Heavily modified freshwater: Potential ecological indicators

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Heavily modified water bodies (HMWBs) are surface water bodies with their physical characteristics modified or altered by sharp engineering works for drainage, water resources development and ecological restoration. Similar to the ecological status (poor, moderate, good and high) of natural water bodies, ecological potential of HMWBs consists of three quality elements, namely i) biology, ii) hydro-morphology, and iii) physico-chemical characteristics. In general, a typology of HMWBs is designated to develop a type-specific methodology for monitoring and assessing the ecological potential of water resources. The typology of HMWBs is categorized according to several criteria, including eco-region type, catchment characteristics, flow intermittency, and dominantly modified hydro-morphological features such as longitudinal morphology and hydrology (Pavlek et al., 2023; Khan and ElKashouty, 2023). The quality targets of HMWBs reveal "good chemical status" which is compliant with natural freshwater bodies and "good ecological potential" which refers to the reference condition for HMWBs that can play a crucial role in the process of assessing ecological potential (Hering et al., 2010; Borja and Elliott, 2007). Such conditions include (i) land drainage, flood protection, and water regulation; (ii) the wider environment for recreation and navigation; (iii) the purpose of fulfilling life-supporting activities such as drinking-water facilities, irrigation and electricity generation; and (iv) miscellaneous sustainable human development activities. Water Framework Directive (WFD) is a framework built by the European Union for the protection of transitional waters, inland surface waters, groundwater and coastal waters (European Union, 2000). Its key objective is to achieve a good ecological status for all water bodies (Upadhyay et al., 2023). However, there is no common or single methodology available for monitoring HMWBs and further to judge maximum and good ecological potential (Erba et al., 2019; Pavlek et al., 2023). In the context of HMWBs, WFD is established as obligatory determinations of their ecological potential rather than their ecological status.

The WFD requires Member States to strictly distinguish ‘natural freshwater bodies’ from ‘HMWBs’ due to the low ecological status as the result of hydro-morphological pressures in HMWBs, which cannot be easily improved under high socio-economic cost. In general, the designation and HMWBs classification completed in several consecutive steps and involve a certain level of complexity (CIS, 2002). Nevertheless, due to hydro-morphological degradation, a significant proportion of European (e.g., Spain, Norway, Germany, Czech Republic etc.) freshwater bodies have been designated as HMWBs. In four member states (Czech Republic, Netherlands, Slovak Republic, and Belgium), more than 50% of the freshwater bodies were designated as HMWBs. Apart from these first four, the remaining member states have on average provisionally identified ~16% of their freshwater bodies as HMWBs and artificial water bodies (AWBs) (Commission of the European Communities, 2007). Since the 1990s, rapid increase in high number of large dams in Norway and Spain, the identification and strategic design of HMWBs are the key steps in the overall development and management of river basins (Ibrekk and Pedersen, 2005; Fernández et al., 2012). Kail and Wolter (2013) stated that pressures at larger spatial scales and alternations in the hydro-morphological characteristics in the river network play a crucial role in HMWBs management in Germany and other comparable rivers in Central Europe. In 2003, the Common Implementation Strategy EU (CIS, 2003) guideline proposed a criterion for the design and identification of AWBs and HMWBs. Moreover, adaptive procedures and guidelines were developed in the United Kingdom for the classification of HMWBs (WFD UK TAG, 2008a) and further to improve the ecological status based on the typology (WFD UK TAG, 2008b). The application of these guidelines is limited in the Mediterranean countries due to strict water regulations and its consumptive use. Likewise, in several developing and developed countries, the criteria for HMWBs and AWBs classification are still under progress and matters of global scientific discussion (EEA, 2018).

Nowadays, a river dammed to form an artificial reservoir for power generation and flood control is a heavily modified river, not an artificial lake (Wang et al., 2023a, b). Due to anthropogenic activities, rivers are among the most affected habitats worldwide, such to the release of untreated chemical pollutants and urban wastewater. In recent decades, with the rapid increase in hydropower development, numerous water bodies have been physically modified thereby hampering ecological status, this is mainly because of river encroachments. Freshwater bodies (rivers, lakes and reservoirs) are identified as HMWBs if they follow the mandate of Article 4.3 (WFD-2000/60/EC). However, it is absolutely unknown how and to what extent biological communities, in particular zooplankton, are affected by these environmental stressors in river ecosystems (Xiong et al., 2016). It was suggested that dispersal affected by water flow had little effect on community structure in heavily polluted rivers, but local environmental factors, especially total nitrogen, phosphorus and emerging organic pollutants, played a significant role in heavily polluted rivers (Li et al., 2023). In the case of phytoplankton, there were insufficient freshwater bodies in the hyperhaline type (salinity>40 psu) and only one member state of Southwestern Europe (Spain) had that typology. Therefore, hyperhalines cannot be intercalibrated, since all freshwater bodies are HMWBs, with a few exceptions in Spain (Ponis et al., 2018;

Romero et al., 2019). Water-level drawdown indicator (WIc) refers to the ratio between sensitive and tolerant macrophyte species which is indifferent to eutrophication (Mjelde et al., 2013), and is applicable to the lakes having low alkalinity, oligotrophic conditions (i.e., low nutrients availability), and surface ice-covered. Thus, WIc is suggested to be a great tool for identifying project risks and designating HMWBs in Nordic lakes (Lammens et al., 2008). In the case of reservoirs, the WFD permits the identification and designation of both AWBs and HMWBs. The prime goal of these water bodies is to achieve good ecological potential and good chemical status, aligning with the intended environmental objectives to increase sustainable water consumption (Padovesi-Fonseca, 2013). Carvalho et al. (2019) pointed out the major weaknesses and strengths of WFD and the key reasons for failure by 2027. Therefore, there is an urgent need to improve assessment methods to capture the interactions between potential stressors to achieve good ecological potential (Voulvoulis et al., 2017).

The ecological status of freshwater bodies is mainly defined on the basis of species composition, diversity and their abundances. Hering et al., (2010) classified ecological status into five classes based on the extent of deviation from reference conditions (refers to type-specific and are different for different freshwater bodies), from 'very good' to 'bad'. Hence, scientific communities, and competent authorities of Member States are charged to define reference conditions quantitatively. However, ecological potential is assessed for both AWBs and HMWBs. The highest ecological potential was identified when all mitigation measures were successfully implemented to improve the environmental quality. Two different approaches towards ecological assessment exist for HMWBs: i) Prague approach was classified according to the assessment of mitigation measures (Kampa and Kranz, 2005), and ii) the common implementation strategy (CIS) guidance approach for biological assessment (CIS Working Group 2.2 on HMWBs, 2003). As HMWBs are not exceptional cases but help the environmentalist, and water resources planners and managers to ensure the comparability with assessment results obtained for natural freshwater bodies. Notably, HMWBs, domains of surface waters, play a crucial role in preserving plant diversity and ecological restoration but underlying ecological mechanisms are unexplored and a matter of debate. Therefore, quality targets should be adapted on a case-by-case basis, in some cases removal of biological quality elements (BQEs; aquatic flora, macrophytes, phytoplankton, fish fauna, and benthic invertebrates) which are directly affected by hydro-morphological pressures, while keeping those that are most sensitive to the other pressures acting on the HMWBs (Lammens et al., 2008).

The aforementioned discussion reveals that it is complex to establish a criterion for HMWBs unless their main environmental processes are well-known. Moreover, given the limited research conducted in these areas, preliminary investigation is highly valuable for gaining an initial understanding of the system. In the future, further developments should be made to determine environmental flows and identify the responses of biological quality elements to hydro-morphological mitigation measures. For the environmental impact assessment (EIA), there is a need for specific environmental assessment strategies built for particular HMWBs to define specific and appropriate methodologies under certain environments and catchment characteristics.

The motivation to set up this special issue "Heavily Modified Freshwater" is to contribute to this debate and expand the knowledge on the role of HMWBs in conserving freshwater biodiversity and the natural environment under rising temperature extremes. This special issue received 28 submissions (review and research articles) from China, India, Germany, Saudi Arabia, Netherlands and the USA, of which 12 papers have been accepted for publication after 2-4 rounds of revisions. The papers submitted and/or accepted for publication in this special issue provide in-depth discussion and practical demonstration of scientific research related to HMWBs and their impacts on ecological integrity and biological diversity. We are confident that the publication of this special issue will keep the readers and aspiring researchers informed about the actual realities, motivating them to find practical engineering solutions to improve ecological integrity and biological diversity. The editors are looking forward to further interaction events and engagements.

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Reference

Borja, A., Elliott, M. (2007). What does 'good ecological potential' mean, within the European Water Framework Directive? Mar Pollut Bull. 54, 1559–64.

Carvalho, L., Mackay, E.B., Cardoso, A.C., Baattrup-Pedersen, A., Birk, S., Blackstock, K.L., Borics, G., Borja, A., Feld, C.K., Ferreira, M.T., Globevnik, L., Grizzetti, B., Hendry, S., Heringe, D., Kelly, M., Langaas, S., Meissner, K., Panagopoulos, Y., Penning, E., Rouillard, J., Sabater, S., Schmedtje, U., Spears, B.M., Venohr, M., van de Bund, W., Solheimm, A.L. (2019). Protecting and restoring Europe's waters: an analysis of the future development needs of the water framework directive. Sci. Total Environ. 658, 1228–1238. https://doi.org/10.1016/j.scitotenv.2018.12.255.

Commission of the European Communities. Commission staff working document. (2007). Accompanying document to the communication from the commission to the European Parliament and the Council 'Towards Sustainable Water Management in the European Union'; the first stage in the implementation of the Water Framework Directive 2000/60/EC [COM (2007) 128.

Common Implementation Strategy (CIS) Working Group 2.2 on Heavily Modified Water Bodies. 2003. Toolbox on identification and designation of artificial and heavily modified water bodies.

Common Implementation Strategy for the Water Framework Directive (2000/60/EC) Identification and designation of heavily modified and artificial water bodies. WFD CIS Guidance Document No. 4 (2002).

EEA (2018). European waters. Assessment of status and pressures 2018. EEA Report No 7/2018. Publications Office of the European Union, Luxembourg 978-92-9213-947-6 https://doi.org/10.2800/303664, ISSN 1977-8449.

Erba, S., Terranova, L., Cazzola, M., Cason, M., Buffagni, A. (2019). Defining Maximum Ecological Potential for heavily modified lowland streams of Northern Italy. Sci. Total Environ. 684, 196–206.
European Union. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23th October 2000, Establishing a Framework for the Community Action in the Field of Water Policy. WFD 2000/60/EC. http://data.europa.eu/eli/dir/2000/60/oj
Fernández, J. A., Martínez, C., & Magdaleno, F. (2012). Application of indicators of hydrologic alterations in the designation of heavily modified water bodies in Spain. Environmental Science & Policy, 16, 31–43. https://doi.org/10.1016/j.envsci.2011.10.004
Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C. K., … Pont, D. (2010). The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. Science of The Total Environment, 408, 4007-4019, https://doi.org/10.1016/j.scitotenv.2010.05.031
Hull, S.C., Freeman, S.M., Rogers, S.I., Ash, J., Brooke, J., Elliott, M. (2004). Methodology for the provisional identification and formal designation of heavily modified water bodies in UK transitional and coastal waters under the EC Water Framework Directive. Environment Agency R&D Technical Report, Bristol UK.
Ibrekk, A.S., Pedersen, T.S. (2005). Characterisation methodology and future challenges of heavily modified water bodies in Norway: case study of the Suldal pilot river basin. Environmental Science & Policy 8 (3), 227–231.
Kail, J., Wolter, C. (2013). Pressures at larger spatial scales strongly influence the ecological status of heavily modified river water bodies in Germany. Science of the Total Environment, 454–455, 40–50.
Kampa, E., Kranz, N. (2005). WFD and Hydromorphology. European Workshop, 17–19 October 2005, Prague, workshop summary report. 2005, available from http://www.ecologicevents.de/hydromorphology/documents/967_summary.pdf
Khan, M.Y.A., ElKashouty, M. (2023). Watershed prioritization and hydro-morphometric analysis for the potential development of Tabuk Basin, Saudi Arabia using multivariate statistical analysis and coupled RS-GIS approach. Ecological Indicators 154, 110766. https://doi.org/10.1016/j.ecolind.2023.110766
Lammens, E., van Luijn, F., Wessels, Y., Bouwhuis, H., Noordhuis, R., Portielje, R., et al. (2008). Towards ecological goals for the heavily modified lakes in the IJsselmeer area, The Netherlands. Hydrobiologia 599: 239–47.
Li, G., Zhao, H., Wang, G., Cong, J., Ji, S., Gao, C., et al. (2023). Response of phosphorus distribution to burn frequency and seasonality in the Sanjiang Plain wetlands (Northeast China). Ecological Indicators, 154. https://doi.org/10.1016/j.ecolind.2023.110673.
Mjelde, M. (2013). Water plants. In: Directorate group water directive 2013. Classification of environmental conditions in water. Ecological and chemical classification system for coastal waters, groundwater, lakes and rivers. Supervisor 02: 2013.

Padovesi-Fonseca, C. (2020). Potential Use of Zooplankton as Ecological Quality Indicator According to Water Framework Directive (WFD) in Central Brazilian Reservoir. Oceanogr Fish Open Access J. 11(3), 555814. https://doi.org/10.19080/OFOAJ.2020.11.555814
Pavlek K., Plantak M., Martinić I., Vinković K., Vučković I., Čanjevac I. (2023). Methodological Framework for Assessing Hydromorphological Conditions of Heavily Modified and Artificial River Water Bodies in Croatia. Water. 15(6), 1113. https://doi.org/10.3390/w15061113
Ponis, E., Giovanardi, F., Facca, C., Buchet, R., Derolez, V., Bernardi Aubry, F., Pagou, K., Garcia, E., Ninevic, Z., Costas, N., Pardo, I., Salas Herrero, F. (2018). Transitional waters Mediterranean geographic Intercalibration group Phytoplankton Ecological Assessment Methods, EUR 29607 EN, 978-92-79-98683-3, Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/239940
Romero, I., Pachés, M., Martínez-Guijarro, R. (2019). Selection of an indicator to assess a highly modified saline ecosystem. Science of The Total Environment, 693, 133656. https://doi.org/10.1016/j.scitotenv.2019.133656
Upadhyay, P., Prajapati, S.K., Kumar, A. (2023). Impacts of riverine pollution on greenhouse gas emissions: A comprehensive review. Ecological Indicators, 154, 110649. https://doi.org/10.1016/j.ecolind.2023.110649
Voulvoulis, N., Arpon, K.D., Giakoumis, T. (2017). The EU Water Framework Directive: from great expectations to problems with implementation. Sci. Total Environ. 575, 358–366. https://doi.org/10.1016/j.scitotenv.2016.09.228.
Wang, J., Yuan, Y., Yu, Z-G., Qu, S., Li, W. (2023b). Effect of turbulence driven by wind on sediment suspension under different submerged vegetation density in Lake Taihu. Ecological Indicators 154, 110767. https://doi.org/10.1016/j.ecolind.2023.110767.
Wang, Y., Wu, N., Liu, G., Mu, H., Gao, C., Wang, Y., et al. (2023a). Incorporating functional metrics Wainto the development of a diatom-based index of biotic integrity (D-IBI) in Thousand Islands Lake (TIL) catchment, China. Ecological Indicators, 153, 110405. https://doi.org/10.1016/j.ecolind.2023.110405.
WFD (Water Framework Directive). (2000). 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. Official Journal of the European Communities, L 327, 22.12.2000, pp. 1–73.
WFD UK TAG. (2008a). Criteria and Guidance Principles for the Designation of Heavily Modified Water Bodies. http://www.wfduk.org/tag_guidance/article_4/heavily_modified_wb/view.
WFD UK TAG. (2008b). Guidance on the Classification of Ecological Potential for Heavily Modified Water Bodies and Artificial Water Bodies. http://www.wfduk.org/tag_guidance/Article%20_11/POMEnvStds/gep_guidance_final/view.
Xiong W., Li, J., Chen, Y., Shan, B., Wang, W., et al. (2016). Determinants of community structure of zooplankton in heavily polluted river ecosystems. Scientific Reports 6(1), 22-43. https://doi.org/10.1038/srep22043