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Hydromorphological assessment as a tool for river basin management: The German field survey method

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Abstract

Physical habitat characteristics are of great importance for the ecological integrity of rivers and creeks. The assessment of these hydromorphological qualities is a fundamental component of sustainable river basin management and ecologically oriented river development.
This paper describes the German field survey method for hydromorphological assessement of streams and points at its potential as a tool for river basin management. We present examples for the application of the method at different management scales: analyzing the overall hydromorphological state at the river basin scale, describing specific hydromorphological characteristics at the river reach scale and monitoring the success of restoration projects at the river segment scale.
We show that the German field survey method proved to be an easy-to-apply and efficient tool for river basin management since its introduction in the year 2000. Beside the method's potentials also several drawbacks have to be considered regarding its application in other regions of the world.

Introduction

The assessment of river ecosystems is gaining importance worldwide. Alone in the countries which implement the European Water Framework Directive (EC 2000) about 300 different biological stream assessment methods are in use (Birk et al. 2012). The evaluation of the ecological status of rivers based on biological indicators also plays an increasingly important role in other parts of the world (Thorne et al. 1997; Gerson Araujo et al. 2003; Bozzetti and Schulz 2004; Haase and Nolte 2008; Moya et al. 2011; Couceiro et al. 2012).

The question of whether or to what extent the state of a stream can be described as natural or unnatural, however, cannot be answered solely on biocenotic-taxonomic interpretations of biological indicators such as benthic invertebrates and fish. The use of these bioindicators has to take into account the hydromorphological characteristics of the watercourse under consideration in order to validate the interpretation of the biological sampling results. A comprehensive evaluation of ecological stream quality must therefore always include a hydromorphological assessment based on natural reference conditions. Only in this way the information obtained from biological monitoring can be interpreted correctly to recognize ecological deficits and target improvements (Verdonschot et al. 2012). Therefore, methods that characterize the hydromorpology of rivers and assess river habitat quality are becoming increasingly important as an element of decision-making in river basin management (Raven et al. 2002).

Several methods for characterizing the physical structure of rivers and assessing habitat quality have been developed since the early 1990s and described in several reviews (Raven et al. 2002; Balestrini et al. 2004; Kondolf and Piégay 2005; Davy-Bowker and Furse 2006; Kamp et al. 2007; Šípek et al. 2010; Ilnicki et al. 2010; Scheifhacken et al. 2012). However, no detailed description of the German field survey method in terms of validity, applicability, monitoring capacity and potential for the usage outside its designated geographical region is given so far.

This paper describes the German field survey method for hydromorphological assessment of streams (Zumbroich 2008). We applied this method assessing 931 km of streams and creeks in the Rur River Basin in the Western German. The potential of the method as a tool for river basin management is presented by three examples: analyzing the overall hydromorphological state at the river basin scale, describing specific hydromorphological characteristics at the river reach scale and monitoring the success of restoration projects at the river segment scale. Furthermore, the applicability of the method is evaluated by interviewing 36 members of the Rur river basin mapping campaign.

Materials and Methods

Research area

The German field survey method was applied in the Rur River Basin which is located mainly in the German state of North Rhine-Westphalia sharing small parts with the Netherlands and Belgium (Figure 1). The river basin covers an area of 2340 km² and contains approximately 2500 km of rivers and creeks. The main Rur River bridges a height difference along its 165 km course of 643 m, with its source located at 660 m.a.s.l. and its mouth at 17 m.a.s.l. The average annual rainfall is 855 mm. In the southern highland regions an annual rainfall of up to 1560 mm is possible (MUNLV 2009). The study area is dominated by rural land use types (grassland, forest and cropland) with the exception of several urban areas (approx. 10 % of the total area).

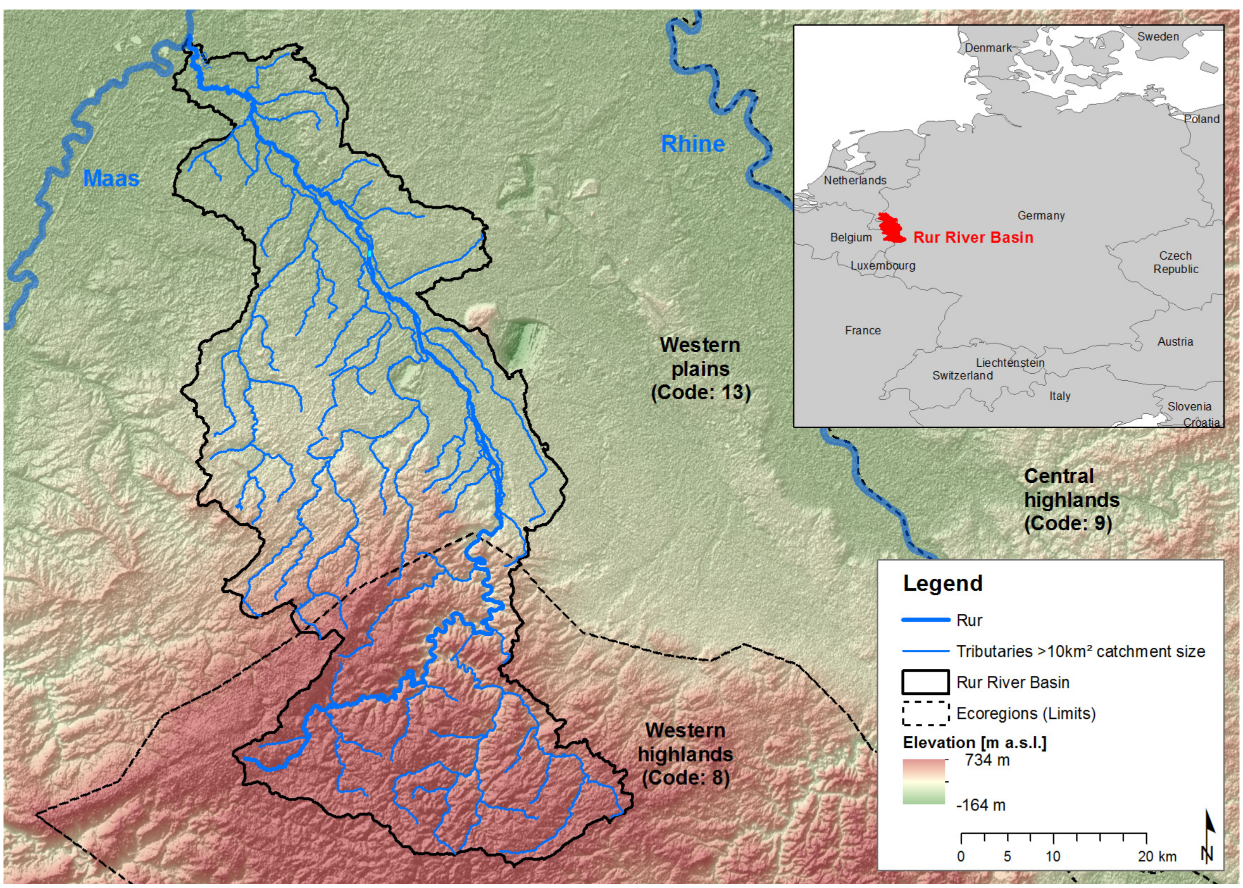

Figure 1. Research area – The Rur River basin

This river basin was chosen for this study due to its great variability of river types. The Rur River basin takes part in two ecoregions according to Illies (Illies 1978; Hering et al. 2004) – the Western plains (Ecoregion 13) and the Western highlands (Ecoregion 8). The ecoregion approach serves as a basis to define 28 different German river types (Pottgiesser and Sommerhäuser 2008) of which ten can be found in the Rur River basin (Table 1).

The stream types of the Western plains are characterized by meandering planform, no pronounced valley forms and sandy river bed substrate with a high share of organic material. The stream types of the Western highlands are characterized by V- and U-shaped valleys, low sinuosity and high substrate diversity composed of sand, gravel, rocks and dead wood.

Table 1. Occurrence and share of stream types in the research area.

Ecoregion	Stream type	Water bodies	Length (km)	Share of overall length (%)
Western plains	Small loess-loam-bottom streams in the lowlands	20	146	16
	Small streams in floodplains	19	123	13
	Mid-sized to large gravel-bottom streams in the lowlands	6	73	8
	Small gravel-bottom streams in the lowlands	11	43	5
	Small sand-bottom streams in the lowlands	4	25	3
	Small streams with organic substrates	4	18	2
	Small siliceous sandstone streams	4	14	1
Western highlands	Small siliceous cobble-bottom streams in lower-mountainous areas	49	334	36
	Mid-sized siliceous cobble/boulder bottom streams in lower mountainous areas	14	134	14
	Small cobble-bottom streams in calcareous lower mountainous areas	4	23	2
	Overall sum	**135**	**931**	**100**

The herein presented work focuses on the German part of the river basin covering 2085 km^2 (91 % of the total area). Only those streams were considered in this study, which comprise a catchment area of at least 10 km^2. Catchments with this minimum size represent the basic management units according to the European Water Framework Directive. Therefore 931 km of rivers and creeks of the Rur River Basin were assessed by using the German field survey method (approximately 37 % of the river basin's streams).

German field survey method for hydromorphological assessment of streams

The German field survey method assesses the structural quality of streams and serves as the basis for local to regional river maintenance and development (LAWA 2000). The streams are assessed over their full length, dividing them into segments. The segment length is determined by the channel width (e.g. a 100 m length is used for a river up to 20 m wide; 500m-segments for a river wider than 20 m) (Scheifhacken et al. 2012). The determination a segment's hydromorphological quality is based on 25 parameters, which are assessed by visual inspection (Table 2). For each parameter, the observed state is determined using a series of options: for example, *low* and *very high* are two of five options for describing flow diversity.

The 25 single parameters are stepwise aggregated into six main parameters, which are further aggregated into river sections (river bed, river banks and floodplain) and a final overall score resp. class. This aggregation is based on simple mean value calculation.

The plausibility of the field results is tested by a cross-check using index-based and functional unit approaches (Figure 1). Deviations between the computed index-based scores from the single parameters and the functional units derived from expert opinion are corrected and thereby the assessment quality is assured (Raven et al. 2002).

Table 2. The 25 single parameters of the German field survey method and their aggregation into main parameters and river sections.

River section	Main parameter	Code	Single parameter
River bed	1 - Planform	1-1	Sinuosity
		1-2	Erosion at bends
		1-3	Bars
		1-4	Special features (indicating natural channel dynamics, e.g. large wood, islands, widening)
	2 - Longitudinal profile	2-1	Artificial barriers (limiting continuity of flow, sediment and migration for biota, e.g. weirs)
		2-2	Artificial impoundments
		2-3	Culverts
		2-4	Riffles and steps
		2-5	Flow-diversity
		2-6	Depth-variability
	3 - River bed structure	3-1	Dominant substrate
		3-2	Bed-fixation
		3-3	Substrate-diversity
		3-4	Bed features (e.g. scour and backwater pools, rapids, cascades)
River banks	4 - Cross-section	4-1	Cross-section form
		4-2	Cross-section depth
		4-3	Bank erosion
		4-4	Cross-section width variability
		4-5	Bridges
	5 - River banks structure	5-1	Riparian vegetation
		5-2	Revetment/Bank protection
		5-3	Bank features
Floodplain	6 - Floodplain	6-1	Land-use
		6-2	Riparian buffer-strip
		6-3	Impeding features

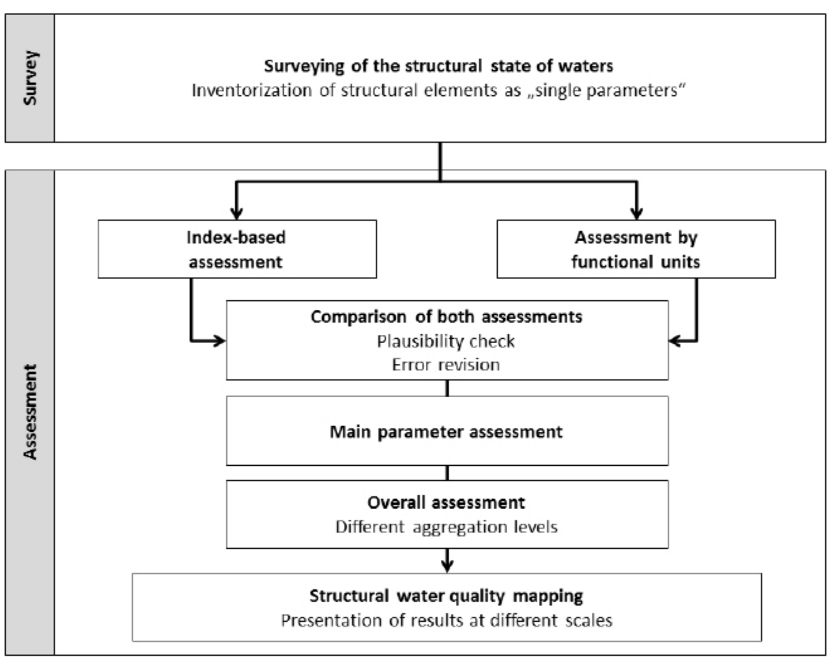

Figure 2. Workflow of the German field survey method (LAWA 2000); modified.

The hydromorphological assessment is calibrated against a hypothetic natural or near-natural reference state of the above mentioned river types (Šípek et al. 2010). Therefore, a pre-requisite for the survey is to define the potential natural condition of a river as the basis for the hydromorphological quality assessment (Kamp et al. 2007). The final assessment comprises a seven-band classification ranging from 'unchanged' to 'completely changed' (Table 3).

Analyzing the hydromorphological state at different spatial scales

The overall hydromorphological state is analyzed for the entire the Rur River Basin. After scoring the overall assessment of each stream segment according to Table 3, the results were grouped into different regional subsets and compared with each other (Rur River vs. tributaries, Western Plains streams vs. Western Highlands streams). The potential difference regarding the hydromorphological quality of these subsets was determined by non-parametric Mann-Whitney-Test with a statistically significant level set at $p < 0.05$ in the Section *Assessment results at different aggregation levels and spatial scales*.
The method's capability for detecting specific hydromorphological potentials and deficits is given on the river reach scale. As an example the assessment results of the main parameter River Bed Structure and the single parameter Riparian Buffer-Strip for the Rur River are presented in Section *Assessment results at different aggregation levels and spatial scales*.
A detailed analysis of the 25 single parameters is demonstrated for three 500m-segments of the Rur River (one restored segment and one up- and downstream of the restoration, respectively) in Section *Assessment results at different aggregation levels and spatial scales*. The monitoring capacity of the method is tested by comparing the results with former assessments of the restored stream segment. The restoration effects were analyzed based on the differences in hydromorphological quality before and after the restoration.

Evaluation of the method's applicability

We conducted interviews with 36 experienced staff-members of the mapping campaign using a standardized ordinal-polytomous questionnaire (Oppenheim 2000) with a five-step verbal rating scale (Table 6). All participants hold at least a Bachelor degree in Geography. The question of interest for this study was: 'How do you rate the applicability of the single parameters of the German field survey?'. In this case the applicability signifies the assessability of the hydromorphological element or process, which is represented by each parameter and has to be observed and evaluated in the field (e. g. bank erosion). We analyzed the results by calculating the percentage of the campaign members answers for each single parameter.

Table 3. Scores and classes of the German field survey method for river habitat monitoring and assessment. The final scoring index is the result of mean value calculation of the single parameters.

Final scoring index	1.0-1.7	1.8-2.6	2.7-3.5	3.6-4.4	4.5-5.3	5.4-6.2	6.3-7.0
Final class	1	2	3	4	5	6	7
Description	Unchanged (natural)	Slightly changed	Moderately changed	Distinctly changed	Obviously changed	Strongly changed	Completely changed

Table 4. Standardized answers of the questionnaire regarding the assessment difficulties of the 25 single parameters of the German field survey method.

Standardized answer	Description
Very easy	The assessment of the parameter is feasible without any difficulty in all cases.
Easy	The assessment is problematic only in exceptional cases.
Intermediate difficulty	The assessment is problematic in some cases.
Difficult	The assessment is often problematic.
Very difficult	The assessment is always problematic.

Results

Assessment results at different aggregation levels and spatial scales

River basin scale

According to Figure 3 the overall hydromorphological quality (final class according to Table 3) of the main Rur River shows to be significantly better than the hydromorphological quality of its tributaries (MEDIAN Rur River = 4.1, MED Tributaries = 4.7, $p < 0.001$). The overall hydromorphological quality inside the Ecoregion Western Highlands shows to be significantly better than the hydromorphological quality inside the Ecoregion Western Plains (MED Western Mountains = 4.0, MED Western Plains = 5.4, $p < 0.001$). This draws the attention regarding restoration efforts towards the tributaries of the Western Plains.

By looking further into the different river sections (river bed, river bank and floodplains) and their hydromorphological quality the restoration focus in consequence is on the river banks of tributaries in the Western Plains and the floodplains of tributaries in both the Western Plains and the Western Mountains (Table 5). Also the river bed of the Rur River and its tributaries inside the Western Plains should be taken into consideration for restoration.

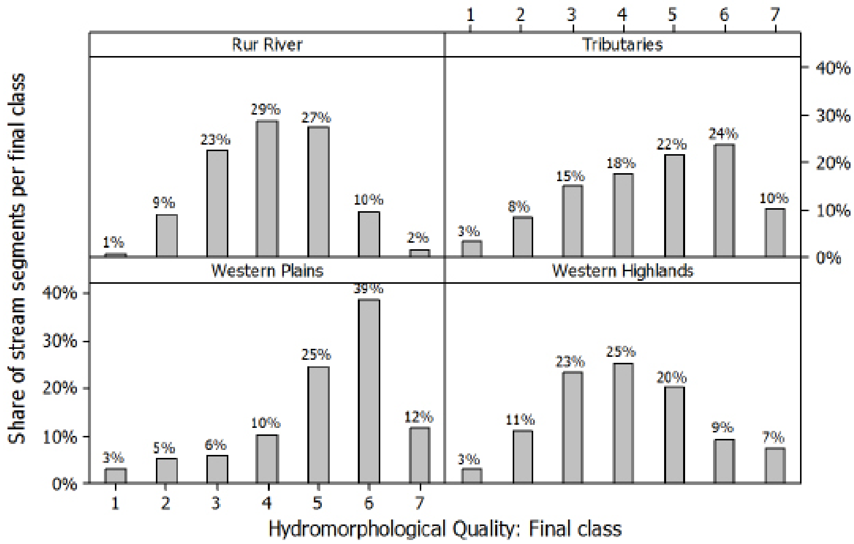

Figure 3. Comparison of the overall hydromorphological quality inside regional subsets. The upper two histograms show the differences of hydromorphological quality by aggregating the water bodies qualities into main Rur River and its tributaries respectively. The two histograms below aggregate the same water bodies according to their ecoregion classification.

Table 5. Comparison of the hydromorphological quality inside regional subsets (Main river vs. tributaries; ecoregion Western plains vs. ecoregion Western mountains) and regading different river sections. (** indicates a significant difference at p <0.001; * indicates a significant difference at p <0.05).

Subset	River bed [MED]	River banks [MED]	Floodplains [MED]
Rur River	4.0*	3.8**	4.0**
Tributaries	4.3*	4.8**	5.5**
p-value	0.04	<0.001	<0.001
Subset	**River bed [MED]**	**River banks [MED]**	**Floodplains [MED]**
Western plains	5.3**	5.5**	5.5**
Western mountains	3.3**	3.5**	5.0**
p-value	<0.001	<0.001	<0.001

River reach scale

At the river reach scale specific river basin management can be handled, such as:

Good habitat characteristics for benthic invertebrates and fish provided by river bed: selection of stream segments with unchanged, slightly changed or moderately changed river bed structure (Assessment class of the main parameter River bed structure ≤ 3).

Riparian buffer strips missing or not fulfilling certain requirements regarding width and vegetation composition: selection of segments with distinctly to completely changed buffer strips (Assessment class of single parameter Riparian buffer strip > 3)

In the case of the Rur River improving river bed structures (e.g. installation of fixed large dead wood) and riparian buffer strip conditions (e.g. land use conversion and reforestation) should be focused in the lower and middle reach (Figure 4).

River segment scale

At the river segment level the hydromorphological differences represented by river beds, river banks and floodplains can be clearly observed in Figure 5. The 5-band representation of provides a straight-forward evaluation of single stream segments and their hydromorphological qualities inside the river bed, river banks and floodplains. It also enables a fast comparison of adjacent segments. In Figure 4 for example, clear differences in all sections can be observed for the segment 458 and its adjacent segments up- and downstream.

The analysis of the single parameters show that the three segments mainly differ in terms of sinuosity, flow-diversity, depth-variability, cross-section variability and the characteristics of the riparian vegetation and nearby land use (Table 6).

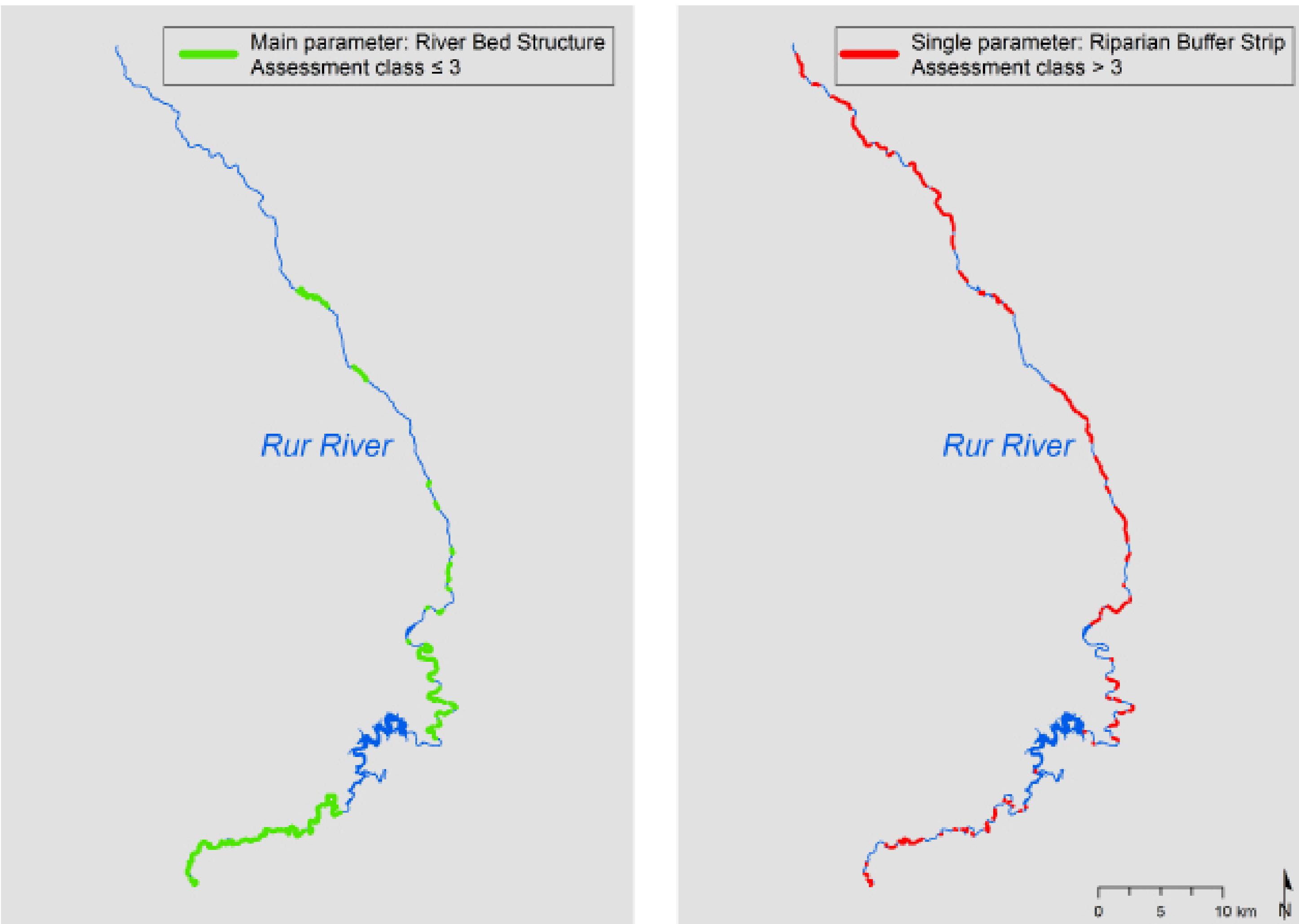

Figure 4. Analysis of the assessment results regarding specific river basin management issues. The colors in this case do not represent assessment classes. They illustrate hydromorphological potentials (green) and deficits (red).

The method can also be used for a rapid monitoring of restoration success in terms of hydromorphological alteration. The segment 458 of the Rur River was assessed using the German field method before its restoration in 2001 and eleven years later in 2012 (Figure 5 and Table 7). The hydromorphological improvement can clearly be identified for all main parameters.

However, for a detailed comparison of a 'before-after restoration' habitat quality taking into account species-specific ecological requirements, high-resolution assessment methods have to be applied (Harby et al. 2005; Mouton et al. 2007; Parasiewics and Walker 2007).

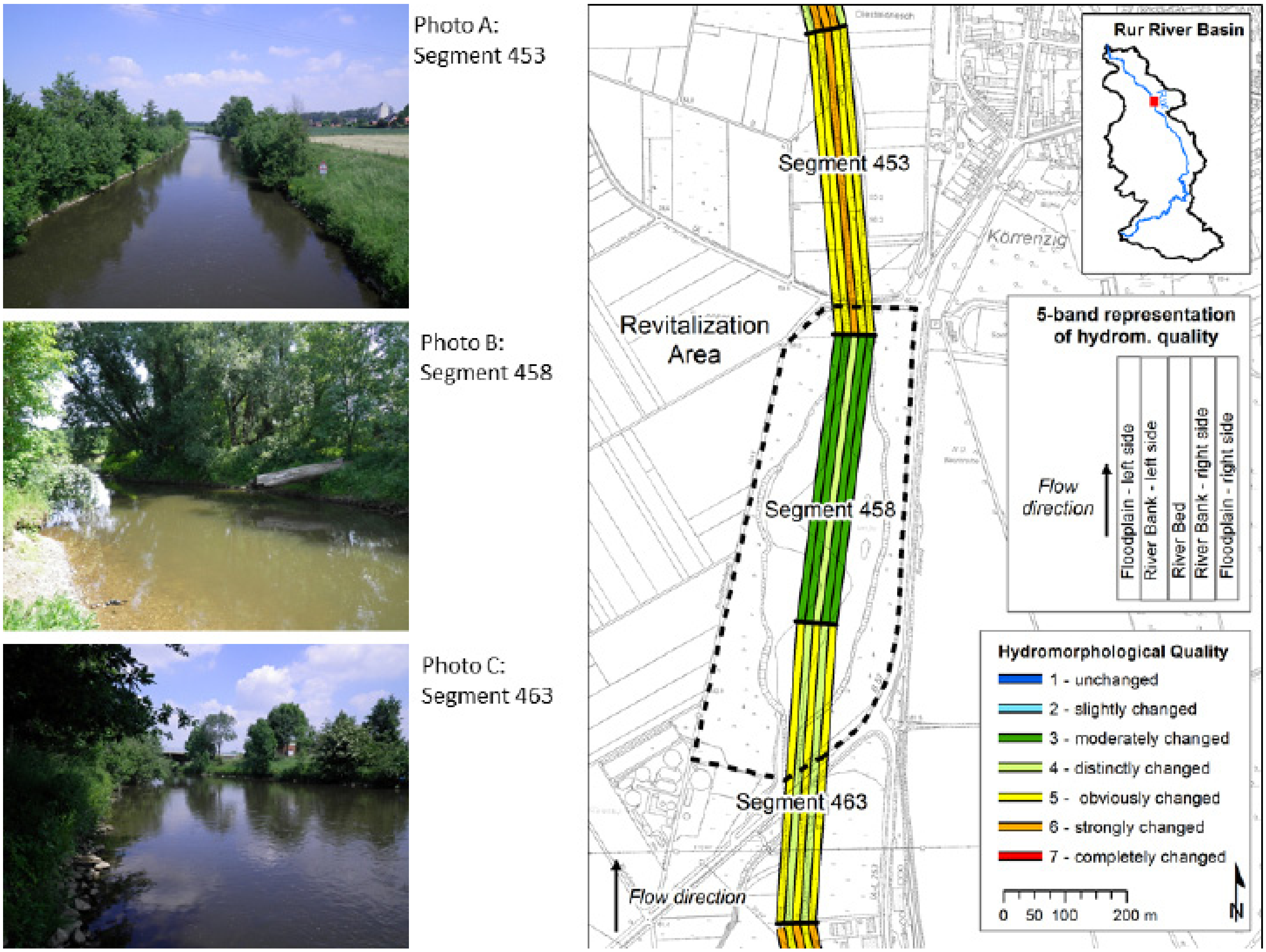

Figure 5. Spatial comparison of a restored segment (ID = 458) with segments upstream (ID = 463) and downstream (ID = 453) using a 5-band representation of the hydromorphological quality (river bed, river banks left/right, floodplains left/right).

Parameter applicability

The 36 members of the mapping campaign evaluated none of the 25 single parameters as *very difficult to assess.*

The parameters sinuosity, special features, substrate diversity, bridges, land use and impeding features where evaluated as *intermediate difficult* or *difficult* by less than 10% of the campaign's staff (light grey bars in Figure 5). With exception of the parameter substrate diversity these parameters are easy to detect in almost all situations.

More than half of the 25 parameters where evaluated as *intermediate difficult* or *difficult* to assess by 10-50 % of the campaign's staff (dark grey bars in Figure 5). Especially parameters related to the stream bed and stream bank cause some problems (erosion, bars, riffles and steps, bed fixation, bed features). These features are hard to detect in case of high turbidity, increased discharge and overgrown vegetation along the river banks. The problems caused by the identification of the riparian vegetation lies in the insufficient botanical skills of the staff – according to individual interviews with the members of the mapping campaign.

Six parameters (culverts, dominant substrate, cross-section form, cross-section depth, revetment/bank protection, riparian buffer-strip) were evaluated as *intermediate difficult* or *difficult* to assess by 50 % or more of the campaign's staff (black bars in Figure 5). The description and assessment of anthropogenic structures like culverts is carried out by taking into account several technical parameters. Mapping staff with a geographic background sometimes lack of the necessary hydro-engineering knowledge. The assessment of the dominant substrate is often impeded by low visibility due to water turbidity. The comparison of anthropogenic altered cross-section form and -depth with the corresponding reference conditions has shown to be one of the most difficult assessment aspects. According to individual interviews this is due to the insufficient instruction in the user manual. The difficulties of detecting bank protection and delineating riparian buffer strips lay in the seasonal vegetation overgrowth.

Table 6. Single parameter comparison of three 500m-segments (restored segment = ID 458, upstream segment = ID 463, downstream segment = 453).

Single Parameters	Segment 463	Segment 458	Segment 453
1-1 Sinuosity	low	moderate	low
1-2 Erosion at bends	none	little	little
1-3 Bars	1-2	1-2	1-2
1-4 Special features	none	1 (island)	1 (island)
2-1 Artificial barriers	glide	none	none
2-2 Artificial impoundments	>100 - 250 m	>100 - 250 m	none
2-3 Culverts	none	none	none
2-4 Riffles and steps	none	none	none
2-5 Flow-diversity	low	moderate	low
2-6 Depth-variability	low	moderate	low
3-1 Dominant substrate	dominant: gravel subordinated: sand, silt organic: none	dominant: gravel subordinated: sand, silt organic: dead wood	dominant: gravel subordinated: sand, silt organic: dead wood
3-2 Bed-fixation	none	none	none
3-3 Substrate-diversity	low	moderate	moderate
3-4 Bed features	1	2	1
4-1 Cross-section form	artificial	near-natural	artificial
4-2 Cross-section depth	deep	moderately deep	moderately deep
4-3 Bank erosion	none	little	little
4-4 Cross-section width variability	none	high	moderate
4-5 Bridges	1	none	1
5-1 Riparian vegetation	left and right: single trees	left and right: forest	left and right: single trees
5-2 Revetment/Bank protection	left and right: reinforced with stones (500m)	left: none (250 - 500 m), reinforced with stones (50 - 100 m) right: none (250 - 500 m),reinforced with stones (100 - 250 m)	left: none (250 - 500 m), reinforced with stones (50 - 100 m) right: none (250 - 500 m),reinforced with stones (100 - 250 m)
5-3 Bank features	none	left: 3 (dead wood) right: 3 (dead wood)	left: 1 (dead wood) right: 1 (dead wood)
6-1 Land-use	left: grassland (>50%) right: cropland (>50%), grassland (10-50%)	left: forest (>50%); grassland, cropland, impeding features (10-50%) right: grassland (>50%); forest, cropland, impeding features (10-50%)	left: grassland (>50%); forest, cropland, impeding features (10-50%) right: grassland (>50%); forest, cropland, impeding features, urban areas (10-50%)
6-2 Riparian buffer-strip	left and right: narrow buffer strip (500m)	left: broad buffer strip (500m) right: forest (500m)	left: broad buffer strip (250 - 500m), none (100 - 250m), narrow buffer strip (100 - 250m) , forest (50 - 100m) right: broad buffer strip (250 - 500m), none (50 - 100m), narrow buffer strip (50 - 100m), forest (50 - 100m)
6-3 Impeding features	none	left: streets (medium distance) right: streets (large distance)	left and right: streets (medium distance)

Table 7. Temporal comparison of the hydromorphological quality before and after restoration at the River Rur segment 458.

Main Parameters	Survey 2001	Survey 2012	Improvement (classes)
1 - Planform	6	4	2
2 - Longitudinal Profile	7	5	2
3 - River bed structure	5	4	1
4 - Cross-section	5	3	2
5 - River banks structure	5	3	2
6 - Floodplain	5	3	2
Final classification	**6**	**4**	**2**

Figure 6. Aerial photographs of the Rur River segment 458 before restoration in 2001 (left) and after restoration in 2012 (right). Source: Eifel-Rur Water Association.

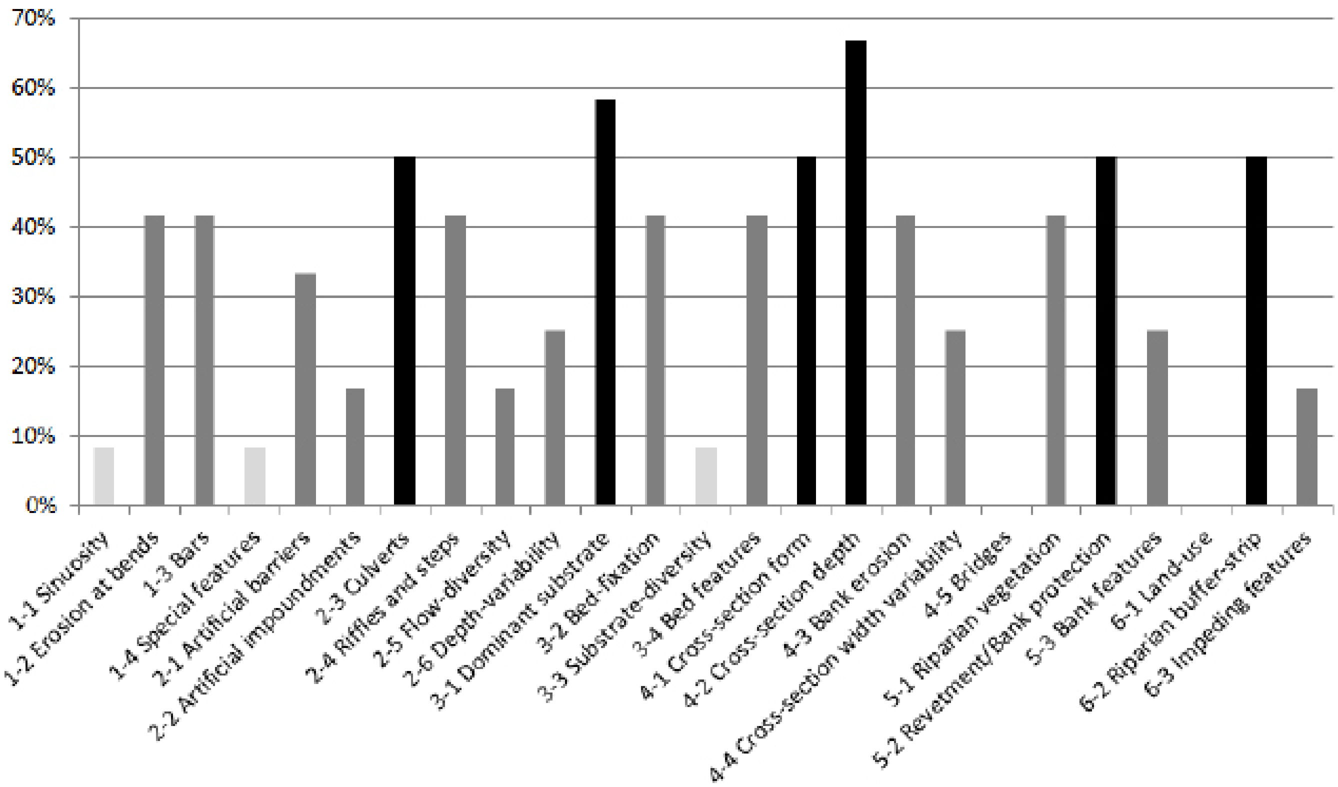

Figure 7. Combined percentage of the campaign members (n = 36) evaluating the assessment of the respective parameters as intermediate difficult or difficult (light grey bars: 0 – 10 % of campaign's members; dark grey bars: >10 % - <50 %; black bars: ≥50 %).

Discussion

In recent years the German field survey method for hydromorphological assessement has produced a most valuable primary data set on the morphological state of German streams. It has shown deficits (UBA 2010), provided strategic planning (LANUV 2011) and initiated many restoration projects (WVER 2009). Furthermore, it is accepted by the public and has found its way into the classrooms. The method is an easy-to-learn and easy-to-use tool for river basin management. The mapping campaign in the Rur River basin showed that professionals with a geographic background can apply the method after a one-week crash course.

The standardized assessment of 100m- or 500m-segments guarantees a consistent spatial and temporal comparison of river segments. The evaluation of 25 single parameters provides a sound basis for a wide range of specific scientific and management-related issues (e.g. long-term and restoration monitoring, hydromorphological deficit analysis, planning and prioritizing of restoration measures, comparative analysis of habitat quality and biological quality elements). Furthermore, the possibility to aggregate single parameter into main parameters and river sections (river bed, river banks and floodplains) allows a fast and straight-forward hydromorphological analysis of river segments, reaches and networks. Last but not least, the method is characterized by a high cost-benefit-balance: up to five kilometers (data preparation, mapping, post-processing) can be assessed per day.

However, for a convenient application in different geographical regions some limitations and specificities have to be addressed. For customized and optimized applications the following modifications are recommended: The strict 100m- resp. 500m-segment approach may mask high-value or low-value river reaches (see also Figure 4). A flexible definition of segment length may improve the realistic assessment of hydromorphological qualities along streams. In cases of long, hydromorphologically homogeneous stream sections (e.g. heavily modified or completely natural sections) a strict division into pre-defined segment lengths is not effective. In such cases a flexible division into homogeneous sections with varying lengths may be appropriate. Several of the 25 single parameters provide redundant information (e. g. depth-variability and flow-diversity, riffles/steps and bed features). A flexible set of the parameters for different purposes (e.g. overview assessment of entire rivers, detailed analysis of specific river segements) may improve the method's efficiency. The access to rivers along their entire length – as required for the German survey method – is sometimes limited in other geographical regions. A combined approach of an overview survey using remote sensing techniques with detailed spot-checks in the field may overcome this issue. A major prerequisite for the application of this method is the definition of specific river types with a detailed description of reference states. Only with such a basis sound and consistent evaluation of hydromorphological deficits can be identified correctly and actions can be targeted towards an improvement of eco-morphological stream conditions.

The authors of this paper currently work on the adaption of the method to different geographical regions.

Conclusion

In this study, we pointed out the potentials of the German field survey method for hydromorphological quality assessment. The method showed to produce valuable information about the hydromorphological conditions of rivers and creeks at different spatial and thematical scales. On the one hand overview maps of the hydromorphological state within entire river basins can be produced and on the other hand detailed questions about hydromorphological meso-habitat issues can be addressed.

The herein presented method provides a cost-effective approach for sound ecological river development. Its results should therefore be considered in river restoration planning to improve the ecological integrity of streams in their entirety. However, specific issues such as the method`s applicability in different geographical regions address a need for further research.

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