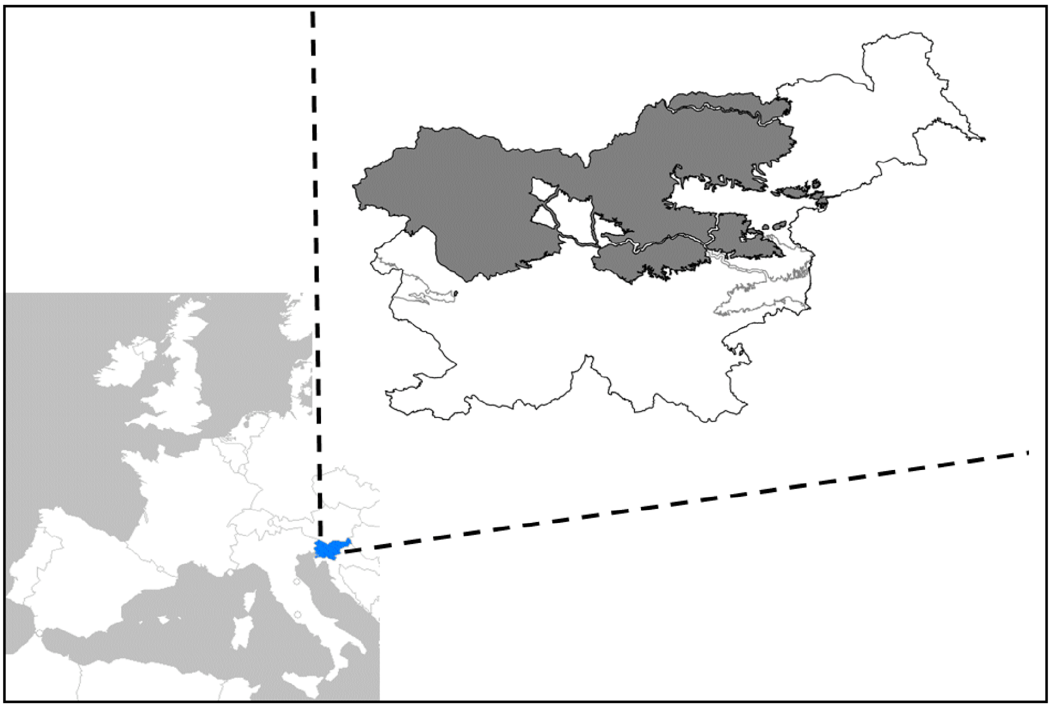

Figure 1. Ecoregion Alps in Slovenia (Urbanic, 2008a). Ecoregion Alps is coloured dark.

Table 1. Bioregions of the Ecoregion Alps in Slovenia (sensu Urbanic, 2008b) and attributes defining the selected river types.

Bioregion	Code	Attribute	Code
Carbonate Alps - Danube river basin	KB-AL-D	Karst spring influence	KI
Silicate Alps	SI-AL	Intermittent stream	Pres
Pre-alpine hills - Danube river basin	PA-hrib-D	Lake outflow influence	IiJ
Carbonate Alps - Adriatic river basin	KB-AL-J	Height above 700 m a.s.l.	>700
Pre-alpine hills - Adriatic river basin	PA-hrib-J	**Catchment size**	
		a) 10-100 km^2 - small rivers	1
		b) 100-1000 km^2 - medium size rivers	2
		c) > 2500 km^2 or mean annual discharge >50 m^3/s - large rivers	VR1

Table 2. List of river types of the Ecoregion Alps included in the survey, number of sites included in the hydromorphological (HM) analysis for each river type, number of sites included in the biological evaluation (BE) for each river type (in brackets number of reference sites) and number of benthic invertebrate (BI) samples (in square brackets number of BI samples from reference sites).

Type number	River type	Code	No. of sites included in the HM analysis	No. of sites included in the BE	No. of BI samples
1	SI_VR1	V1	4	4 (1)	16 [4]
2	SI_4_KB-AL-D_1	KBD1	7	3 (1)	12 [4]
3	SI_4_KB-AL-D_1_>700	KBD1>	6	6 (2)	24 [8]
4	SI_4_KB-AL-D_1_KI	KBD1KI	14	8 (2)	32 [8]
5	SI_4_KB-AL-D_1_Pres	KBD1P	1	1 (1)	4 [4]
6	SI_4_KB-AL-D_2	KBD2	4	3 (3)	12 [4]
7	SI_4_KB-AL-D_2_IiJ	KBD2IJ	1	1 (0)	4 [0]
8	SI_4_KB-AL-D_2_KI	KBD2KI	4	4 (1)	16 [4]
9	SI_4_KB-AL-J_1	KBJ1	4	4 (4)	16 [16]
10	SI_4_KB-AL-J_1_KI	KBJ1KI	6	6 (6)	24 [24]
11	SI_4_KB-AL-J_2	KBJ2	1	1 (1)	4 [4]
12	SI_4_KB-AL-J_2_KI	KBJ2KI	1	1(1)	4 [4]
13	SI_4_PA-hrib-D_1	PAD1	13	12 (3)	48 [12]
14	SI_4_PA-hrib-D_1_KI	PAD1KI	7	3 (0)	12 [0]
15	SI_4_PA-hrib-D_2	PAD2	12	6 (2)	28 [8]
16	SI_4_PA-hrib-J_1	PAJ1	15	10 (4)	40 [16]
17	SI_4_PA-hrib-J_1_KI	PAJ1KI	2	0 (0)	0 [0]
18	SI_4_PA-hrib-J_2	PAJ2	4	2 (1)	8 [4]
19	SI_4_PA-hrib-J_2_KI	PAJ2KI	2	0 (0)	0 [0]
20	SI_4_SI-AL_1	SIAL1	10	10 (1)	14 [1]
21	SI_4_SI-AL_1_>700	SIAL1>	2	2 (2)	8 [8]
22	SI_4_SI-AL_2	SIAL2	6	6 (0)	24 [0]

Survey of morphological properties

For the survey of morphological properties UK RHS protocol (Raven *et al.* 1998, Environment Agency 2003) was selected as diversity of both, natural and modified habitat features are recorded. In the recording presence or in some cases also the extent of features is regarded. Following the RHS protocol, each survey was carried out over a

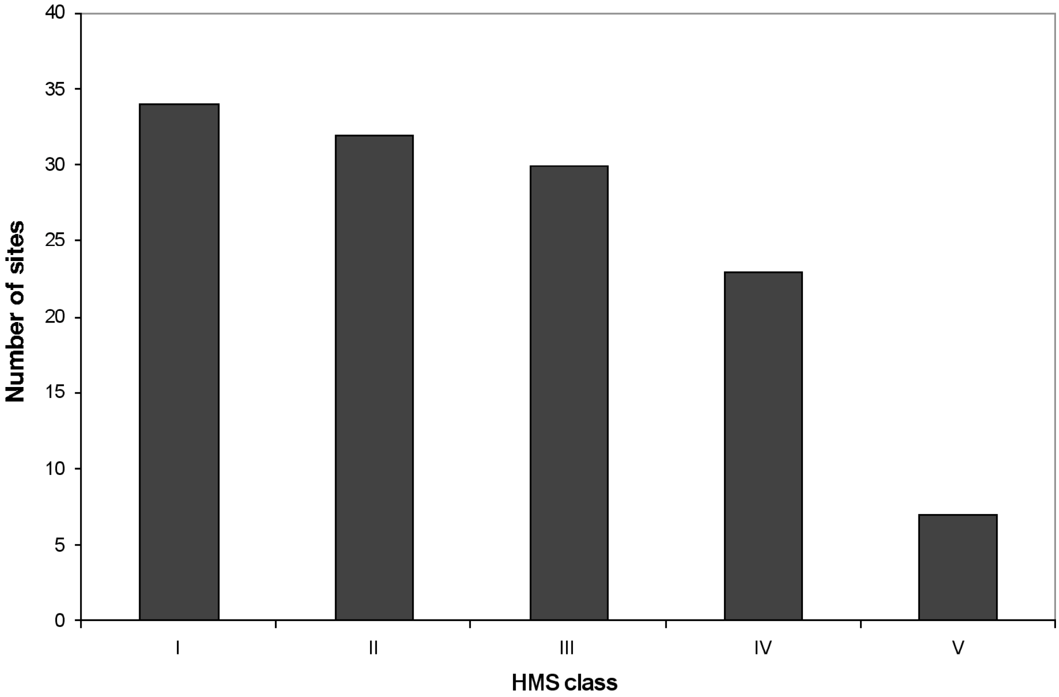

Figure 2. Distribution of the study sites according to the habitat modification scores (HMS).

500-m long stretch of the river. Along those 500 m thorough observations were carried out on 10 equally spaced spot checks. The distance between each spot check was 50 m. At each spot check, predominant substrate and physical features of channel and banks were recorded, as well as flow-type, channel vegetation type, land-use and vegetation structure of banks and adjacent land. Channel and banks features were also recorded along the whole stretch in a sweep up part of survey and were considered in the overall assessment. Land use in the 50 m stretch from the channel, special features of banks and channel, banks profile and some other features were considered in this sweep up assessment. 33 features were recorded at each site. RHS survey was conducted in such a way that the location of the benthic invertebrate sampling site was centred at the eight RHS spot check (the third most downstream transect).

Survey of hydrological properties

For the survey of hydrological properties two features were considered: distance from the impoundment and the number of tributaries between the impoundment and the site. Data on tributaries were gathered from the Slovenian map of river catchments classes.

SI_HM METHOD AND HYDROMORPHOLOGICAL INDICES

Morphological status

For the assessment of the hydromorphological status of rivers indices were developed in which variables that came out of the RHS survey were incorporated. In order to evaluate the characteristics of local river features and to consider the influence of those features on benthic invertebrate communities, a certain weight was appointed to each morphological feature recorded in the survey. The appointed values were chosen considering expert opinion or literature sources, so that not only the presence and extent of the feature, but also its influence on the benthic invertebrate community was considered in the final evaluation. In general, values for natural features were higher for features that improve habitat quality or enhance habitat diversity for benthic invertebrates as the diversity of habitats is one of the elements that determine the diversity of species (Petts 2000, Giller and Malmquist 1998, Feld 2004) and for the artificial features values were higher for the features that have the most adverse effects on benthic invertebrates (Tables 3-4).

For the natural material of banks values were appointed according to substrate size. The highest value was appointed to bedrock and the lowest to clay (Table 3). In the RHS survey only the predominant type of a substrate is recorded although other types are also present. This can bee seen from the sweep up part of the survey form. The designation of values for a certain substrate size was therefore based on the fact that where larger fractions were predominant also smaller fractions were present providing more diversified habitats and contributing to the habitat quality (Williams 1978). Therefore higher values were appointed to larger sizes of a substrate. For artificial bank materials values were appointed according to the degree of negative influence of a certain material on the benthic invertebrate community. The highest value was appointed to concrete and the lowest to builders waste (Table 4) as concrete provides the lowest diversity of microhabitats and connectivity between channel and adjacent habitats.

For bank and channel modifications, those modifications that have a greater influence on the natural habitat were appointed a higher value. For marginal features of streams, values were appointed according to the positive effects of certain feature on the benthic invertebrate community. The highest value was appointed to the vegetated point bar and the lowest to the unstable cliff (Table 3). In the category of flow types the highest value was appointed to free flow and the lowest for imperceptible flow based as in the case of substrate size on the fact that also slower flow types were always present

Table 3. Values for natural morphological river feature types.

Predominant natural bank material	Value
Bedrock (BE)	5
Boulder (BO)	4
Coble (CO)	3
Gravel/Sand (GS)	2
Earth (EA)	1
Clay (CL)	0

Bank features	Value
None (NO)	0
Eroding cliff (EC)	0.5
Stable cliff (SC)	1
Unvegetated point bar (PB)	2.5
Vegetated point bar (VP)	3.5
Unvegetated side bar (SB)	2
Vegetated side bar (VS)	3
Natural berm (NB)	4

Predominant channel substrate	Value
Bedrock (BE)	6
Boulder (BO)	5
Coble (CO)	4
Gravel (predominating)/Pebble (G(P))	3.5
Gravel/Pebble (GP)	3
Gravel/Pebble (predominating) ((G)P)	2.5
Sand (SA)	2
Silt/Mud (SI)	1
Clay (CL)	0

Predominant flow	Value
Freefall (FF)	7
Chute (CH)	6
Broken standing waves (BW)	5.5
Unbroken standing waves (UW)	5
Chaotic flow (CF)	4
Rippled (RP)	3
Upwelling (UP)	2.5
Smooth flow (SM)	2
No perceptible flow (NP)	1
No flow (dry) (DR)	0

Channel features	Value
None (NO)	0
Exposed boulders (RO)	1
Unvegetated mid-channel bar (MB)	3
Vegetated mid-channel bar (VB)	4
Mature island (MI)	5
Vegetated rock (VR)	2
Exposed bedrock (EB)	1.5

Land use	Value
Broadleaf/mixed woodland (semi-natural) (BL)	8
Broadleaf/mixed plantation (BP)	7.5
Coniferous woodland (semi-natural) (CW)	7
Coniferous plantation (CP)	6.5
Orchard (OR)	3
Scrub and Shrubs (SC)	5.5
Tall herb/rank vegetation (TH)	5
Rough unimproved pasture (RP)	4
Improved/semi-improved grassland (IG)	2
Tilled land (TL)	1
Wetland (WL)	4.5
Suburban/urban development (SU)	0
Irrigated land (IL)	1
Parkland or gardens (PG)	3

Banktop and bankface vegetation structure	Value
Bare (B)	0
Uniform (U)	1
Simple (S)	2
Complex (C)	3

Channel vegetation types	Value
None or not visible	0
Liverworts/mosses/lichens	3
Emergent broad-leaved herbs	4
Emergent reeds/sedges/rushes/grasses	4
Floating-leaved (rooted)	1
Free-floating	0.5
Amphibious	1.5
Submerged broad-leaved	5
Submerged fine-leaved	5
Submerged linear-leaved	5
Filamentous algae	2

Unmodified bank profiles	Value
None	0
Vertical/undercut	0.5
Vertical with toe	1
Steep (> 45°)	2
Gentle	3
Composite	4
Natural berm	5

Extent of trees	Value
None	0
Isolated/scattered	1
Regularly spaced. single	2
Occasional clumps	3
Semi-continuous	4
Continuous	5

beside faster ones. For some features (Table 5) that were recorded in the sweep-up part their extent was considered and points were appointed according to the their extent. If they were present and cowered less than 33% of the area 1 point was appointed for that feature but if they cowered more than 33% 2 points were appointed. Regarding the channel being choked with vegetation one point was appointed only if more than 33% of the channel was being choked with it. For the artificial features as dams/weirs, bridges, fords, deflectors, culverts, sluices and outfalls size was the attribute decisive for appointment of points. If they were recognised as minor, intermediate or major they were appointed 1, 2 or 3 points respectively. Out of recorded morphological features and their appointed values 7 variables were created (bank features, channel features, riparian features, land use within 50 m; features of interest along 500 m of the river) and used for evaluation of the morphological status of sites included in the research. Five of those variables were included in the calculation of the **River habitat quality index (RHQ)** and two for the **River habitat modification index (RHM)**.

Table 4. Values for artificial morphological river feature types.

Predominant artificial bank material	Value
Concrete (CC)	6
Wood piling (WP)	3
Gabion (GA)	4
Brick/laid stone (BR)	5
Rip-rap (RR)	2
Builders waste (BW)	0.5
Bank modifications	**Value**
None (NO)	0
Resectioned (reprofiled) (RS)	3
Reinforced (RI)	4
Poached (PC)	2
Poached bare(PC(B))	2.5
Embankment (EM)	1
Artificial channel material	**Value**
Artificial channel material (AR)	1

Channel modifications	Value
None (NO)	0
Culverted (CV)	5
Resectioned (RS)	2
Reinforced (RI)	3
Dam/weir/sluice (DA)	4
Ford (FO)	1
Artificial/modified bank profiles	**Value**
None	0
Resectioned (reprofiled)	1.5
Reinforced – whole	5
Reinforced – top only	2.5
Reinforced – toe only	4
Artifical two stage	1.5
Poached bank	2
Embanked	3
Set-back embankment	0.5

Table 5. Sweep-up morphological river features.

Sweep-up morphological river feature	
Shading of channel	Flow types along 500 m
Overhanging boughs	Channel and bank features along 500 m
Exposed bankside roots	Features of special interest along 500 m
Underwater tree roots	Channel realignment
Fallen trees	Water impoundment by weir/dam
Coarse woody debris	

River habitat quality index (RHQ)

A ***river habitat quality index*** considers five river habitat quality variables and its value was calculated according to the equation 1:

$$RHQ = Sc_{bf} + Sc_{cf} + Sc_{rf} + Sc_{lu} + Sc_{f} \quad (1)$$

where: **RHQ** - river habitat quality index; **Sc_{bf}** - score for bank features; **Sc_{cf}** - score for channel features; **Sc_{rf}** - score for riparian features; **Sc_{lu}** - score for land use within 50 m; **Sc_{f}** - score for features of interest along 500 m of the river.

Scores of the river quality variables were calculated using following equations:

For ***bank features*** the score was calculated using the equation 2:

$$Sc_{bf} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} (a_{bji} \cdot f_{bji}) + \frac{\sum_{k=1}^{l} (a_{bpk} \cdot e_{bpk})}{s}}{2} + e_{bbr} + e_{bur} + e_{bft} \quad (2)$$

where: **Sc_{bf}** – score for bank features; **a_{bji}** – value appointed to a ith category of a jth bank feature (b)*; **a_{bpk}** – value appointed to a kth category of a pth bank feature (b)**; **f_{bji}** – frequency of a ith category of a jth bank feature (b); **e_{bpk}** – extent of the kth category of a pth bank feature (b); **e_{bh}** – extent of the hth bank feature (b)***; **n** – frequency of a jth feature; **s** – number of types; **l** – number of categories of the k-th bank feature (* bank material, bank features, bankface vegetation structure, banktop vegetation structure; ** unmodified bank profiles; *** exposed bankside roots, underwater tree roots, fallen trees).

As the surveying method records some features on both river sides the score included in the final score for bank features was divided by 2 as it is seen in the equation 2. For bank profiles where the number of types that can appear is not designated, scores were divided by the number of types that were recorded, so that an average score of all present types was calculated (Equation 2). The same was done for land use within 50 m of a banktop.

For ***channel features*** the score was calculated using the equation 3:

$$Sc_{cf} = \sum_{l=1}^{o} \sum_{i=1}^{n} (a_{cli} \cdot f_{cli}) + \sum_{j=1}^{p} (a_{cftj} \cdot e_{cftj}) + \sum_{m=1}^{r} \sum_{k=1}^{m} (a_{cmk} \cdot e_{cmk} \cdot f_{cmk}) + e_{cd} + e_{ccv} \quad (3)$$

where: $\mathbf{Sc_{cf}}$ – score for channel features; $\mathbf{a_{cli}}$ – value appointed to a ith category of a lth channel feature (c)$^{+}$; $\mathbf{a_{cftj}}$ – value appointed to a jth category of a fth channel feature (c)$^{++}$; $\mathbf{a_{cmk}}$ – value appointed to a kth category of a mth channel feature (c)$^{+++}$; $\mathbf{f_{cli}}$ - frequency of a ith category of a lth channel feature (c); $\mathbf{f_{cmk}}$ - frequency of a kth category of a mth channel feature (c); $\mathbf{e_{cmk}}$ – extent of a kth category of a mth channel feature (c); $\mathbf{e_{cs}}$ – extent of a sth channel feature (c) $^{++++}$; **n** – number of categories of the i-th feature; **p** – number of categories of the j-th feature; **m** – number of features of the k-th feature; **o, r** – number of features ($^{+}$ predominant channel substrate, predominant flow at spot-check; $^{++}$ flow types along 500 m; $^{+++}$ channel feature type, channel vegetation type; $^{++++}$ coarse woody debris, channel chocked with vegetation, channel vegetation type).

For ***riparian features*** the score was calculated using the equation 4:

$$Sc_{rf} = \frac{\sum_{i=1}^{n} a_{rlui} \cdot f_{rlui} + \sum_{j=1}^{m} a_{rtj}}{2} + e_{rs} + e_{rob} \quad (4)$$

where: $\mathbf{Sc_{rf}}$ – score for riparian features; $\mathbf{a_{rlui}}$ – value appointed to a ith category of a luth riparian feature (r) $^{\#}$; $\mathbf{a_{rtj}}$ – value appointed to a jth category of a tth riparian feature (r) $^{\#\#}$; $\mathbf{e_{rk}}$ – extent of a kth riparian feature (r) $^{\#\#\#}$; $\mathbf{f_{rlui}}$ – frequency of a ith category of a luth riparian feature (r); **n** – number of categories of the i-th feature; **m** – number of categories of the j-th feature ($^{\#}$ land use within 5m; $^{\#\#}$ extent of trees; $^{\#\#\#}$ shading of channel, overhanging boughs).

For ***land use within 50 m*** of the channel the score was calculated using the equation 5:

$$Sc_{lu} = \frac{\sum_{i=1}^{m} e_{lui} \cdot a_{lui} \cdot f_{lui}}{2 \cdot m} \quad (5)$$

where: $\mathbf{Sc_{lu}}$ – score for land use within 50 m; $\mathbf{a_{lu}}$ – value appointed to a i-th category of a land use type (lu); $\mathbf{e_{lu}}$ – extent of a i-th category of a land use type (lu) within 50 m (lu); $\mathbf{f_{lui}}$ – frequency of a i-th category of a land use type (lu); **m** – number of present categories of the land use types.

For ***features of interest along 500 m*** of the river the score was calculated using the equation 6:

$$Sc_f = \sum_{j=1}^{m} \sum_{i=1}^{n} e_{fji} \tag{6}$$

where: Sc_f – score for features of interest along 500 m of the river; e_{fji} – extent of i-th category of a j-th feature along a 500 m reach of the river [x]; **n** – number of categories of the features of interest along 500 m of the river; **m** – number of features ([x] channel or bank feature along 500 m, feature of special interest along 500 m).

River habitat modification index (RHM)

For the calculation of the river habitat modification index two variables were considered, bank modifications and channel modifications.

The ***bank modifications*** score was calculated using the equation 7:

$$Sc_{bmo} = \frac{\sum_{j=1}^{o} \sum_{i=1}^{n} (a_{bji} \cdot f_{bji}) + \frac{\sum_{k=1}^{m} (a_{bmpk} \cdot e_{bmpk})}{m}}{2} \tag{7}$$

where: Sc_{bmo}- score for bank modifications; a_{bji} – value appointed to a i-th category of a j-th bank modification feature (bmo)[*]; a_{bmpk} – value appointed to a k-th category of a mp-th bank modification feature (bmo)[**]; f_{bji} – frequency of a i-th category of a j-th bank modification feature (bmo); e_{bmpk} – extent of a k–th category of a mp-th bank modification feature (bmo); **m** – number of present categories; **o** – number of features ([*] artificial bank material, bank modification; [**] artificial/modified bank profiles).

The ***channel modifications*** score was calculated according to the equation 8:

$$Sc_{cmo} = \sum_{j=1}^{m} \sum_{i=1}^{n} (a_{cji} \cdot f_{cji}) + \sum_{k=1}^{o} s_k + e_{cmr} + e_{cmi} \tag{8}$$

where: Sc_{cmo}- score for channel modifications; a_{cji} – value appointed to a i-th category of a j-th artificial/modified channel feature (cmo)[+]; f_{cji} – frequency of a i-th category of a j-th artificial/modified channel feature (cmo); s_k – value for size of a k-th artificial feature[++]; e_{cl} – extent of a l-th channel modification feature (cmo)[+++]; **n** – number of categories of the i-th feature; **m** – number of features; **o** – number of artificial features types ([+] predominant artificial channel substrate, channel modification; [++] dam/weir, bridge, ford, deflector; [+++]channel realignment, water impounded by dam).

The ***river habitat modification index*** value was calculated by adding up the bank and channel modification scores using the equation 9:

$$RHM = Sc_{bmo} + Sc_{cmo} \tag{9}$$

where: **RHM** - river habitat modification index; **Sc_{bmo}**- score for bank modifications; **Sc_{cmo}** - score for channel modifications.

Hydrological status

Development of the hydrological status assessment was based on the idea that changes in benthic communities caused by the major impoundments upstream of the site should be considered. Only impoundments where water impounded behind the dam extended to a certain length were considered. Obligatory distance varied according to the catchment's size area (Table 6).

Table 6. Length of water impoundments needed to be classified as a major impoundment.

Catchment's size class	**Length of impoundment (km)**
< 10 km^2	0.1
10-100 km^2	0.5
100-1000 km^2	1
1000-2500	1.5
> 2500 km^2 or mean annual discharge >50 m^3/s	2

For the evaluation of the influence of impoundments two variables were considered: distance from the impoundment and the number of tributaries between the impoundment and the site. The power of each variable included in the assessment was based on the catchments' size classes of inflowing tributaries and the catchment's size class of the river at the confluence site. Catchments class size linked to the size of the catchments area resembled the amount of water flowing within the stream or river. For each site, the distance from impoundment and number and catchment's size classes were therefore gathered. Only the last impoundment before the sampling site was considered for the main channel and tributaries. If the catchments size of the tributary was smaller than 10 km^2, they were considered only if they had an impoundment that fulfilled the selected criterion. The calculated hydrological influence was expressed as ***Hydrological modification index* (HLM).** A principle of the weighting of each variable included in the HLM was considered and developed. A value of the HLM(mc,t) (between 0 and 1) according to the distance of the sampling site from an impoundment was calculated using the equation 10:

$$HLM_{(mc,\ t)} = lb + ((di-lbd) \cdot 0.2/(udb-lbd)) \quad (10)$$

where: **$HLM_{(mc, t)}$**- hydrological modification of a main channel (mc) or tributary (t); **lb** – lower class boundary value of $HLM_{(mc, t)}$; **di** – distance from impoundment; **ubd** – upper class boundary distance; **lbd** – lower class boundary distance.

and class boundary values from the table 7.

Table 7. Lower and upper distance boundaries and class boundaries with respective classes.

Lower and upper boundary distance from impoundment (km)	Lower and upper class boundary value	Class
0-0.1	0-0.2	5
0.1-1	0.2-0.4	4
1-5	0.4-0.6	3
5-10	0.6-0.8	2
10-50 and more (or no impoundment upstream)	0.8-1	1

Higher the distance from the impoundment, higher is the value of $HLM_{(mc, t)}$. The value of the Hydrological modification index (HLM) includes also information on the presence of tributaries between the impoundment and the assessed site and was calculated using the equation 11:

$$HLM = \frac{1000 \cdot HLM_{mc} + 1000 \cdot \sum_{i=1}^{n} HLM_{t} + 100 \cdot \sum_{i=1}^{m} HLM_{t1} + 10 \cdot \sum_{i=1}^{l} HLM_{t2} + \sum_{i=1}^{k} HLM_{t3}}{1000 + n \cdot 1000 + m \cdot 100 + l \cdot 10 + k} \quad (11)$$

where: **HLM** – hydromorphological modification index at the sampling site; **HLM_{mc}** – hydromorphological modification value of the main channel; **HLM_{t}** – hydromorphological modification value of the tributary that at the confluence belongs to the same catchment area size class as the river; **HLM_{t1}** – hydromorphological modification value of the tributary that has at the confluence the catchment area size for one class smaller than the river; **HLM_{t2}** – hydromorphological modification value of the tributary that has at the confluence the catchment area size for two classes smaller than the river; **HLM_{t3}** – hydromorphological modification value of the tributary that has at the confluence the catchment area size for three classes smaller than the river; **n, m, l, k** – number of tributaries of the same catchment area class.

The HLM value increases with the degree of hydrological intactness and the size of the catchment area. On the other hand, if tributaries upstream of the site are influenced by impoundments this lowers the final HLM value. If a sampling site is located in the area of the water impoundment, the HLM is 0.

Hydromorphological status

Hydromorphological status was expressed as the value of a *Hydromorphological modification index* (HMM). For its calculation, combinations of two indices were considered: normalised value of Morphological modification index (RHM) and value of Hydrological modification index (HLM). Values of HMM were calculated according to the equation 12:

$$HMM = (w \bullet BV) + [(1-w) \bullet WV] \tag{12}$$

where: **HMM** – hydromorphological modification index; **w** – weight of the index that belongs to a better class; **(1-w)** – weight of the index that belongs to a worse class; **BV** – index that belongs to a better class (RHM or HLM); **WV** – index that belongs to a worse class (RHM or HLM).

The power of each index included in the calculation depended on the level of alteration it expressed and the index that was ranged in the worst class was given greater weight considering rule 1:

if	absolute class difference	**than**	weight of index that belongs to a better class (w)	**and**	weight of index that belongs to a worse class (1-w)
	4		0.1		0.9
	3		0.2		0.8
	2		0.3		0.7
	1		0.4		0.6
	0		0.5		0.5

(1)

Classes and class boundaries were the same as the ones used for hydrological modifications (Table 7).

Hydromorphological quality and modification multimetric indices

With HMM only hydromorphological modifications were considered. For expression of combined hydromorphological modification and habitat quality, an additional multimetric index *hydromorphological quality and modification index* (HQM) was developed combining indices RHQ, RHM and HLM. As with the HMM the power of each index depended on the grade of alteration it expressed.

For calculation of HQM equation 13 was developed. The average of the normalised values of indices river habitat quality index (RHQ) and river habitat modification index (RHM) were calculated and considering rule 1 ratio between calculated value and hydrological modification (HLM) was determined by the equation 13:

$$HQM = (a \cdot (RHQ + RHM)/2) + (b \cdot HLM) \qquad (13)$$

where: **HQM** – hydromorphological quality and modification index; **RHQ** – river habitat quality index; **RHM** – river habitat modification index; **HLM** – hydrological modification index; **a** – value of the weight for (RHQ + RHM) depending on the rule 1; **b** – value of the weight for HLM depending on the rule 1.

Values of RHQ and RHM were normalized according to the equation 14:

$$\text{Value} = \frac{\text{Variable value - Lower anchor}}{\text{Reference value - Lower anchor}} \qquad (14)$$

For RHQ, which represents habitat quality, minimal value that can be appointed was assigned as the lover anchor and median of reference sites as the reference value. Normalisation for RHQ was preformed within each national river type, as its value is type specific. For RHM, which represents habitat modification, maximal value that could be appointed for heavily modified sites were designated as lower anchor (229) and for the reference value, values that are appointed when there is no modification were used (0).

Hydromorphological reference conditions

This research dealt with hydromorphological conditions only. Sites were designated as reference sites only if the sum of habitat modification scores (HMS) did not exceed 5 points. Moreover, because severe pollution can also influence river hydromorphological conditions an additional reference condition criterion was defined; all sites had to be classified at least as good regarding water pollution. For confirmation of the appropriate selection, comparison of RHQ values between reference and impaired sites was also performed. Mean values of the RHQ scores of the reference sites were also tested by one-way ANOVA to test if conditions within 22 ecological river types enable grouping of different types in larger groups with the view to maximise the number of comparable sites and available data.

Biological evaluation of the indices included in the SI_HM method

In the first step all benthic invertebrate data sets representing a certain hydromorphological river type (according to the results of the one-way ANOVA test, data of national river types were grouped in two hydromorphological river types) were analysed by non metric multidimensional scaling (NMS) using Bray-Curtis distance measure. The dimension of the solution depended on the stress, a measure that explains the discrepancy between the multidimensionality of the data and the final (low-dimensional) ordination. According to Clarke (1993) and Podani (2000), stress values between 0.1 and 0.2 represent acceptable results. Therefore the lowest possible number of dimensions was selected that fulfilled the required criterion with a stress lower than 0.2. Usually a two or three-dimensional solution was chosen. All NMS ordinations were provided by the program WinKyst (Smilauer 2003). Further, Spearman's Correlation Coefficients for the correlation of the hydromorphological indices (RHQ, RHM, HLM, HMM, HQM) with each multivariate NMS axes were calculated. In the second step each benthic invertebrate data set representing national river types was analysed following the same procedure in order to compare results. All correlation coefficients were calculated using SPSS 13.0.

Evaluation of hydromorphological properties

Morphological properties

Sites included in the survey belonged to the alpine streams and had certain characteristics. Banks were steep and predominantly composed of gravel and sand (53%). Bank special features were quite rare; the most common were side bars without vegetation which were present in less than 10% of the spot checks. Channel substrate was predominantly composed of cobbles (39%) or gravel and pebbles (34%), boulders were predominant channel substrate in 17%, and all the other materials were scarcer. For the flow types rippled was the most common type (38%), followed by unbroken waves (25%) and broken waves (17%). In the channel exposed boulders were the most common feature appearing at 10% of spot checks. Broadleaf and mixed semi-natural woodland was the most common land use in 5 m as well as in 50 m zone along the river and was present at around 50% of the spot checks. In the 50 m zone woodland was absent only at 10 sites, but suburban developments were also present at 75% of the sites. The next most frequent land use along the 5 m zone was improved/semi-improved grassland that was present at 17% of the spot checks. Vast majority of the banks had been vegetated with complex vegetation, especially on the bankfaces (70%) and only 4% of the spot checks were bare. In contrast, vegetation in the channel was scarce, 34% of the spot checks were bare, mosses and filamentous algae were registered at 40% and 32%

respectively. Other vegetation types were present only as an exception. Shading of the channel was frequent; trees on the banks were predominantly continuous, frequently with overhanging boughs. Fallen trees and coarse woody debris in the channel were recorded at 70% and 84% respectively. As features of interest riffles were predominant but pools, natural cascades and boulders bigger than 1 m were also common. Bank reinforcement was the most common modification, and it was present at 23% of the spot checks and mostly the whole bank was reinforced. 3 sites had artificial banks along the whole length of the survey area. Rip rap was the most common bank reinforcement (48%) followed by brick/laid stone and concrete (20%), other materials were scarcer. Channel modifications were rare; reinforcements were present at less than 2% of the spot checks. One of the frequent artificial features was a weir. All together there were 297 of them, but only at 22 sites water was impounded behind them. Bridges were also a common feature and were recorded at 54 sites, all other features were scarcer.

Assessment of the morphological status of sampling sites using indices included in the SI_HM method

Assessment of the morphological quality of sites using indices included in the *SI_HM* methodology gave 33 variables of which 22 were for river habitat quality and 11 for river habitat modification (Tables 8-9). Within the evaluation of river habitat quality features, the highest amount of points was appointed for land use within 5 m of banktop, followed by the stream features predominant flow at spot-check and predominant channel substrate (Table 8). For habitat modification features, the highest amount of points was appointed for channel modifications (Table 9).

Hydromorphological indices included in the SI_HM method

Type specific ranges and median of hydromorphological indices are included in Table 10.

The range of RHQ values was 224 points with the median of 251. The span of RHM values was 106.5 and the span of HLM was 0.42 with only three types where impoundments that met the criterion were present, therefore the value of the medians was mostly 1. Indices HMM and HQM were also relatively high ranging from 0.64 and 0.63 to 1, respectively.

Table 8: Variables for the calculation of the RHQ index (maximum (max), minimum (min), median and sum of points (sum).

Variables of the national methodology (SI_HM)	MAX	MIN	MEDIAN	SUM
Predominant natural bank material	43.0	0.0	20.5	2525.0
Bank features	15.8	0.0	2.9	471.5
Banktop vegetation structure	30.0	9.0	24.0	2926.0
Bankface vegetation structure	30.0	9.0	27.5	3298.0
Unmodified bank profiles	3.0	0.0	1.4	178.0
Exposed bankside roots	1.0	0.0	0.5	63.0
Underwater tree roots	1.0	0.0	0.0	31.0
Fallen trees	1.0	0.0	1.0	88.0
SUM of bank variables	**113.4**	**23.0**	**78.5**	**9580.5**
Predominant channel substrate	52.0	22.0	37.0	4716.0
Predominant flow at spot-check	55.0	10.0	40.5	5000.5
Flow types along 500 m	9.0	2.0	6.0	731.0
Channel features	21.5	0.0	2.0	417.0
Channel vegetation types	155.0	0.0	20.0	2796.0
Coarse woody debris	2.0	0.0	1.0	106.0
Channel chocked with vegetation	1.0	0.0	0.0	1.0
SUM of channel variables	**207.0**	**70.0**	**107.8**	**13767.5**
Land use within 5 m of banktop	80.0	12.0	50.1	6301.0
Extent of trees	5.0	0.0	5.0	570.0
Shading of channel	2.0	0.0	1.0	157.0
Overhanging boughs	2.0	0.0	1.0	136.0
SUM of riparian variables	**89.0**	**14.0**	**57.6**	**7164.0**
Land use features within 50 m of banktop	8.0	0.8	2.8	425.6
SUM of land use variables within 50 m of banktop	**8.0**	**0.8**	**2.8**	**425.6**
Bank and channel features along 500 m	10.0	0.0	3.0	443.0
Features of interest along 500 m	8.0	0.0	2.0	311.0
SUM of variables of interests along 500 m of the river	**15.0**	**0.0**	**6.0**	**754.0**
RHQ	**377.25**	**153.33**	**251.2**	**31925.0**

Table 9: Variables for the calculation of the RHM index (maximum (max), minimum (min), median and sum of points (sum).

Variables of the national methodology (SI_HM)	MAX	MIN	MEDIAN	SUM
Predominant artificial bank material	53.5	0.0	3.0	936.0
Bank modifications	49.5	0.0	6.0	1290.8
Artificial/modified bank profiles	5.0	0.0	2.5	268.9
SUM of bank variables				**2495.6**
Artificial channel material	3.0	0.0	0.0	20.0
Channel modifications	15.0	0.0	0.0	82.0
Dam/weir	44.0	0.0	0.0	297.0
Bridges	11.0	0.0	0.0	128.0
Fords	2.0	0.0	0.0	9.0
Deflectors	3.0	0.0	0.0	5.0
Channel realignments	2.0	0.0	0.0	10.0
Water impounded by weir/dam	2.0	0.0	0.0	23.0
SUM of channel modifications				**574.0**
RHM	**106.5**	**00.0**	**15.5**	**3069.6**

Table 10. Type specific range and a median for hydromorphological indices.

Type	RHQ		RHM		HLM		HMM		HQM	
number*	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median
HM type	153-377	251	0.0-106.5	15.5	0.58-1.00	1.00	0.64-1.00	0.96	0.63-1.00	0.88
1	209-289	258	0.3-57.5	16.0	0.58-0.92	0.88	0.69-0.92	0.85	0.64-0.96	0.78
3	228-270	246	6.5-32.5	14.9	1.00-1.00	1.00	0.92-0.98	0.96	0.85-0.90	0.88
4	156-349	194	0.0-90.5	57.0	1.00-1.00	1.00	0.67-1.00	0.84	0.63-0.98	0.76
6	194-295	239	7.5-36.6	32.8	1.00-1.00	1.00	0.91-0.98	0.92	0.79-0.93	0.84
13	153-312	238	1.0-95.0	15.1	1.00-1.00	1.00	0.68-1.00	0.96	0.63-0.94	0.87
14	192-282	231	11.0-60.0	23.0	1.00-1.00	1.00	0.83-0.97	0.94	0.76-0.91	0.86
15	180-331	227	0.0-98.0	46.9	0.73-1.00	1.00	0.67-1.00	0.84	0.66-0.92	0.80
20	196-323	222	0.0-106.5	15.1	1.00-1.00	1.00	0.64-1.00	0.96	0.66-0.96	0.87
22	173-246	204	10.0-76.5	39.5	1.00-1.00	1.00	0.78-0.98	0.89	0.72-0.88	0.79

* Explanations for national river type numbers are in Table 2, HM type includes all sites.

Testing of reference sites

Comparison of means between RHQ values of reference and impaired sites by one way ANOVA confirmed that RHQ values of reference sites differ from impaired sites (Figure 3). Comparison of means of RHQ scores of reference sites between different national stream types by one way ANOVA revealed that the 22 analysed national river types can be grouped in two hydromorphological river types (Figure 4 and Tables 11, 12). Reference values (median of reference sites) and lower anchors of hydromorphological indices are presented in Table 13.

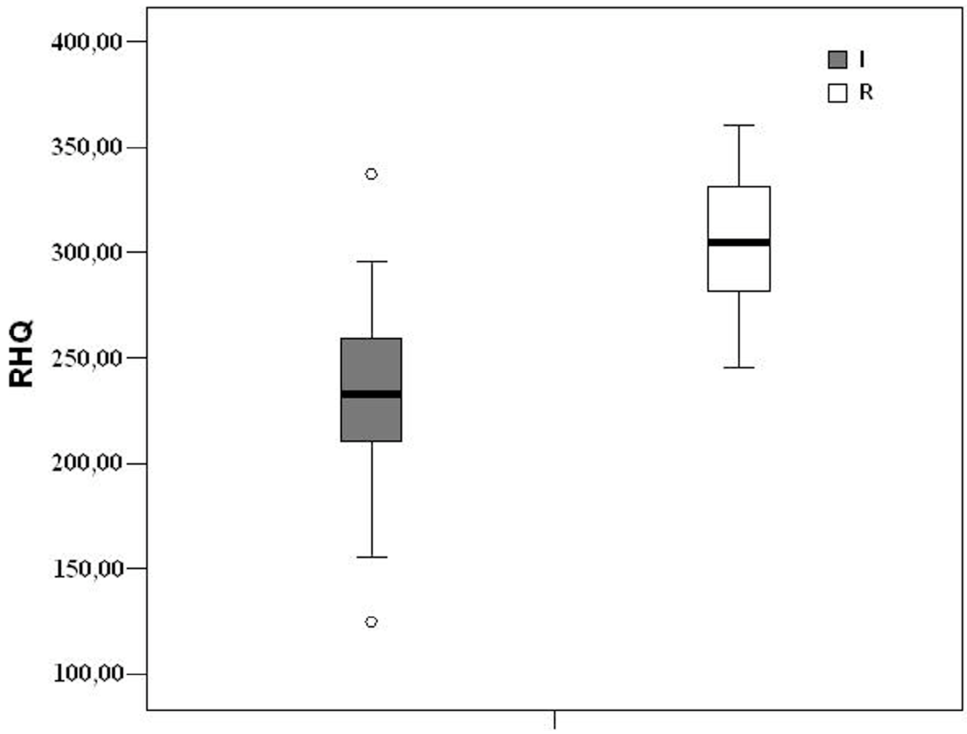

Figure 3. Diagram of quartile spans for the River habitat quality index (RHQ) (I - impaired sites, R - reference sites).

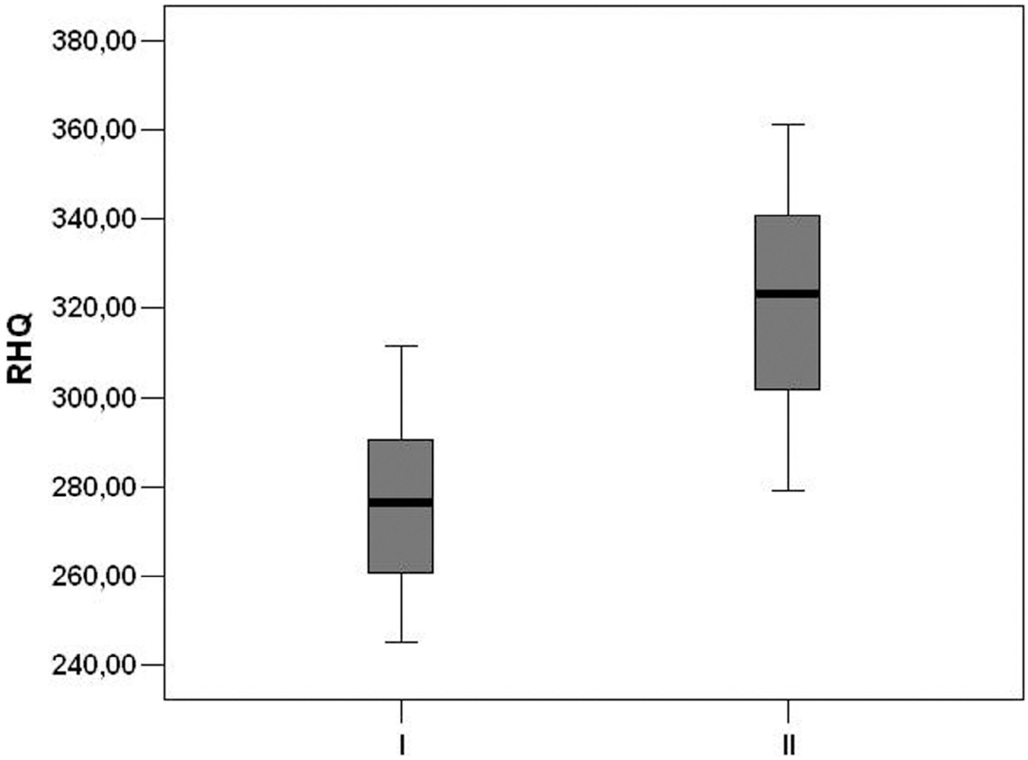

Figure 4. Diagram of quartile spans for the River habitat quality index (RHQ) of the reference sites for the two hydromorphological types.

Table 11. Test of homogeneity of variances of RHQ scores of reference sites between two hydromorphological types.

Levene Statistic	df1	df2	Sig.
0.827	1	32	0.370

Table 12. One way ANOVA analysis of means of RHQ scores of reference sites between two hydromorphological types.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15490.09	1	15490.09	27.45	0.000
Within Groups	18057.78	32	564.31		
Total	33547.87	33			

Table 13. Reference values (median of reference sites) and lower anchors.

	RHQ	RHM	HLM	HMM	HQM
Reference value	304.87	20	1.00	1.00	0.96
Lower anchor	2	229	0	0	0

Biological evaluation of hydromorphological alteration

Sites of different habitat quality were scattered evenly along the NMS axes (Figure 5) and Spearman's rho correlations between hydromorphological variables and NMS axis were low in the case where national types were grouped in the two hydromorphological river types (Table 14). Correlations were higher between hydromorphological variables and NMS axes if separate national river types were considered.

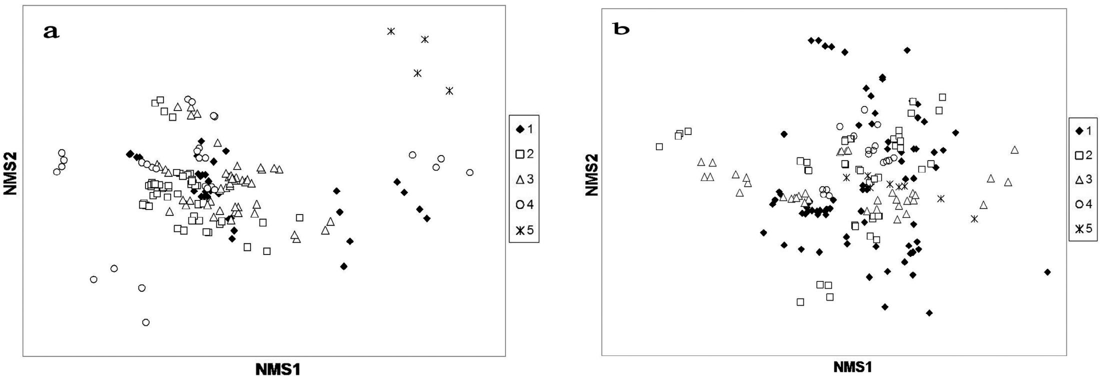

Figure 5. NMS ordination plot of sites belonging to the hydromorphological river type I (a) and II (b). Symbols indicate UK_RHS HMS class.

Table 14. Spearman's rho correlations between hydromorphological variables and NMS axis of the two hydromorphological types (HM) and of each national river types and statistical significance (** <0.01, * p<0.05).

Type number	Type code	RHQ	RHM	HLM	HMM	HQM
	HM type I	-0.30*	0.24	-0.59**	-0.29*	-0.60**
	HM type II	-0.05	-0.01	a	-0.07	0.07
1	V1	0.23	0.80 **	-0.60 *	-0.86 **	-0.72 **
3	KBD1>	-0.05	0.82 **	a	-0.79 **	-0.47 *
4	KBD1KI	0.66 **	-0.71 **	a	0.71 **	0.73 **
6	KBD2	-0.90 **	0.86 **	a	-0.89 **	-0.91 **
13	PAD1	-0.02	0.61 **	a	-0.62 **	-0.47 **
14	PAD1KI	0.94 **	0.81 **	a	-0.84 **	-0.80 **
15	PAD2	-0.09	-0.55 **	0.55 **	0.85 **	0.87 **
20	SIAL1	-0.83 **	0.22	a	-0.21	-0.60 *
22	SIAL2	-0.89 **	0.83 **	a	-0.84 **	-0.85 **

a - could not be computed because at least one of the variables was constant.

DISCUSSION

Development of a methodology for the assessment of hydromorphological status of rivers was the main objective of this study. Firstly hydromorphological properties of rivers were surveyed followed by the development of different indices for the evaluation of hydromorphological status using modified RHS_SI variables. Due to the varied geomorphologic and ecologic conditions in the considered ecoregion Alps the selected sites belonged to numerous river types (22). Nevertheless, they possessed typical hydromorphological characteristics of alpine streams related to high energy flows (Szoszkiewicz *et al.* 2006). For benthic invertebrate communities not only the local conditions in the channel are important but also the conditions of the riparian and surrounding areas (Giller and Malmquist 1998, Bis and Hauer 2001, Sponseller *et al.* 2001). There are different opinions on the spatial scale at which the parameters that are decisive for the benthic invertebrate communities should be assessed. For the analysis the sites were grouped according to the national river types so that they did not differ in the catchment-related variables. The difference was at the small scale-site related hydromorphological variables.

The RHS protocol (Raven *et al.* 1998, Environment Agency 2003) was used for the survey of morphological properties as the RHS method has previously been proven to be useful for the evaluation of ecological status, although the need for some refinements was suggested (Erba *et al.* 2006, Tavzes *et al.* 2006, Tavzes 2006). Evaluation of habitat quality by the RHS method named Habitat Quality Assessment (HQA) considers only the variability of morphological features. While developing the SI_HM methodology we were of the opinion that also the type of recorded features is important as different habitat conditions support different ecological structure (Beisel *et al.* 1998, Giller and Malmquist 1998, Matthaei and Townsend 2000, Urbanic and Toman 2007). Therefore we developed SI_HM variables by adding values to different types of features. and combined them in the River habitat quality index (RHQ). Similarly, the evaluation of habitat modification by the RHS method (Raven *et al.* 1998) named Habitat Modification Score (HMS) considers only the presence of artificial morphological features. In our approach, different values were appointed also to artificial morphological river features, since not all artificial features have the same impact on organisms. Instead of Habitat Modification Score (HMS) used in RHS, river habitat modification index (RHM) was developed. Besides these two indices for evaluation of morphological status, three additional indices were developed. For the assessment of hydrological status we considered the presence of major impoundments on the main channel as well as on tributaries upstream of the site. Hydrological status of a site was expressed by the value of the hydrological modification index (HLM). Water impoundments have a great influence on river communities upstream and downstream of the impoundment (Lorenz *et al.* 2004, Bunn and Arthington, 2002, FISRWG 2001). We took into consideration the influence along the whole length of the impoundment and downstream influences as we wanted to asses hydrological changes due to the changes in water flow dynamics. Only two considered national types (SI_V1 and SI_4_PA-hrib-D_2) had major impoundments present and consequently the value of the HLM differed from 1. Correlations between NMS axes and HLM were significant (Table 14) which confirmed that there is a relation between HLM and benthic invertebrate composition. As benthic communities are influenced by combination of morphological and hydrological effects a multimetric hydromorphological modification index (HMM) was developed. The new index was developed as a combination of River habitat modification index (RHM) and Hydrological modification index (HLM). The calculations were developed in a way that the type of modification which is worse was given a higher weight as this is the one that has a prevailing influence on benthic invertebrate community at a given site. In this way we also regulated the assessed modification so that if one type of modification was not present we did not get false positive results. Correlations between NMS axes and HMM for single national river types (Table 14) confirmed the appropriateness of these calculations as correlations are higher when multimetric HMM is used in comparison to correlations with RHM or HLM. Another multimetric index, hydromorphological quality and modification index (HQM) was developed, which combines morphological habitat quality (RHQ) and modification (RHM) as well as hydrological modification (HLM). The idea of prevalence of the worse variable is maintained but for the morphological conditions both habitat quality and habitat modifications status are considered equally and for the final evaluation of the hydromorphological status they are combined with the value of HLM. National river types where impoundments were present did not have a significant correlation between RHQ and NMS axes. With addition of assessment of hydrological status (HLM) in the multimetric index (HQM), correlations became significant and stronger. Similar rise was observed in cases where correlations between RHM and NMS axes were low. Correlations between NMS axes and HQM are a best balance between all three indices and HQM can be used for the evaluation of general hydromorphological status which reflects conditions to which benthic invertebrate communities respond.

On the basis of hydromorphological properties (RHQ index), different national river types were grouped in two hydromorphological types (Fig. 3). RHQ index was selected as it was the only one composed of only natural features that determine properties of rivers. However, corresponding benthic invertebrate communities did not confirm grouping of national types in two hydromorphological types as there was no grouping of sites from certain hydromorphological type along the NMS ordination. This indicates that habitat diversity is less important than other ecological factors used for river typology (Urbanic 2007). Moreover, also correlations between NMS axes and the developed indices (RHQ, RHM, HLM, HMM, HQM) were higher in the case where single national river types were considered than in the case where hydromorphological types were considered. High correlations between hydromorphological indices and NMS axes considering separate national river types confirm that SI_HM method and its indices developed in this study are appropriate for the evaluation of hydromorphological status of rivers in the ecoregion Alps. Moreover, the developed hydromorphological indices can be used for developing a multimetric index for the assessment of the impact of hydromorphological alteration on benthic invertebrates

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