INTEGRATING HYDROMORPHOLOGICAL DATA INTO THE ASSESSMENT OF RIVER ECOSYSTEM SERVICES

DOI:
UDC: 556.5.04:551.4(437.3)

Ján Babej[1]
Jiří Jakubínský[1]
Žaneta Straňáková[1]
Ana M. Petrović[2]
Tomáš Galia[3]
Veronika Kalníková[4]
Valentina Nikolova[5]
Martin Pavel[6]
Stanislav Ruman[3]
Jiří Schneider[7]

[1]Global Change Research Institute, The Czech Academy of Sciences, 603 0 Brno, **Czech Republic**;
[2]Geographical Institute "Jovan Cvijić" of the Serbian Academy of Sciences and Arts, 11000 Belgrade, **Serbia**;
[3]Department of Physical Geography and Geoecology, University of Ostrava, Chittussiho 10, 71000 Ostrava, **Czech Republic**;
[4]Nature Conservation Agency of the Czech Republic, Kaplanova 1931/1, 14800 Prague, **Czech Republic**;
[5]Department of Geology and Geoinformatics, University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, **Bulgaria**;
[6]Sterplan a.s., Pod dráhou 1637/4, 170 00 Prague, **Czech Republic**;
[7]Department of Environmentalistic and Natural Resouces; Faculty of Regional Development and International Studies, Mendel University in Brno, Tř. Generála Píky 2005/7, 61300 Brno, **Czech Republic**;

ABSTRACT

EU Member States monitor, in accordance with the Water Framework Directive (WFD, 2000/60/EC), the quality elements of water bodies, which subsequently inform the development of river basin management plans. Building on the EU Biodiversity Strategy 2030, there is growing recognition of how rivers contribute to ecosystem service provision and how management measures may influence these benefits. Given the time and resource demands of collecting environmental data, it is increasingly important to explore whether existing monitoring data can support estimates of ecosystem service provision and, at the same time, enable the identification of ecologically valuable and degraded river reaches. This study examines the potential of hydromorphological monitoring data collected under the Czech HYMOS methodology (developed in accordance with EN 14614:2020), using a single water body of the Olše River in northeastern Czechia. Five river reaches were assessed, revealing marked spatial differences in hydromorphological conditions, ranging from good to poor status. These contrasts highlight the ability of hydromorphological monitoring data to distinguish between river sections with differing ecological quality and management relevance, thereby supporting their use in identifying reaches with higher conservation value or greater restoration needs. Furthermore, many hydromorphological indicators can act as proxies for the capacity of river ecosystems to provide ecosystem services, including erosion control, sediment retention, habitat provision, thermal regulation, water availability, flood attenuation, and cultural benefits. At the same time, the study highlights limitations of reach-based indicators that record only the proportion of anthropogenic pressures without their precise spatial localization. A more spatially explicit representation of pressures would improve the assessment of ecosystem service capacity and enable more robust evaluation of changes following restoration measures. Overall, the findings underline the value of hydromorphological monitoring as a key input for ecosystem-based river management and conservation planning.

Keywords: Hydromorphology, Ecosystem Services, River Basin Management Plans

INTRODUCTION

According to the Water Framework Directive (WFD, Directive 2000/60/EC) [1], it is the responsibility of Member States to assess the hydromorphological condition of watercourses as part of their ecological status assessment. However, the role of hydromorphology in ecological status assessments currently remains somewhat marginal, as it is primarily used to confirm a “high” status determined based on biological and physico-chemical elements [2], [3]. A comprehensive assessment of hydromorphology, including the evaluation of hydrological regime, river continuity, and morphological conditions, provides significantly broader potential for application. It provides key information for (i) delineating individual water bodies and identifying heavily modified reaches [4], (ii) designing the optimal placement of monitoring sites [5], [6], and (iii) identifying anthropogenic pressures and improving the understanding of pressure–response (cause–effect) relationships [7]. Such information is valuable for water managers in planning restoration measures, designing interventions to improve ecological status, and overall river management [8], [9]. Enhanced understanding of cause–effect relationships is particularly achievable through the application of modern hydromorphological assessment methodologies based on the updated standard EN 14614:2020 [10], which place greater emphasis on process-based aspects of river systems than previous habitat-oriented methods.

At the same time, the question arises as to what further potential exists for the use of data derived from hydromorphological assessments of water bodies. Over the past decade, increasing efforts have been made to systematically integrate ecosystem services assessments into river basin management plans [11], [12], [13]. Such an approach enables a stronger linkage between the assessment of ecological status, benefits for human well-being, and decision-making processes within river basin planning and management [14]. Ecosystem services assessments help to clarify the benefits provided by river ecosystems and to evaluate how proposed management measures may influence the delivery of these services. Improvement of the ecological status of water bodies should therefore not be understood solely as an environmental objective, but also as a means of enhancing the capacity of aquatic ecosystems to provide services from which society benefits [15]. This perspective may contribute to greater societal acceptance of management measures and to a more effective targeting of proposed interventions.

Although references to ecosystem services increasingly appear in river basin management plans across European Union Member States, their application remains largely fragmented and insufficiently integrated, limiting their practical translation into water management strategies. This may explain why the ecosystem services concept is only marginally addressed in the most recent third River Basin Management Plans. The main barriers to its wider application include methodological inconsistencies, data constraints, and limited administrative capacity [16].

From this perspective, it is therefore appropriate to consider how data that are already routinely collected as part of regular water body monitoring can be more effectively utilised, and how such data can be systematically translated into ecosystem services assessments.

The aim of this article is to use the Olše River in the north-eastern Czech Republic as a case study (i) to assess the applicability of hydromorphological assessment data for identifying river reaches of high ecological relevance, including those potentially warranting legislative protection, and (ii) to propose a conceptual framework for using hydromorphological assessment data in ecosystem services assessments within the context of river basin management planning.

STUDY AREA

The Olše River originates in the Silesian Beskids in Poland and flows for approximately 16 km before crossing into the Czech Republic. The total length of the river from its source to the confluence with the Odra River is 89 km, and its catchment area covers 1,120 km². The geology of the catchment is dominated by easily erodible flysch, consisting of alternating layers of sandstones and clays, often calcareous in composition. The valley floor is composed of Quaternary gravels and sands, which, under natural or near-natural conditions, are reworked by the river to form extensive gravel bars along the channel. Tributaries of the Olše are mostly short, steep streams with high longitudinal gradients, contributing additional sediment to the main channel.

The hydrology of the Olše River is characterized by a pluvio-nival regime, with peak flood occurrences in spring due to snowmelt and in summer to early autumn as a result of intense precipitation events. The river supports characteristic vegetation of gravel banks and floodplains, including the association *Tussilagini farfarae-Calamagrostietum pseudophragmitae* Pawłowski & Walas 1949, with the endangered grass *Calamagrostis pseudophragmites* [17] as well as *Phalaris arundinacea, Petasites kablikianus, P. hybridus* and *Salix purpurea* [18].

Since the late 19th century, the Olše River has experienced extensive anthropogenic modifications, including channelization, embankments, weirs, ramps, and bed sills. Both these structural interventions and the concurrent reforestation of the catchment, which diminished sediment input, have promoted channel incision [19] and significantly disrupted the river's longitudinal and lateral continuity. In several reaches, the channel is incised down to the flysch bedrock.

Despite past channel modifications, repeated flood events, most recently the >100-year flood in 2024, have partially damaged riverbank structures and facilitated natural recovery of the channel. This has resulted in the formation of near-natural river reaches alongside regulated sections within the studied water body, corresponding to Olše from the confluence with the Lomná River to the confluence with the Ropičanka River (water body code HOD 0770; Figure 1). The catchment area upstream of the studied water body is 164 km², while the total catchment area of the monitored water body section is 221 km². The water body is 26 km long and passes through the towns of Jablunkov and Třinec. The average annual discharge at the Český Těšín gauging station, located in the lower

part of the water body, is 7.43 m³/s. The average channel gradient is 0.4 %, ranging from 0.6 % in the upper reaches to 0.3 % in the lower reaches.
Morphologically, the near-natural reaches of the river exhibit sinuous planform with lateral gravel bars and, in some areas, multiple threads forming wandering channels. In contrast, the regulated reaches maintain a sinuous channel pattern, but gravel bars are generally absent or poorly developed. A large part of the water body is located within a Special Area of Conservation (SAC) under the EU Habitats Directive (92/43/EEC), which aims to maintain or restore natural habitat types and species of European interest; however, the current protection regime does not fully address hydromorphological conditions.

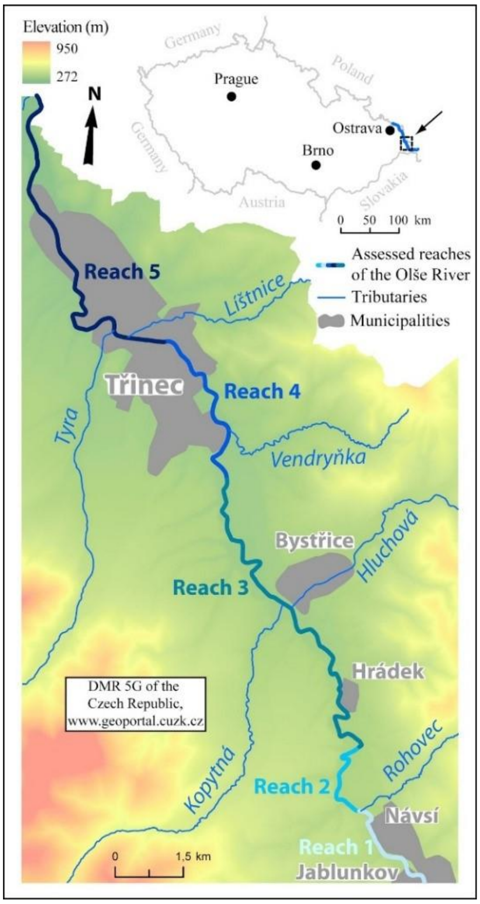

Figure 1. Overview map showing the location of the assessed reaches of the Olše River water body HOD 0770.

DATA AND METHODS

To assess the hydromorphological status and its elements – hydrological regime, continuity, and morphological conditions – we applied the HYMOS methodology [20], which has been officially approved by the Czech Ministry of the Environment for evaluating the hydromorphological condition of watercourses in the Czech Republic. The methodology was developed based on the requirements of EN 14614:2020 [10].
Since designated water bodies in European countries, including the Czech Republic, are often highly heterogeneous in terms of river types and the influence of anthropogenic pressures [21], it was necessary to divide the studied water body of Olše River into

homogeneous reaches prior to the assessment. As the water body under study does not exhibit significant changes in valley slope, channel confinement, or stream size along its length, the segmentation was based on the occurrence of notable changes in channel morphology, particularly in planform and cross-sectional modification, as well as on the presence of obstacles in the riverbed. Based on these criteria, the water body was divided into five reaches (Figure 1).

Field surveys were conducted during low flow conditions (1.3 m^3/s at the Český Těšín gauging station). A 2 km-long part of the fifth segment downstream of the town of Třinec could not be assessed in the field because it is located on private property and was therefore evaluated using remote sensing data only.

During the surveys, in addition to recording the indicators used for scoring hydromorphological condition, precise locations of bank and bed stabilizations, channel modifications (cross-section and bed features), substrate alterations and other relevant features were documented. These data were subsequently used to create vector layers in GIS representing anthropogenic pressures and channel modifications. Based on this information, the indicators of the river channel most contributing to a deterioration of the hydromorphological condition, reflecting the influence of human modifications, were identified.

When analysing the potential use of hydromorphological assessment data for ecosystem services evaluation, we followed the list of ecosystem services defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [22]. Based on an extensive literature review, indicators were selected and developed for eight ecosystem services, enabling the assessment of the level of provision of selected ecosystem services using data derived from the hydromorphological assessment.

RESULTS

Two of the five assessed reaches (2 and 3) achieved good hydromorphological status, representing the most valuable sections of the studied river (Table 1). Both reaches are characterized by a sinuous channel with alternate bars, locally transitioning towards a wandering pattern, which corresponds to the defined reference near-natural channel type (sinuous with alternate bars to wandering). In contrast, reaches 1, 4 and 5 exhibit a sinuous planform with a low representation of gravel bars.

Reaches 2 and 3 are characterized by a predominantly near-natural channel morphology, a relatively high diversity and frequency of geomorphic units typical for a gravel-bed river, and limited bank stabilization (Figure 2). Where present, bank modifications are mainly associated with bridges and transport infrastructure crossings. Slightly lower scores within this group were recorded for reach 2, where remnants of historical cross-sectional modifications and a somewhat higher proportion of stabilized banks persist. These alterations are reflected in a reduced frequency of occurrence of geomorphic units typical for the given river type, compared to reach 3.

Figure 2. a) restored river reach with extensive gravel bars, b) exposed bedrock resulting from channel incision, c) regulated river channel of the Olše in the town of Třinec.

Table 1. Basic characteristics of the assessed segments of the Olše River water body HOD 0770, including channel length and slope, and the results of the hydromorphological condition assessment and its elements (calculated scores and classification status).

Reach no.	Length (m)	Channel slope (%)	Hydro-morphological conditions		Hydrological regime		Continuity conditions		Morphological conditions	
			Score	Status	Score	Status	Score	Status	Score	Status
1	2505	0,6	0,41	3	0,68	3	0,33	4	0,33	4
2	2176	0,5	0,70	2	0,82	2	0,56	3	0,74	2
3	8616	0,5	0,73	2	0,82	2	0,60	3	0,82	2
4	4165	0,3	0,48	3	0,77	2	0,32	4	0,49	3
5	8430	0,4	0,36	4	0,59	3	0,21	4	0,29	4

High status (1): 0,85 ≤ Score ≤ 1,00; Good status (2): 0,70 ≤ Score < 0,85; Moderate status (3): 0,40 ≤ Score < 0,70; Poor status (4): 0,20 ≤ Score < 0,40; Bad status (5): 0,00 ≤ Score < 0,20 (Threshold values according to HYMOS methodology [])

Poor hydromorphological status was recorded in reach 5, which flows through the urban area of the town of Třinec and the industrial complex of the Třinec ironworks (Figure 2). Reach 1, located within the built-up areas of Jablunkov and Návsí, was classified at the lower threshold of moderate status, whereas reach 4, flowing through the suburban zone of Třinec, achieved a slightly higher score. This was primarily related to a lower extent of bank stabilization and the local presence of near-natural channel sections.

The dominant anthropogenic pressure negatively affecting the hydromorphological condition of the assessed reaches is the high density of stabilization structures and weirs located upstream of the study reaches. These structures significantly disrupt longitudinal continuity and natural sediment transport from the source areas of the catchment. In combination with historical channel modifications – particularly channel enlargement and alterations of both cross-sectional and longitudinal profiles – these pressures have led to progressive channel incision and a substantial reduction in regularly inundated floodplain areas. At several locations, the channel has incised down to the bedrock (Figure 2). As a result of these combined pressures, continuity conditions achieved only moderate status in reaches 2 and 3 and poor status in reaches 1, 4 and 5

Alterations of the channel planform affected approximately 58% of reach 1, 42% of reach 4 and 75% of reach 5, while modifications of the cross-sectional profile were recorded along 57%, 35% and 67% of the respective reach lengths. A reduced occurrence of geomorphic units was observed along 73% of reach 1, 39% of reach 4 and 67% of reach 5, and bank stabilization affected 57%, 23% and 69% of these reaches, respectively. Additional anthropogenic pressures contributing to the failure to achieve at least good status in reaches 1, 4 and 5 include intensive maintenance of riparian vegetation (tree removal and mowing), the presence of transverse barriers within the channel (weirs and ramps), and extensive bank stabilization, which together limit bank erosion processes and disrupt lateral continuity. In reach 5, up to 24% of the reach length was affected by impounded conditions caused predominantly by abstraction weirs.

Table 2 summarizes the proposed conceptual framework linking hydromorphological assessment outputs with ecosystem services through key ecological processes and assessment indicators applicable in river basin management planning. Based on an extensive literature review, eight ecosystem services were identified that can be assessed using data applied in hydromorphological evaluations. These include data collected during field surveys, remote sensing data, hydrological data derived from gauging stations, flood inundation modelling and databases of water abstractions.

Five of the eight ecosystem services listed in Table 2 represent regulating services (habitat provision, thermal regulation, water dilution capacity, flood flow attenuation and erosion control), as they are underpinned by natural ecosystem processes and contribute to environmental regulation and stability. The proposed assessment indicators allow for the evaluation of the capacity of ecosystems to provide these services, reflecting their structural characteristics, natural conditions and current land-use patterns.

Two ecosystem services represent cultural services. Educational and scientific value was assessed based on the density of educational trails within the floodplain, while aesthetic service was assessed based on the occurrence of natural planform patterns. In both cases, the indicators represent the capacity for service provision, i.e. the potential attractiveness of the area under current land-use conditions rather than the actual level of service use. The remaining ecosystem service addresses water supply, including abstractions for drinking water, agriculture and industry. In contrast to the other services, this indicator reflects the actual level of ecosystem service use rather than its potential capacity.

Table 2. List of ecosystem services together with the ecological processes and/or components providing the service and the indicators used for their assessment based on hydromorphological data. Provisioning ecosystem services are indicated in orange, regulating services in green, and cultural services in blue.

Ecosystem service	Ecological process and/or component providing the service	Indicator used for assessment
Water provisioning	Hydrological potential for surface water availability for drinking water supply, agriculture and industry	Water abstractions (m³/year) [23], [24] Maes
Habitat provision	Maintenance of longitudinal continuity of the river	Anthropogenic fragmentation index
	Physical habitat conditions within the river channel	Assessment of morphological conditions [23] Maes
Thermal regulation	Shading and cooling of water by riparian vegetation	Linear extent of woody riparian vegetation along the river (%) [24]
Water dilution capacity	Dilution and downstream transport of pollutants by flowing water	Flow reduction due to water abstraction (%/year)
Flood flow attenuation	Transformation of flood flows	Extent of floodplain inundation (m² of flooded area / m² of floodplain), [23]
Erosion control and sediment retention	Floodplain capacity to reduce water erosion	Proportion of erosion-control effective surfaces within the floodplain (%) [24], [25]
Educational and scientific value	Landscape features enabling educational activities	Density of educational trails within the floodplain (km/km²)
Aesthetic service	Landscape features enabling aesthetic appreciation	Occurrence of meandering sections and gravel-bed reaches with extensive bars and islands in high-gradient valleys (%)

DISCUSSION

Our assessment demonstrates that hydromorphological evaluation can effectively identify river reaches of high ecological value and provide a robust basis for assessing ecosystem services. Traditionally, hydromorphological data have been used primarily to support the identification of high ecological status under the WFD. As a result, hydromorphological assessments have so far not been systematically applied to a large proportion of water bodies across EU Member States, including within the third river basin management plans [26]. Our results show that hydromorphological data have broader applicability in river management and conservation planning. This is particularly relevant in the context of ongoing efforts to reverse biodiversity loss, as highlighted in the EU Biodiversity Strategy 2030, and in the proposed Nature Restoration Law, where hydromorphological information can inform restoration of terrestrial, coastal, and freshwater ecosystems (Article 4) and contribute to the re-establishment of natural river continuity and floodplain functions (Article 9).

Hydromorphological assessment based on process-oriented approaches provides a perspective on river systems that captures the cumulative imprint of past and ongoing anthropogenic pressures [27], [28]. In the Olše water body, this approach is illustrated through the assessment of five reaches. Reaches 2 and 3, which scored ‘good’ in the hydromorphological assessment, demonstrate how natural river processes can persist despite historical interventions. In contrast, the more modified sections, particularly reaches 1, 4, and 5, reveal the long-term consequences of channel engineering, bank stabilization, and sediment disruption, consistent with patterns reported in European and global rivers [29], [30], [31].

These findings reinforce the value of hydromorphological indicators as tools for screening and prioritizing river sections for conservation or targeted restoration, rather than solely evaluating compliance with ecological status thresholds. By integrating structural and functional data, this approach provides context on the degree of modification across the river network, helping to interpret historical pressures and identify areas that retain key natural features. Protecting these relatively intact reaches is essential to prevent further degradation from interventions such as post-flood bank reinforcement, sediment extraction, or the construction of abstraction weirs, which could compromise the hydromorphological condition. The HYMOS methodology, standardized under EN 14614:2020 [10] and compatible with the Morphological Quality Index [32], ensures that such assessments are transferable across Europe, supporting evidence-based river basin management and restoration planning.

Hydromorphological monitoring data also provide a valuable foundation for ecosystem service (ES) assessments. While hydromorphological indicators themselves are not ecosystem services, they represent key parameters describing ecosystem state [33], [34]. Although these indicators primarily reflect the current ecosystem state, they can serve as effective proxies for evaluating the capacity to deliver certain services. For example, assessments of morphological conditions inform the potential for habitat provision, lateral continuity supports evaluation of flood flow attenuation, and hydrological regime alterations provide insight into water dilution capacity. In practice, this demonstrates that the distinction between state indicators and capacity proxies is manageable, and much of the data required to evaluate service provision capacity can be derived from existing hydromorphological monitoring.

Despite this potential, there are important limitations. These assessments are complex and require specialized expertise, with reliable data collection and interpretation dependent on appropriate sampling design, staff training, and quality control protocols [35]. Data coverage is often spatially uneven, which limits consistent applicability across all river sections. For example, in the Czech Republic, hydromorphology in third river basin management plans was assessed solely from remotely acquired data, excluding some relevant anthropogenic pressures [36]. Additionally, when data are collected for predefined sections, only the percentage occurrence of anthropogenic pressures is recorded, without precise spatial localization. This limitation may complicate future re-evaluation or the assessment of changes in capacity following restoration measures.

It is also important to note that hydromorphological data do not directly measure functional outputs of ecosystem services. Full integration of ES assessments into planning requires moving from quantifying service provision capacity to evaluating actual service flows and quantifying associated social benefits, which entails combining hydromorphological data with other relevant information [23], [37]. Nevertheless, hydromorphological information can support implementation of the EU Biodiversity Strategy 2030 by enabling targeted river protection, identifying free-flowing reaches, modelling the effects of restoration measures on free-flowing river functions, and guiding the efficient allocation of limited restoration resources [38].

CONCLUSION

This study highlights the critical role of hydromorphological assessments in understanding and managing water bodies. Hydromorphology provides an integrative perspective, capturing the long-term imprint of anthropogenic pressures on channel structure, continuity, and hydrological processes. Our findings demonstrate that hydromorphological evaluations can effectively identify river reaches of high ecological value and serve as a robust tool for prioritizing areas for conservation or restoration.
Beyond supporting ecological status assessments under the WFD, hydromorphological data offer a unique opportunity to assess the capacity of ecosystems to provide services, including habitat provision, flood regulation, and water quality maintenance. However, to fully harness this potential in river basin management, assessments must move beyond capacity indicators toward evaluating service flows and quantifying social benefits, integrating hydromorphological data with socio-economic and hydrological information. Given their relevance for both ecological assessment and ecosystem service evaluation, hydromorphological methods deserve greater emphasis in monitoring programs and policy frameworks. Strengthening their role will not only improve understanding of river functioning and long-term degradation trends but also enable evidence-based prioritization and planning of restoration measures. Ultimately, integrating hydromorphology more systematically into river management can support the sustainable conservation of river ecosystems while aligning with broader biodiversity and ecosystem service objectives.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support provided by the project Incorporating the concept of ecosystem services assessment into future river basin plans (WAMPES, SS07010080) funded by the Technology Agency of the Czech Republic (TA CR) under the Environment for Life programme. This work was also supported by the Dynamic Planet Earth Research Programme of the Strategy AV21 – Top research in the public interest.

REFERENCES

[1] EU Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX
%3A32000L0060

[2] REFCOND, Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters. Produced by Working Group 2.31 Reference conditions for inland surface (REFCOND), Common Implementation Strategy of the Water Framework Directive, European Commission, 86 pp, 2003.

[3] Borisavljević, A., The Danube in Serbia – Ecological Status and Management Issues, Transylvanian Review of Systematical and Ecological Research, 12, pp 91-100, 2011.

[4] Vincent, C., Heinrich, H., Edwards, A., Nygaard, K., Haythornthwaite, J., Guidance on typology, reference conditions and classification systems for transitional and coastal waters. Produced by: CIS Working Group 2.4 (COAST), Common Implementation Strategy of the Water Framework Directive, European Commission, 119 pp, 2002.

[5] European Commission, Monitoring under the Water Framework Directive. In Common Implementation Strategy for the Water Framework Directive (2000/60/EC); European Commission: Brussels, Belgium, 153 pp, 2003.

[6] Schmölz, K., Felber, A., Wolfgang, M. Thaler, M., Wieser, J. Persiano, S., Bertoldi, G., Tasser, E., The hydromorphology index I_{HM} based on fish requirements, River Research and Applications, 39, pp 1037-1053, 2023.

[7] Rinaldi, M., Belletti, B., Bussettini, M., Comiti, F., Golfieri, B., Lastoria, B., Marchese, E. Nardi, L., Surian, N., New tools for the hydromorphological assessment and monitoring of European streams, Journal of Environmental Management, 202, pp 363-378, 2017.

[8] Müller, H, Hörbinger, S., Franta, F., Mendes, A., Li, J., Cao, P., Baoligao, B., Xu, F., Rauch, H.P., Hydromorphological Assessment as the Basis for Ecosystem Restoration in the Nanxi River Basin (China), Land, 11, 2022.

[9] Borisavljević, A., Kostadinov, S. Integrated River Basin Management of Južna Morava River, Bulletin of the Serbian Geographical Society, 92, pp 135-160, 2012.

[10] EN 14614, Water quality - Guidance standard for assessing the hydromorphological features of rivers, Brusel, European Committee for Standardization, 2020.

[11] Akinsete1, E., Apostolaki, S., Chatzistamoulou, N., Koundouri, P., Tsani, S., The Link between Ecosystem Services and Human Wellbeing in the Implementation of the European Water Framework Directive: Assessing Four River Basins in Europe, Land, 11, 2019.

[12] Vlachopoulou, M., Coughlin, D., Forrow, D., Kirk, S., Logan, P., Voulvoulis, N., The potential of using the Ecosystem Approach in the implementation of the EU Water Framework Directive, Science of The Total Environment, 470–471, pp 684-694, 2014.

[13] Grizzetti, B., Liquete, C., Antunes, P., Carvalho, L., Geamănă, N., Giucă, R., Leone, M., McConnell, S., Preda, E., Santos, R., Turkelboom, F., Vădineanu, A., Woods, H., Ecosystem services for water policy: Insights across Europe, Environmental Science & Policy, Elsevier, 66, pp 179-190, 2016.

[14] Blackstock, K.L., Martin-Ortega, J., Spray, C.J., Implementation of the European Water Framework Directive: what does taking an ecosystem services-based approach add?, In: Martin-Ortega, J., Ferrier, R.C., Gordon, I.J., Khan, S. (ed.), Water Ecosystem Services A Global Perspective, Cambridge University Press, pp 57-64, 2015.

[15] Souliotis, I., Voulvoulis, N., Incorporating Ecosystem Services in the Assessment of Water Framework Directive Programmes of Measures, Environmental Management, 68, pp 38-52, 2021.

[16] Stevenson, H., Auld, G., Allan, J.I., Elliott, L., Meadowcroft, J., The Practical Fit of Concepts: Ecosystem Services and the Value of Nature, Global Environmental Politics, 21, pp 3-22, 2021.

[17] Skokanová, H., Unar, P., Janík, D., Havlíček, M., Potential influence of river engineering in two West Carpathian rivers on the conservation management of *Calamagrostis pseudophragmites*, Journal for Nature Conservation, 25, pp 42-50, 2015.

[18] Chytrý, M., Šumberová, K., Hájková, P., Hájek, M., Hroudová, Z., Navrátilová, J., Čtvrtlíková, M., Sádlo, J., Lososová, Z., Hrivnák, R., Rydlo, J., Oťaheľová, H., Bauer, P., Hanáková, P., Ekrt, L., Ekrtová, E., Michalcová, D., Žáková, K., Danihelka, J., Králová, Š., Karimová, K., Tichý, L., Hájek, O., Kočí, M. Vegetace České republiky. 3, Vodní a mokřadní vegetace Academia, Praha, 2011.

[19] Škarpich, V., Hradecký, J., Dušek, R., Complex trans-formation of the geomorphic regime of channels in theforefield of the Moravskoslezské Beskydy Mts.: Case study of the Morávka River (Czech Republic), Catena, 111, pp 25-40, 2013.

[20] Babej, J., Jakubínský, J., Němejcová, D., Pechanec, V., Kožený, P., Vyvlečka, P., Výravský, D., Polášek, M., Krásná, K., Straka, M., Cudlín, O., Purkyt, J., Procházková, V., Donoval, J., Štěrbová, L., Včeláková, R. Metodika hodnocení ekologického stavu útvarů povrchových vod tekoucích (kategorie řeka) pomocí hydromorfologických složek. Brno, Praha, Olomouc: Ústav výzkumu globální změny AV ČR, v. v. i., Výzkumný ústav vodohospodářský T. G. Masaryka, v. v. i., Univerzita Palackého v Olomouci, pp 200, 2024. Available from: https://hymos.czechglobe.cz/vystupy.php.

[21] CIS ECOSTAT hydromorphology, River Hydromorphological Assessment and Monitoring Methodologies – FINAL REPORT. Part 1 – Summary of European country questionnaires. Part 2 – Summary report of workshop – Key conclusions & recommendations, Workshop on Methods for River Hydromorphological Assessment and Monitoring of the expert group hydromorphology, 20-22 November 2017, Madrid, 2018.

[22] Brondízo, E.S., Settele, J., Díaz, S., Ngo, H.T., Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES Secretariat, Bonn, Germany, pp 309-384, 2019.

[23] Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Rivero, I.M., Guerra, C., Castillo, C.P., Vallecillo, S., Baranzelli, C., Barranco, R., e Silva, F.B, Jacobs-Crisoni, C., Trombetti, M., Lavalle, C., Mapping and Assessment of Ecosystems and their Services, European Commission, Joint Research Centre, Institute for Environment and Sustainability, Luxembourg, pp 131, 2014.

[24] Egoh, B., Drakou, E.G., Dunbar, M.B., Maes, J., Willemen, L. Indicators for mapping ecosystem services: a review. Publications Office of the European Union, Luxembourg, pp 113, 2012.

[25] Liquete, C., Piroddi, C., Drakou, E.G., Gurney, L., Katsanevakis, S., Charef, A., Egoh, B., Current status and future prospects for the assessment of marine and coastal ecosystem services: a systematic review, PloS one, 8, e67737, 2013.

[26] European Environment Agency, Water Framework Directive - Quality Elements, online: https://www.eea.europa.eu/en/analysis/maps-and-charts/water-framework-directive-quality-elements, cited [3. 2. 2026].

[27] del Tánago, M.G., Gurnell, A.M., Belletti, B., de Jalón, G., Indicators of River System Hydromorphological Character and Dynamics: Understanding Current Conditions and Guiding Sustainable River management, Aquatic Sciences, 78, pp 35-55, 2015.

[28] Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M., Moir, H., Roni, P., Pollock, M.M., Process-based Principles for Restoring River Ecosystems, BioScience, 60, pp 209-222, 2010.

[29] Brierley, G., Fryirs, K., Outhet, D., Massey, C. Application of the River Styles framework as a basis for river management in New South Wales, Australia, Applied Geography, 22, pp 91-122, 2002.

[30] Rinaldi, M., Belletti, B.,Van de Bund, W., Bertoldi, W., Gurnell, A., Buijse, T., Mosselman, E. Review on eco-hydromorphological methods, REstoring rivers FOR effective catchment Management, Project funded by the European Commission within the 7th Framework Programme (2007 – 2013), pp 202, 2013.

[31] Scorpio, V., Comiti, F., Liébault, F., Piegay, H., Rinaldi, M., Surian, N. Channel changes over the last 200 years: A meta data analysis on European rivers, Earth Surface Processes and Landforms, 49, pp 2651-2676, 2024.

[32] Rinaldi, M., Bussettini, M., Surian, N., Comiti, F., Gurnell, A.M., Guidebook for the evaluation of stream morphological conditions by the Morphological Quality Index (MQI), pp 177, 2016, Available from: https://www.researchgate.net/publication/

322012176_Guidebook_for_the_evaluation_of_stream_morphological_conditions_by_the_Morphological_Quality_Index_MQI

[33] Grizzetti, B., Lanzanova, D., Liquete, C., Reynaud, A., Cardoso, A.C., Assessing water ecosystem services for water resource management, Environmental Science & Policy, 61, 194-203, 2016.

[34] Burkhard, B., Kroll, F., Nedkov, S., Müller, F., Mapping ecosystem service supply, demand and budgets, Ecological Indicators, 21, pp 17-29, 2012.

[35] Newson, M., Raven, P., Professional and citizen science to monitor and improve the physical habitat quality of rivers, Progress in Physical Geography: Earth and Environment, 50, 2025.

[36] Babej, J., Jakubínský, J., Pechanec, V., Koženy, P., Němejcová, D., Vyvlečka, P., Assessment of the hydromorphological status of river water bodies in the Czech Republic using HYMOS methodology, VTEI, 67, pp 30-40, 2025.

[37] Palomo, I., Felipe-Lucia, M.R., Bennett, E.M., Martín-López, B., Pascual, U., Disentangling the Pathways and Effects of Ecosystem Service Co-Production, Advances in Ecological Research, 54, pp 245-283, 2016.

[38] Newson, M.D., Large, A.R.G., 'Natural' rivers, 'hydromorphological quality' and river restoration: a challenging new agenda for applied fluvial geomorphology, Earth Surface Processes and Landforms, 31, 1606-1624, 2006.